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COMPOUNDS & ADVANCED SILICON

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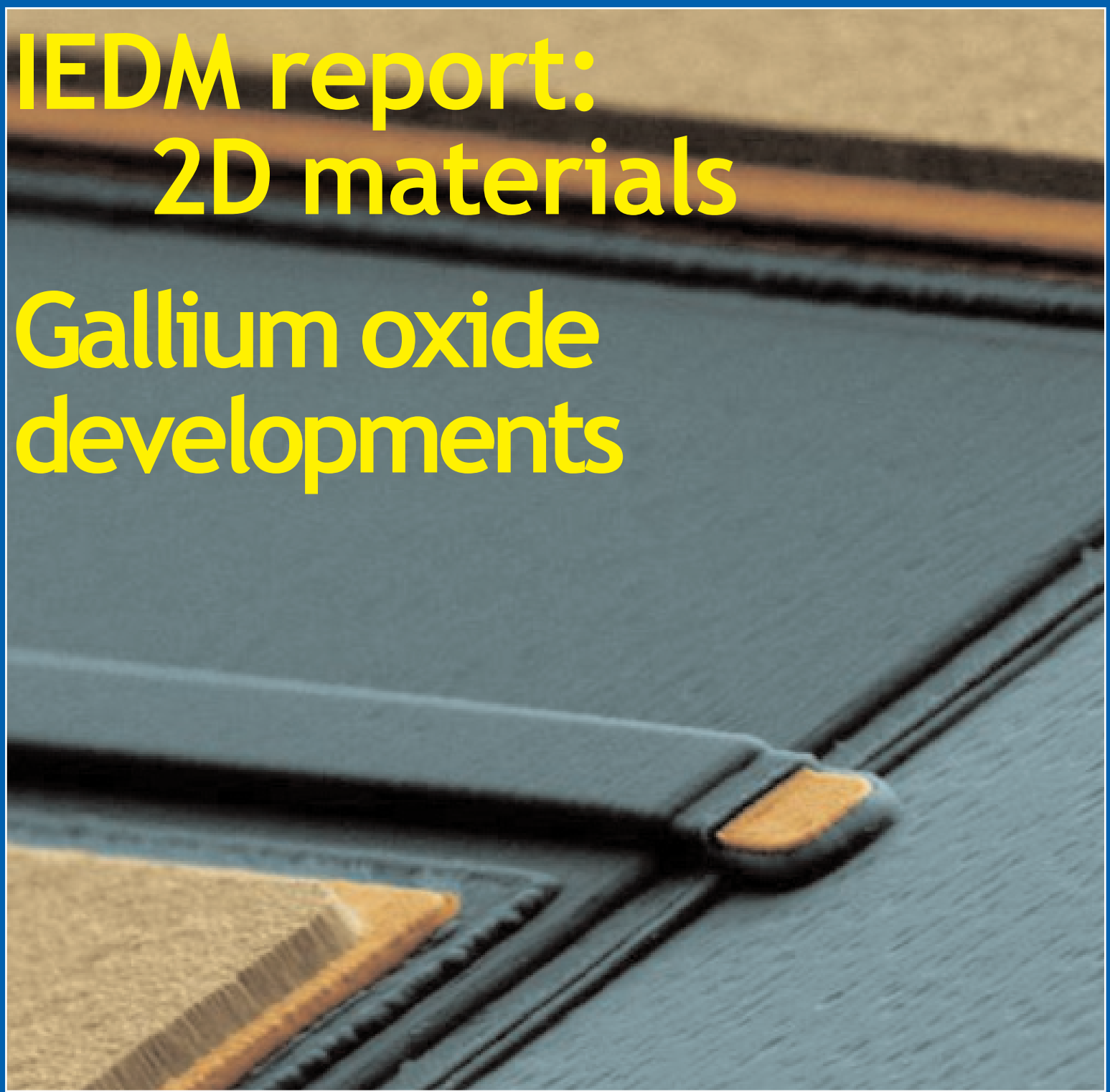
www.semiconductor-today.com

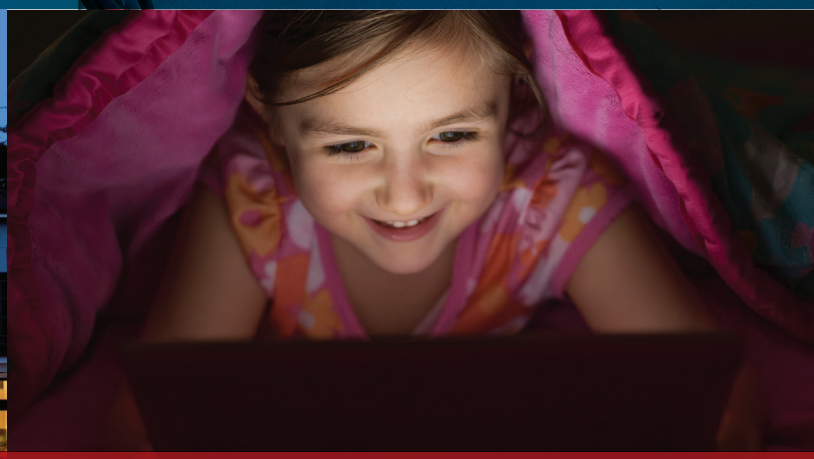


IEDM report: 2D materials

Gallium oxide developments

HRL offering GaN MMIC foundry • Aledia raises €30m
SDK expanding SiC epi capacity • VisIC samples 1200V GaN module

Lower Cost LEDs



Faster LED Adoption

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

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

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

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

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

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Veeco's New TurboDisc EPIK700 GaN MOCVD System

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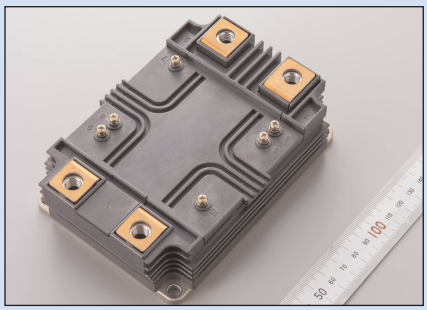
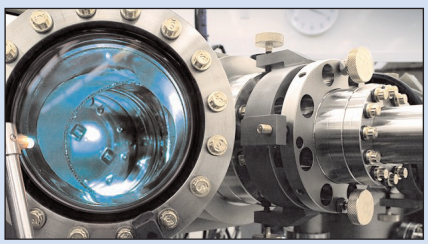
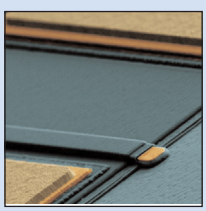
p12 Anokiwave has opened a millimeter-wave IC design verification laboratory in its San Diego office.



p16 Mitsubishi Electric's new 6.5kV full-SiC power semiconductor module, said to offer record power density of 9.3kVA/cm^3.



p28 HRL Laboratories has announced a new shared foundry service, offering millimeter-wave GaN technology for MMIC fabrication through multi-project wafer runs.



Cover: False-color, plan-view SEM image of a lateral Ga_2O_3 FET with an optically defined gate. From near (bottom) to far (top): the source, gate and drain electrodes. Metal is shown in yellow and orange, dark blue represents dielectric material, and lighter blue denotes the Ga_2O_3 substrate.. **p14**

editorial

New materials driving growth

After last issue's report on presentations at the IEEE's International Electron Devices Meeting (IEDM) in December spanning vertical power and high-speed III-V devices, on pages 74–80 of this issue we complete our reporting on IEDM by covering the use in both microelectronic and optoelectronic devices of two-dimensional materials such as the transition-metal dichalcogenide molybdenum disulphide, boron nitride, black phosphorous, carbon nanotubes and graphene. Such monolayer atomic-scale structures are of growing interest for beyond-silicon capabilities like smaller-scale, higher-density and faster-switching transistors, as well as for extending the wavelength range of photodetectors.

Also, on page 30 we report how Saudi Arabia's King Abdullah University of Science and Technology (KAUST) is working on varying the boron content in the alloys boron aluminum nitride and boron gallium nitride to tune the material through a wide range of spontaneous and piezoelectric polarization, so that an interface with conventional nitride semiconductor material could enable the formation of optical and electronic junction devices with better performance than existing devices.

Another new material — the wide-bandgap semiconductor gallium oxide — is addressed on page 14 (as a replacement for silicon in lower-cost, smaller microelectronic field-effect transistor devices) and on page 15 (for bandgap- and hence wavelength-tunable ultraviolet sensors, by alloying with aluminium oxide and indium oxide).

In the meantime, 'conventional' wide-bandgap semiconductor technology is continuing to proliferate. Following an initial expansion (to be completed in April), Tokyo-based SDK has already decided to further expand its capacity for producing high-quality-grade silicon carbide epiwafers for power devices, driven by applications such as inverter modules for railcars, on-board battery chargers, and rapid charging stations for electric vehicles (EVs). For similar reasons, ON Semiconductor has partnered with Audi to develop electronics for autonomous and electric vehicles — see page 18.

Product developments in GaN FETs and power ICs are being showcased at the Applied Power Electronics Conference (APEC) by Navitas, Transphorm, EPC and Renesas (see pages 24–26). In addition, HRL is now offering a gallium nitride MMIC foundry service (page 28). Regarding GaN-on-silicon in particular, VisIC is now sampling the first 1200V GaN modules, and is announcing a manufacturing partnership to use the 650V GaN-on-Si process of Taiwan's TMSC (the world's biggest silicon wafer foundry) — see page 23, while MACOM has agreed for its GaN-on-Si technology to be used by silicon-based chip maker STMicroelectronics to manufacture products for high-power RF applications. On pages 84–85, Dresden-based GaN-on-Si epitaxy firm ALLOS reports that France's IEMN-CNRS research institute has demonstrated a 1400V breakdown voltage on its epiwafers. The firm is now seeking an industrial partner that wants to develop 1200V devices (citing the technology's ability to compete with SiC-based devices, but at lower cost).

Meanwhile, the market for radio-frequency GaN devices is forecasted by Yole Développement to rise at a compound annual growth rate (CAGR) of 22.9%, more than tripling from $380m in 2017 to $1.3bn in 2023 (see pages 88–89). In particular, Yole reckons that most sub-6GHz macro network cells will use GaN devices because LDMOS silicon can no longer hold up at such high frequencies and gallium arsenide is not optimum for high-power applications.

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

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

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HVM: High Volume Manufacturing

Millimeter-wave and microwave RF transceiver market growing at 11.56% CAGR to 2021

The global market for millimetre-wave and microwave RF transceivers (including applications in mobile phones, tablets, smart TVs, PCs and laptops, and set-top boxes) will grow at a CAGR of 11.56% during 2017–2021, according to a report by TechNavio

One trend is the proliferation of Internet of Things (IoT) applications (enabling devices to collect data using sensors and actuators and to transmit data to a centralized location on a real-time basis). Representing one of the fastest-growing markets worldwide, it is estimated that 33 billion devices will be connected through IoT by 2021, generating a total of about 50 trillion GB of data.

One driver in the market is the deployment of next-generation LTE wireless networks. The increase in data consumption has led to the adoption of next-generation LTE networks, such as LTE and LTE Advanced. The growing consumption of mobile data has resulted in the growth of commercial networks, making LTE the fastest-developing mobile technology, notes the report.

Specific bands have been designated for LTE, but they vary from one carrier to another. For example, the iPhone 6 from Verizon Communications uses different bands compared with the iPhone 6 from AT&T. The use of multiple bands that are often widely spaced apart causes LTE and 3G interference from different RF sources.

One of the fastest-growing markets, it is estimated that 33 billion devices will be connected through IoT by 2021

Market trends include the growing applications of IoT; the introduction of the coax transceiver chip; the growth in technological convergence; the advent of WCC communication; the era of wearable technology; and telecom firms demonstrating an inclination toward millimetre-wave solutions.

Key vendors include Broadcom, MediaTek, Microchip Atmel, Qorvo, Qualcomm Technologies, and Skyworks Solutions, as well as Analog Devices, Cisco, GCT Semiconductor, Lime Microsystems, Microsemi, NVIDIA, NXP Semiconductors, Phi Microtech, Silicon Motion, Spreadtrum Communications, STMicroelectronics, and Texas Instruments.

www.technavio.com/report/global-millimeter-wave-and-microwave-rf-transceiver-market

Fiber-optic components market to grow at 10% CAGR from $17.15bn in 2018 to $27.6bn in 2023

The fiber-optic components market will rise at a compound annual growth rate (CAGR) of 10% from $17.15bn in 2018 to $27.6bn in 2023, according to a report from MarketsandMarkets. Factors that are driving growth are the increasing deployment of data centers, growing Internet penetration and data traffic, and rising demand for bandwidth and reliability.

AOC market to grow fastest

Cloud technology has developed rapidly with the beginning of the Big Data age. To satisfy the demands of higher bandwidth and more applications in a variety of cloud computing environments, active optical cables (AOCs) have been developed. The AOC market is hence expected to grow at the highest CAGR.

100G data rate to hold largest share of market by 2023

The market for 100G is growing as it offers high-speed, increased data rate, pre-defined user configuration, and complete automation capabilities. 100G is hence expected to hold the largest share of the fiber-optic components market by 2023.

Communications to be largest application

Among various applications, communications is expected to have the largest share of the market between 2018 and 2023. Growth is attributed to the mass utilization of digital technologies and applications in telecoms, data centers and enterprises, as well as positive trends in broadband and Big Data management.

APAC to be biggest region

The largest market by geographic region during the forecast period is expected to be the Asia Pacific (APAC), where rising industrialization and infrastructure development offer enormous opportunities for the use of fiber-optic components across various applications.

Major players in the fiber-optic components market are cited as Finisar (USA), Lumentum (USA), Broadcom (USA), Sumitomo Electric (Japan), and Accelink Technologies (China), Acacia Communications (USA), Emcore (USA), Fujitsu Optical Components (Japan), Furukawa Electric (Japan), and II-VI (USA).

www.marketsandmarkets.com/Market-Reports/fiber-optic-component-market-63775446.html

Prices of high-power ceramic-substrate and mid-power 3030 packaged LEDs in China down slightly in January

Some high-power ceramic-substrate LED and mid-power 3030 packaged LED products on the China market both saw a slight price drop in January as suppliers were trying to clear inventory at the year end, notes market research firm LEDinside (a division of TrendForce).

With new products released and more promotions, the prices of mid-power 3030 package products may be lowered further after the Chinese New Year, says analyst Terri Wang. On the other hand, the market share of high-power LED products is shrinking and current orders come mainly from existing customers, so overall prices in the high-power segment are expected to remain stable in the future. Manufacturers will rely on product performance upgrades and efficiency improvement to maintain market share, it is reckoned.

In addition, under the increasingly fierce competition in the packaged LED market for lighting products, major international manufacturers are continuing their efforts in the automotive LED market. The use of LEDs in headlamps has proliferated: Osram, Nichia and Seoul Semiconductor have all introduced single-chip LEDs for low-beam applications. Currently, headlamp products available on the market use mostly two single-chip LEDs for low beam, and one 4-chip or 5-chip LED for high beam. Some products use three or four single-chip LEDs for low beam. Single-chip automotive LEDs are usually 1–5W, with minimum luminous flux of 80–300lm, notes LEDinside.

www.ledinside.com

Silicon photonics market growing at 17.02% CAGR from $199.363m in 2017 to $511.851m in 2023

The silicon photonics market will rise at a compound annual growth rate (CAGR) of 17.02% from $199.363m in 2017 to $511.851m in 2023, according to a report from Knowledge Sourcing Intelligence LLP.

A major driver is the growing focus on the miniaturization of components. Due to enhancing data transfer speed by improving performance in terms of computation, communication, and measurement, manufacturers are replacing conventional copper cabling with silicon photonics. Growing bandwidth across multiple markets (including data centers and telecom) is expected to bolster the silicon photonics market in the coming years.

Key industry players are cited as Intel Corp, Kaiam Corp, Mellanox Technologies, Adva Optical Networking, and IBM.

www.researchandmarkets.com/publication/m39nht2/4463684

Qorvo's quarterly Infrastructure & Defense Product revenue up 20% year-on-year

Despite weaker demand from largest customer and China in near term, premium mobile products plus defense, IoT and GaN to drive growth, margin expansion and greater free cash flow in fiscal 2019

For its fiscal third-quarter 2018 (ended 30 December 2017), Qorvo Inc of Greensboro, NC, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has reported revenue of $844.8m, up 2.9% on $820.6m last quarter and 2.4% on $825.4m a year ago (and exceeding the midpoint of the $830-850m guidance by almost $5m). Revenue from China comprised about 20% of the total (lower than historically).

Mobile Product (MP) revenue was $642m, down 2.3% on $656.8m a year ago but up 1.9% on $630m last quarter, driven by a very strong ramp in support of product launches at the firm's largest customer.

Infrastructure & Defense Product (IDP) revenue was a record $202.7m, up 6.7% on $190m last quarter and 20% on $168.6m a year ago (the seventh consecutive quarter of double-digit year-on-year growth). This reflects continued strength in defense (up more than 50% year-on-year, driven by advanced radars and other electronic warfare products) and in connectivity including Wi-Fi and emerging Internet of Things (IoT) applications, as well as gallium nitride (GaN, which is becoming the technology of choice for transmit amplifiers at all major base-station OEMs, says Qorvo).

In particular, during the quarter, Qorvo achieved record Smart Home revenue (up 30% year-on-year), and secured design wins in support of Samsung remote controls.

"IDP has delivered nine out of ten sequential growth quarters since we repositioned our portfolio to target defense, base station, automotive, smart home, IoT, Wi-Fi and optical markets," notes president & CEO Bob Bruggeworth.

On a non-GAAP basis, gross margin has risen further, from 44.3% a year ago and 47.4% last quarter to 48% (exceeding the 47.5% guidance, and back to the levels of fiscal 2016).

Operating expenses were $150.8m (17.9% of sales), cut from $158.2m (19.3% of sales) last quarter (and below the forecasted $158m) due to being ahead of schedule with ongoing productivity efforts plus the timing of program spending.

Operating income has risen further from $208.7m (operating margin of 25.3% of sales) a year ago and $230.5m (28.1% margin) last quarter to $254.3m (30.1% margin), fulfilling a commitment made last year to achieve a quarter in fiscal 2018 with an operating margin exceeding 30%. This was despite mobile volumes and fab utilization falling short of expectations this fiscal year.

Beginning late in the quarter, demand trends in mobile deteriorated at our largest customer and also in China

Net income has likewise risen further, from $177.3m ($1.35 per diluted share) a year ago and $198.4m ($1.52 per diluted share) last quarter to $220m ($1.69 per diluted share, above the $1.60 guidance).

"Our third quarter results exceeded guidance, driven by higher revenue, improved gross margin, and effective cost control," comments chief financial officer Mark Murphy. "We also achieved record free cash flow on strong operating performance and lower capital spend."

Cash flow from operations rose from $219.9m last quarter to $270.1m. Capital expenditure (CapEx) fell further, from $67.8m last quarter to $45.5m (compared with $136.5m a year ago) after the completion of recent expansions. Free cash flow was hence a record $224.6m (up from $152.1m last quarter and just $83.9m a year ago). During the quarter, cash and cash equivalents rose from $574.9m to $841.3m.

"With recent tax legislation, we can more freely deploy cash for investments in growth and repurchasing shares," notes Murphy. In the December quarter, Qorvo repurchased $80m of stock.

"Beginning late in the quarter, demand trends in mobile deteriorated at our largest customer and also in China," notes Bruggeworth. "This weakness is impacting our near-term expectations," he adds.

For its fiscal fourth-quarter 2018, Qorvo hence expects revenue to fall to $645–665m. This is despite IDP being flat to up slightly in the single-digits sequentially (and up by more than 20% year-on-year, to over 30% of total revenue).

Due mainly to reduced volumes of low-band power amplifier duplexers (PADs) and an increased mix of higher-margin IDP business, gross margin should be flat-to-up 50 basis points sequentially (i.e. 48–48.5%, up 550 basis points from the trough of 42.8% in fiscal Q2/2017 to the midpoint of the current guide).

Operating expenses are forecast to increase slightly to $153m due to development program spending and seasonal factors including payroll taxes.

Despite diluted earnings per share falling to about $1.05, free cash flow is expected to still be strong, at about $200m.

"While near-term market demand has weakened in handsets, our

longer-term outlook has improved on recent developments with mid/high-band PADs, Phase 6 design wins, and cellular IoT and other connectivity applications," says Bruggeworth.

During the December quarter, Qorvo sampled a custom mid/high-band PAD to an additional marquee smartphone customer; began production of next-generation RF Fusion front-ends for Phase 6 architectures (including mid/high-band and low-band integrated PAD modules); secured design wins for bulk acoustic wave (BAW)-based band 1+3 quadplexers in support of the top four China-based smartphone OEMs; and sampled what is claimed to be the industry's first RF front-end module meeting 5G standalone and 5G non-standalone requirements to multiple mobile device customers and baseband chipset suppliers. Qorvo was also selected by Qualcomm to supply an automotive front-end module (FEM) for a cellular-to-everything reference design, enabling vehicle connectivity. In addition, it co-developed what is claimed to be the industry's smallest cellular IoT module with Nordic Semiconductor, enabling global LTE-M/narrowband IoT applications. Overall, design wins in the December quarter were up by more than 40% year-on-year.

"We expect continued robust growth in IDP in 2018 [with the annualized revenue run-rate quickly moving towards $1bn], and in mobile we are gearing up for an aggressive ramp of a custom mid/high-band PAD in the second half of the calendar year," says Bruggeworth. "This is the most valuable and highly integrated placement in mobile RF, representing what we call the integration hub in the main path of the RF system," he adds. "This is a significant customer validation of our BAW technology and multiplexing expertise. Coupled with gains in antenna tuning and envelope tracking, we expect this to drive another generation of year-over-year growth with these top customers," he adds.

"Our efforts to leverage our technology position and improve the operating performance of our business are paying off and we expect to sustain this progress," says Murphy. "In fiscal 2019 we expect robust IDP growth to continue, supported by trends in defense, IoT and GaN," he adds. "We are hitting key milestones to realign the mobile product portfolio from lower- to higher-margin products and securing design wins in the industry's most attractive segments."

While our near-term revenue outlook has been impacted by weaker demand signals from our largest customer and from China, in fiscal year 2019 we expect our premium mobile products and continued strength in defense, IoT and GaN to support revenue growth, margin expansion and greater free cash flow in fiscal year 2019

"We expect to see significant benefits from these efforts starting in the second half of this calendar year," says Murphy. "As our product mix and overall fab utilization improve, we expect gross margins to continue to expand [above 49% for fiscal 2019, including reaching 50% in at least one quarter]. That contemplates Richardson, our largest fab [for BAW filters], moving up over 80% utilization in the next 6 months as well as increased utilization in our GaAs fabs and over 80% utilization in our China back-end assembly & test factories. This will be partially offset by lower utilization rates in our SAW [surface acoustic wave] fabs as we migrate resources to bolster recent successes and future opportunities in BAW and more selectively compete for SAW-based opportunities," he adds. On average, fab utilization should be a positive effect going into fiscal 2019.

"Our current projection would indicate SAW will be down year-over-year in the second half," notes Bruggeworth. "We are investing in a lot of key technologies in SAW which will help enable many different products that are coming, but with majority of those products we are going to focus going forward on products that combine BAW with SAW to really make unique product offerings and leverage that asset further," he adds. The proportion of Mobile revenue that is BAW-related is expected to rise less than 25% for fiscal 2018 to over 30% in fiscal 2019, then over 40% in fiscal 2020. In fiscal 2021 nearly half of Mobile business should BAW-related (some of which will require SAW filter content as well).

"With a more focused product portfolio, restructuring efforts taking full effect and productivity remaining a priority, we also expect OpEx efficiency to improve further [targeting below 20% of sales for fiscal 2019]," says Murphy. "We are on track to achieve the operating margin target we laid out at our Investor Day last May of 33% by fiscal year 2020," he adds.

Qorvo expects CapEx to be below 10% of sales for fiscal 2019 (down from 18% last year) and below 8% the next year. "For example, we are going to be able to increase our BAW capacity 70% from current capacity to fiscal year 2020 at only about $80m of spend," says Murphy. "With more profitable growth in mobile and robust growth in IDP, expanding operating margins and lower levels of CapEx we are targeting free cash flow of $800m in fiscal year 2019," he adds. "While our near-term revenue outlook has been impacted by weaker demand signals from our largest customer and from China, in fiscal year 2019 we expect our premium mobile products and continued strength in defense, IoT and GaN to support revenue growth, margin expansion and greater free cash flow in fiscal year 2019."

www.qorvo.com

Skyworks' quarterly revenue up 7% sequentially to a record $1.052bn

Targeted cash return raised from 40–50% of free cash flow to 60–75%

For its fiscal first-quarter 2018 (ending 29 December 2017), Skyworks Solutions Inc of Woburn, MA, USA (which makes analog and mixed-signal semiconductors) has reported record revenue of $1.052bn, up 7% on $984.6m last quarter and up 15% on $914.3m a year ago (and exceeding guidance of $1.05bn), driven by strong global demand for the firm's wireless communications engines.

"The December quarter was a strong mobile quarter, especially driven by some new platform ramps with our largest customer [Foxconn]," notes senior VP & chief financial officer Kris Sennesael. Mobile (Integrated Mobile Systems and Power Amplifiers) hence comprised slightly above the usual 75% of revenue and Broad Markets slightly below 25%.

"As connectivity performance requirements intensify, Skyworks is leveraging our mixed-signal expertise, scale and customer relationships to power the mobile economy and capitalize on several strategic growth catalysts," says president & CEO Liam K. Griffin. "Our system solutions are enabling everything from industrial robotics to drones, autonomous vehicles, wireless infrastructure, home security systems and virtual assistants," he adds.

Highlights during the quarter include:

- ramping ZigBee and Bluetooth devices for Nest's portfolio of residential alarms;
- delivering connectivity solutions for Google Home Max wireless speakers;
- shipping AEC-Q100-grade modules to leading European auto manufacturers;
- being designed into Sylvania's smart light bulbs for the connected home;
- launching LTE-Cat 1 engines across Amazon's Kindle Oasis e-readers;
- supporting NetGear's Orbi Wi-Fi system for outdoor mesh networks;
- enabling Comcast's DOCSIS 3.1 broadband routers;
- deploying LTE-A telematics modems for next-generation OnStar applications;
- unveiling the SkyOne WiFi portfolio of highly integrated wireless networking engines;
- leveraging SkyOne and SkyBlue across ZTE and HTC mobile phones;
- securing massive MIMO design wins with leading infrastructure provider for China;
- powering Motorola, Oppo, Vivo and Xiaomi flagship smartphone launches with a suite of SkyLiTE, Wi-Fi and switching solutions; and
- partnering with XY Findables to enable innovative tracking devices.

On a non-GAAP basis, gross margin has risen from 51% last quarter to a record 51.4% (towards the top end of the 51–51.5% guidance).

Operating expenses (OpEx) were $127m, up from $123m last quarter but cut from 12.5% of revenue to 12%.

Operating income was $414m (operating margin of 39.4% of sales), up from $379.2m last quarter and $354.3m (38.8% margin) a year ago.

Net income has risen further, from $301.6m ($1.61 per diluted share) a year ago and $338.8m ($1.82 per diluted share) last quarter to a record $371.5m ($2.00 per diluted share, exceeding the $1.91 guidance by $0.09).

Cash flow from operations was $360.8m (down from $425.4m last quarter). However, capital expenditure (CapEx) has dropped from $85m last quarter to $28.2m. Free cash flow $332.6m (free cash flow margin of 31.6% of revenue, exceeded the 30% target). During the quarter, Skyworks paid dividends of $59.1m and spent $172.5m to repurchase 1.7 million shares of common stock. Overall, cash balance rose by $64.7m, from $1.617bn to $1.682bn.

"Given our broad-based design-win momentum, we expect to outperform our addressable markets in the March quarter," says Sennesael.

Despite this, for fiscal second-quarter 2018, Skyworks expects revenue growth to slow to 6–8% year-on-year, with fewer unit shipments for mobile customers' premium flagship models offsetting the steady growth in broad markets plus a slight turnaround in China (flat to up a bit) and Skyworks' Korean customer up year-on-year. Gross margin should hence fall to 50.5–51%. OpEx is expected to rise to $131m. At the midpoint of $910m in revenue, diluted earnings per share should fall to $1.60 (up 10% year-on-year).

In second-half 2018, Skyworks expects to see accelerating gains in Mobile (with unit shipments catching up). "We have some really powerful design wins that have been cemented, and it is just a matter of time for those to actually make it into our profit & loss," says Griffin. "With the recent launch of our breakthrough Sky5 platform, Skyworks is well positioned to accelerate 5G deployments," he adds.

"We are going to increase CapEx in the March quarter and June quarter, as we get ready for the ramp up in the second half in the calendar year [taking full-year CapEx to at least 10% of revenue]. This is both related to capacity extensions as well as technology investments," says Sennesael. "In terms of insourcing our filter operation, we continue to make good progress there toward a 75% insource [to be reached in a couple quarters]," he adds. "We're still working on a number of BAW [bulk acoustic wave] technologies and solutions to drive higher frequencies and to address 5G... that's

what our Sky5 platform is going to do," says Griffin. "We have the opportunity to pursue just about of every type of filter that we would need. Some of those will be in-house; some would be through partnerships," he adds.

"Based on our expanding reach within flagship platforms, and with design-win momentum across broad markets, we expect accelerated top-line growth and further margin improvements throughout the balance of the fiscal and calendar year [towards the targets of 53% gross margin and 40% operating margin]," says Sennesael.

"Skyworks enters 2018 with strong momentum," notes Griffin. "Our outperformance is being driven by a vibrant, dynamic mobile ecosystem; one that rewards companies who can resolve architectural complexity with simplified integrated solutions," he adds. "Over the past five years, our revenues have more than doubled, EPS has more than tripled, and our operating cash flow is up five times. Our strong cash generation is allowing us the flexibility to continue to invest to win, while substantially increasing our targeted cash return to shareholders."

Reflecting confidence in its business model and outlook, Skyworks' board of directors has approved a new $1bn stock repurchase program. This has been triggered by the fact that, of the firm's $1.682bn cash reserves, about $1bn is offshore and can now be repatriated without any further tax consequences (due to recent changes to tax legislation in the USA).

Skyworks' board has also declared a cash dividend of $0.32 per share, payable on 15 March, to stockholders of record at the close of business on 22 February.

"Coupled with the added flexibility of the recently passed tax legislation, our strong free cash flow generation allows us to leverage stock repurchases, dividends and capital expenditures to drive higher shareholder returns and investment for future growth," says Sennesael. "As a result, we are increasing our targeted cash return rate to shareholders from the 40–50% range historically to a level of 60–75% of free cash flow going forward." The targeted full-year free cash flow margin is 30% of revenue.

www.skyworksinc.com

Skyworks announces new $1bn stock repurchase program

Skyworks' board of directors has authorized the repurchase of up to $1bn of the firm's common stock from time to time prior to 31 January 2020, on the open market or in privately negotiated transactions, in compliance with applicable securities laws and other legal requirements.

The newly authorized stock repurchase program replaces in its entirety the $500m stock repurchase program that was approved by the board on 17 January 2017 and had about $2m of repurchase authority remaining.

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

Skyworks currently expects to fund the repurchase program using its working capital. As of 29 December 2017, the company had cash and cash equivalents of $1.7bn.

Skyworks and Broadcom collaborate on 802.11ax Max WiFi platforms

Skyworks' new portfolio of 802.11ax wireless connectivity solutions is being used by Broadcom Ltd in its recently launched Max WiFi reference platforms.

Skyworks' modules integrate high-power transmit and low-noise receive amplification with precision switch capability in an ultra-compact form factor that, when paired with a modem, incorporate all the essential functionality between the system-on-chip (SoC) and the antenna. Specifically, Skyworks' 2.4GHz and 5.0GHz 802.11ax modules and Broadcom's Max WiFi solutions provide four times faster download speeds, six times faster upload speeds, enhanced coverage and up to seven times longer battery life compared with 802.11ac Wi-Fi products available on the market currently, it is reckoned.

"This strategic partnership gives our customers a unique opportunity to deliver best-in-class wireless experiences for consumers across many new markets spanning multimedia streaming, autonomous cars and augmented/virtual reality," says David Stasey, VP & general manager of diversified analog solutions for Skyworks.

Next-generation 802.11ax devices have been widely adopted across the consumer electronics industry, as companies throughout the ecosystem begin developing solutions and products in support of the new standard. End applications for the Max WiFi modules include Wi-Fi routers, residential gateways, enterprise access points, and client devices. A key benefit of the 802.11ax standard is that it allows for a more robust and dedicated connection with data-intensive applications such as 4K TV, particularly when multiple users are streaming Wi-Fi simultaneously.

According to ABI Research, 802.11ax devices will account for 57% of Wi-Fi chipsets by 2021.

www.broadcom.com

Anokiwave opens mmW verification and test lab

Anokiwave Inc of San Diego, CA, USA — which provides highly integrated silicon core chips and III-V front-end integrated circuits for millimeter-wave (mmW) markets and active antenna-based solutions — has opened a millimeter-wave design verification laboratory in its San Diego office, enabling rapid characterization of its product portfolio of mmW ICs for 5G, SatCom, and radar markets.

The lab has test instrumentation and wafer probing capability up to

50GHz that supports both rapid characterization of new products and increased applications engineering evaluation capacity.

"Investing in the facility in San Diego will increase our design verification capacity, which ultimately improves our time-to-market," says founder & chief technology officer Nitin Jain. The new lab is "the latest example of Anokiwave's commitment to the emerging mmW 5G, SatCom and radar markets," he adds.

Anokiwave says that the new lab space allows it to continue to aid the evolution of the active antenna market with industrialized, production-ready products for millimeter-wave active antennas.

26GHz 5G mmW reconfigurable 256-element active antenna array

Anokiwave has announced the latest product in its family of mmW Phased Array Antenna Innovator's Kits, the AWA-0142, driven by the AWMF-0135 26GHz 5G quad core IC with embedded functions for remote telemetry and low-latency steering.

The AWA-0142 is a 256-element, reconfigurable active electronically scanned antenna covering the 24.25–27.5GHz band, delivering +60dBmi (1KW) of EIRP (equivalent isotropic radiated power) with an effective Rx noise figure (NF) of 5dB. The Anokiwave Active Antennas are claimed to be the first commercially available family of phased arrays that enable the development and measurement of radio links and channel models, as well as for rapid prototyping and testing of electronically beam-steered radio links through low-latency beam update rates.

"We see 26GHz as another important 5G band, especially in Europe and China," says Anokiwave technology fellow Ian Gresham. "With the introduction of this latest array to the current portfolio of Active Antenna Innovator kits, Anokiwave is paving the way for network operators to roll out 5G coverage using the mmW bands," he adds. "The array is based on our first-generation 26GHz 5G quad core IC, and allows for real-time active beam-steering applications in a single 256-element or in a 4x64-element configuration that enables 4x4 MIMO testing."

Developed with Ball Aerospace for mmW 5G wireless markets, the AWA-0142 includes an integrated controller that can steer the beams to predetermined positions within a wide scan volume with minimal latency and system sensitivity.

The AWA-0142 Innovator's kits are available now. Customers may also license the technology for their own array development activities.

www.anokiwave.com

Anokiwave launches family of ICs supporting 3GPP

Anokiwave has launched the first product in a new family of second-generation 5G silicon quad core ICs that enable 3GPP-compliant base stations with the worldwide release of the 39GHz AWMF-0156 IC. The second-generation IC family is part of Anokiwave's on-going strategy to enable the commercialization of 5G mmW systems with silicon ICs.

The AWMF-0156 operates at 37.1–40.0GHz, supports four radiating elements, and includes gain and phase controls for analog RF beam steering. Anokiwave's patent-pending IP blocks implemented in silicon technology are said to enable low-cost hybrid beam forming with high energy efficiency and low-latency beam steering.

"Anokiwave is delivering innovative, production-ready ICs for the 5G market with industry-first ICs at 26GHz, 28GHz and 39GHz and continues its leadership with today's announcement of the world's first family of 5G silicon core ICs that enable 3GPP compliance," says Anokiwave technology fellow Ian Gresham. "The new generation of core ICs is an essential product family that allows network operators to roll out 5G coverage in earnest, starting in 2018."

The AWMF-0156 is a highly integrated silicon IC packaged in a wafer-level chip-scale package (WLCSP), fitting within the typical 3.8mm lattice spacing at 39GHz.

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

www.anokiwave.com

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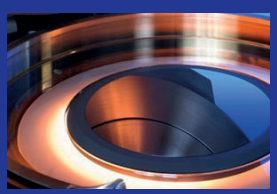

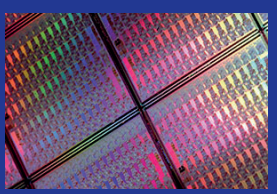

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Gallium oxide as replacement for silicon in lower-cost, smaller microelectronic devices

Wide-bandgap FETs suit high-voltage, high-power and power-switching applications

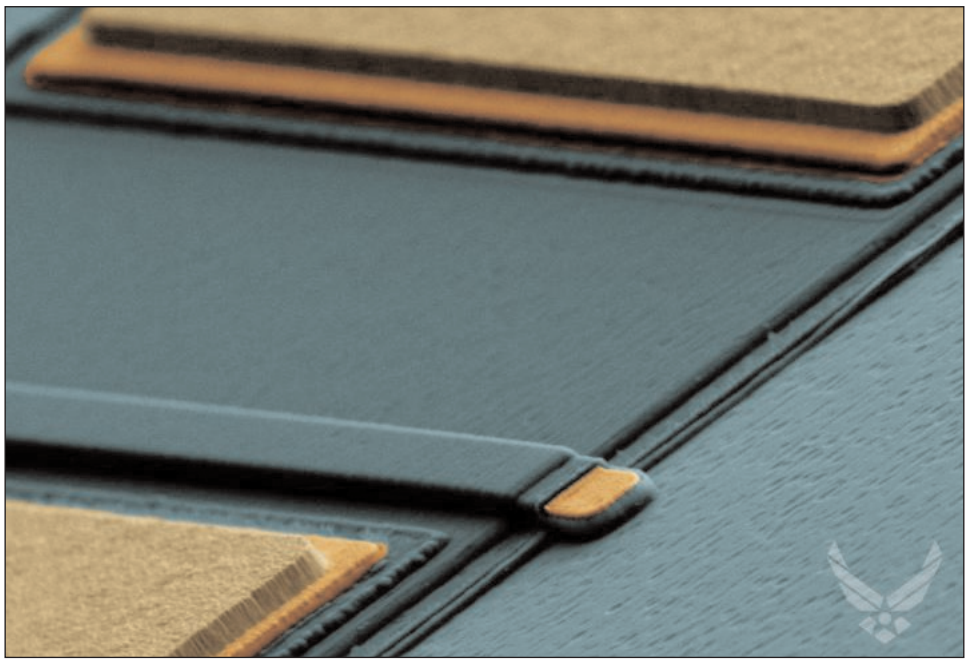
Masataka Higashiwaki and Gregg Jessen at the US Air Force Research Laboratory (AFRL) have outlined a case for producing microelectronics using gallium oxide in a Guest Editorial 'The dawn of gallium oxide microelectronics' in Applied Physics Letters 112, 060401 (2018).

Despite being the long-time incumbent material for microelectronics, silicon faces limitations, particularly with scalability for power applications. Pushing semiconductor technology to its full potential requires smaller designs at higher energy density.

"One of the largest shortcomings in the world of microelectronics is always good use of power: Designers are always looking to reduce excess power consumption and unnecessary heat generation," says Jessen, principal electronics engineer at AFRL. "Usually, you would do this by scaling the devices. But the technologies in use today are already scaled close to their limits for the operating voltage desired in many applications. They are limited by their critical electric field strength."

Transparent conductive oxides (TCOs) are key emerging materials in semiconductor technology, offering the unusual combination of conductivity and transparency over the visual spectrum. One conductive oxide in particular has unique properties that allow it to function well in power switching: gallium oxide (Ga_2O_3), which has a very large bandgap.

Higashiwaki and Jessen focus on field-effect transistors (FETs), which could greatly benefit from gallium oxide's large critical electric field strength — a quality that Jessen says could enable the design of FETs with smaller geometries and aggressive doping profiles that would destroy any other FET material.



A false-color, plan-view SEM image of a lateral Ga_2O_3 FET with an optically defined gate. From near (bottom) to far (top): the source, gate and drain electrodes. Metal is shown in yellow and orange, dark blue represents dielectric material, and lighter blue denotes the gallium oxide substrate.

The material's flexibility for various applications is due to its broad range of possible conductivities — from highly conductive to very insulating — and high-breakdown-voltage capabilities due to its electric field strength. Consequently, gallium oxide can be scaled to an extreme degree. Large-area gallium oxide wafers can also be grown from the melt, lowering manufacturing costs.

The next application for gallium oxide will be unipolar FETs for power supplies. Critical field strength is the key metric here. The critical field strength of Ga_2O_3 is more than 20 times that of silicon and more than twice that of SiC and GaN

"The next application for gallium oxide will be unipolar FETs for power supplies," Jessen says. "Critical field strength is the key metric here, and it results in superior energy density capabilities. The critical field strength of gallium oxide is more than 20 times that of silicon and more than twice that of silicon carbide (SiC) and gallium nitride (GaN)," he adds.

The authors discuss manufacturing methods for Ga_2O_3 wafers, the ability to control electron density, and the challenges with hole transport. Their research suggests that unipolar Ga_2O_3 devices will dominate. They also detail Ga_2O_3 applications in different types of FETs and how the material can be of service in high-voltage, high-power and power-switching applications.

"We are just beginning to understand the full potential of these devices for several applications," reckons Jessen.

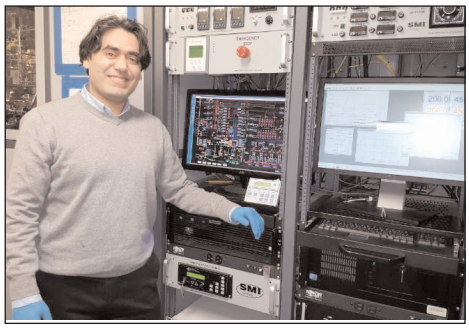
https://doi.org/10.1063/1.5017845

SMI receives DOE SBIR award to evaluate bandgap tunability of gallium oxide by alloying with aluminium oxide and indium oxide on large-area substrate

Structured Materials Industries Inc (SMI) of Piscataway, NJ, USA — which provides chemical vapor deposition (CVD) systems, components, materials, and process development services — has received a US Department of Energy (DOE) Small Business Innovation Research (SBIR) award to evaluate the energy bandgap tunability of gallium oxide (Ga_2O_3) by alloying the material with aluminium oxide (Al_2O_3) and indium oxide (In_2O_3).

The ongoing effort is being conducted in collaboration with professor Lisa Porter and professor Robert Davis of Carnegie Mellon University (CMU). An assessment of Ga_2O_3 bandgap tunability is needed in order to increase the selectivity of sensors for the UVA, UVB and UVC bands, which is a focus of the project. The materials are grown using metal-organic chemical vapor deposition (MOCVD).

"Tuning the energy gap of Ga_2O_3 will establish an even broader range of applications for the material, such as graded heterostructures for optoelectronic devices, photodiodes (PDs) with tunable cutoff wavelengths, as well as optical filters with tunable transmission range," believes SMI research scientist Dr Serdal Okur, who leads the firm's Ga_2O_3 efforts. "Tuning the bandgap of high-quality materials will allow us to better assess optoelectronic properties… In_2O_3 and Al_2O_3 are good candidates to realize the bandgap engineering of Ga_2O_3. Additionally, we decided to use the MOCVD technique as it offers many advantages for ultimate device fabrication, including high growth rates, conformal deposition over device topography, and the capability for scale-up to high-volume production," he adds.



Dr Serdal Okur observing a growth run using an SMI in-house MOCVD reactor.

"In our current DOE project, SMI will demonstrate gallium oxide (GO)-, aluminium gallium oxide (AlGO)- and indium gallium oxide (InGO)-based UV sensors that cover the whole UV spectrum," says Okur. "In particular, these devices will be very important to detect UV photons from liquid Ar (argon) and Xe (xenon) scintillators, both at 128nm and 175nm, respectively, in particle physics experiments," he adds. "SMI will further develop the MOCVD growth parameters and hardware to extend control of energy bandgap tuning of Ga_2O_3 with good-quality crystals. The company, in collaboration with CMU, will continue to explore the potential of large-area Ga_2O_3-based alloys with the intention of making the aforementioned sensors more economical and readily available than competing materials in UV sensing applications," Okur continues.

The "extensive knowledge" of Porter and Davis in this area and CMU's Nanofabrication Facility plays a critical role in the DOE project and related efforts, comments SMI's president & CEO Dr Gary S. Tompa. SMI's proprietary rotating disc oxide MOCVD reactor technology will be used in the project to demonstrate that Ga_2O_3 films can be deposited uniformly on large-area substrates. "We are pleased to showcase our in-house MOCVD reactor system capabilities for this Ga_2O_3 growth," says Tompa. "Based on our past experience and industry standards, we will use a 13"-diameter susceptor for Ga_2O_3 growing in Phase II," he adds. "We were also able to configure the platter for single-wafer (150, 200 or 300mm) or multiple-wafer (100mm or smaller) loads, which will help in evaluating the process."

www.smicvd.com
www.cmu.edu/engineering/materials/people/faculty/bios/porter.html

Mitsubishi Electric's new 6.5kV full-SiC power module achieves record power density, enabling smaller, more efficient power equipment for railcars and electric power systems

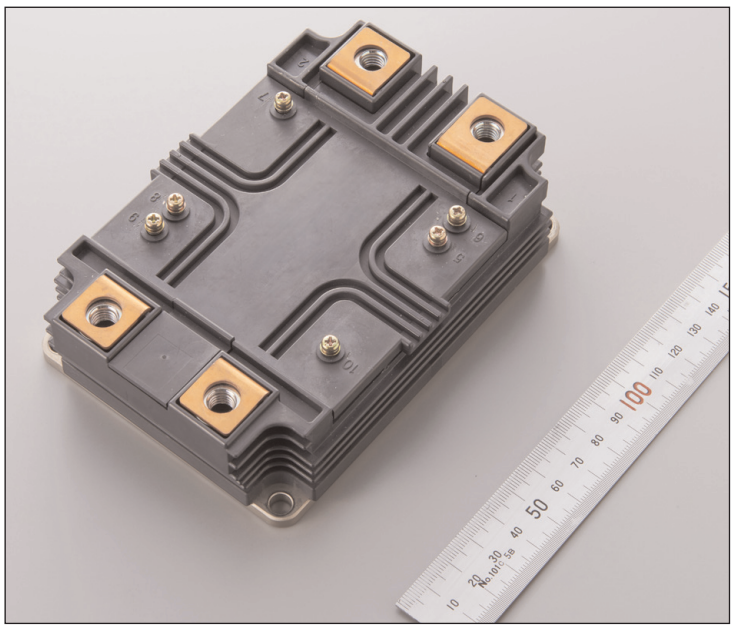
Tokyo-based Mitsubishi Electric Corp says that, among power semiconductor modules rated 1.7–6.5kV, its newly developed 6.5kV full silicon carbide (SiC) power semiconductor module is believed to offer record power density of 9.3kVA/cm^3, which is 1.8x the 5.1kVA/cm^3 of a conventional silicon insulated-gate bipolar transistor (IGBT) module (the new full-SiC power module will be compatible with Mitsubishi Electric's HV100-series silicon IGBT modules).

Mitsubishi Electric is replacing its conventional silicon power semiconductor modules with more energy-efficient SiC power semiconductor modules as key components for power electronics equipment. Previously, the firm commercialized a traction inverter using 3.3kV full-SiC power semiconductor modules for railcars in 2013.

Conventionally, power circuits use two power semiconductor modules connected in series, which requires high voltage in excess of the modules' rated voltages. The new single module, with a higher rated voltage, significantly simplifies the circuit. Also, replacing silicon IGBT modules with full-SiC modules substantially reduces switching loss (cutting power loss by a third). In addition, operating frequency can be increased (by four-fold) to allow smaller peripheral components, leading to more compact equipment.

As well as enabling higher operating frequencies, full-SiC technology improves the power density and efficiency for smaller and more energy-efficient high-voltage power electronics equipment, says Mitsubishi Electric.

The record power density is made possible by the innovative structure, with integrated metal-oxide-semiconductor field-effect transistor (MOSFET) and diode on a single chip (drastically reducing the chip area). Conventional power semiconductor modules use two separate chips (a MOSFET and a diode). Integrating the diode in the MOSFET chip drastically reduces the module's footprint.



Prototype 6.5kV full-SiC power semiconductor module.

In addition, the newly developed package includes a new insulating substrate capable of high thermal conductivity and high heat tolerance has been adopted (the result of a cooperative effort involving four material manufacturers). Die bonding to the insulating substrate is achieved using Mitsubishi Electric's own reliable technology.

Record power density is made possible by the innovative structure, with integrated MOSFET and diode on a single chip (drastically reducing the chip area)

Power electronics equipment is used widely in consumer appliances, industrial machinery and railcars, all of which are trending toward higher energy efficiency, reduced sizes and high voltages. Mitsubishi Electric therefore expects the new module to lead to smaller and more energy-efficient power electronics equipment for high-voltage railcars and electric power systems.

Development of the 6.5kV full-SiC power module has been supported by a project subsidized by Japan's New Energy and Industrial Technology Development Organization (NEDO). In addition to the four material manufacturers (DOWA Electronics Materials Co Ltd, Mitsubishi Materials Corp, Denka Co Ltd and Japan Fine Ceramics Co Ltd) project partners also include three universities (Tokyo Institute of Technology, Shibaura Institute of Technology, and Kyushu Institute of Technology) and one public research institute (National Institute of Advanced Industrial Science and Technology).

The number of patents pending for the technology amount to nine in Japan and three outside Japan. Going forward, Mitsubishi Electric says it will continue to further develop the technology and conduct further reliability tests.

www.mitsubishielectric.com/semiconductors/products/powermod

ROHM opens European test lab for power electronics

Purpose-designed test benches ensure scalability and flexibility

Demonstrating the deployment of its global strategy for the power semiconductor market in Europe, ROHM Semiconductor has opened its new European 'Power Lab', located at its European headquarter in Willich-Münchheide, near Dusseldorf, Germany. The project took several months and ended in 2017 with approval by Germany's TÜV, a global technical services provider of quality, safety and sustainability solutions.

The 300m^2 lab's purpose is the analysis of power components and systems to provide customers with support at the application level. The test lab is hence equipped with several test benches with a separate high-voltage area.

"Electric vehicles, charging station infrastructure, industrial machinery, solar and wind power plants as well as white goods such as washing machines require more and more power semiconductors to comply with the energy efficiency requirements, which have to be tested and validated at early stage of the development phase," says Power Lab head Aly Mashaly, manager of the Power Systems Department. "Because there were no suitable test benches on the market, we decided to develop and design the test benches based on our own requirements subsequently. In this way, we ensure the high scalability of the test benches and their flexibility for future modifications," he adds.

New test lab for power components.

ROHM can electrically characterize all of its semiconductor components such as silicon carbide (SiC) MOSFETs, SiC diodes, insulated-gate bipolar transistors (IGBTs), silicon power MOSFETs and gate drivers, with voltages up to 8000V_{DC}.

The power test bench enables tests on AC/DC, DC/DC, DC/AC and AC/AC converters under real application conditions up to 15kVA. Additionally, high-precision measurements of efficiency and losses can be performed with power analyzers.

Among this test bench's special features are an AC power supply (grid emulator) and electronic loads (AC and DC). Maximum voltages under test are 1500V_{DC} and 400V_{AC}.

The calorimetric test bench is for analyzing the thermal behavior of power discrete devices, modules, electronic boards and complete power electronics systems. This test bench can test with very high current supplies of hundreds of Amps and has a climatic chamber for testing under special temperature conditions ranging from –40°C to +180°C. Humidity can be set between 10% and 98%.

The high-voltage test bench for voltages up to 8000V is located in a separate room to protect the tester during the operation.

ROHM can also investigate and test the insulation sections (clearance and creepage distances) at the board and system levels up to 6000V.

"This investment shows our determination to be one of the major suppliers in SiC and silicon power discrete and integrated device technologies," says ROHM Europe's president Christian André. "The new Power Lab is a central piece of our quality and reliability scheme."

www.rohm.com/eu

Diamond Electric uses GaN to develop business-card-sized thin 1kW isolated bidirectional DC–DC converter

Diamond Electric Mfg Co Ltd of Osaka, Japan (which makes ignition coils for automobiles, and designs and makes DC–DC convertors such as power conditioners, onboard chargers and onboard DC/DC converters) has developed a business-card-sized, thin isolated bidirectional DC–DC converter (IBDC).

By adopting GaN-based power semiconductors, the technology can substantially downsize and reduce the weight of DC–DC converters (which are essential for rechargeable batteries) and is expected to contribute to the proliferation of electric vehicles (EVs) and smart grids.

In recent years, the requirements of large-capacity batteries for EVs and smart grids have caused the voltages of rechargeable batteries to rise. Demands are therefore growing for higher-level isolation of DC–DC converters to ensure safety and to meet safety standards.

Diamond Electric has hence developed the IBDC by fully utilizing its (patent pending) controlling technology. The IBDC combines both charger and discharger circuits.

By adopting high-frequency switching technology (up to 2MHz), Diamond Electric has developed the ultra-compact IBDC (93.5mm x 60mm x 10.5mm excluding the control circuit and heatsink).

Further, the use of GaN-based power semiconductors has enabled high conversion efficiency (up to 95%) despite the high-frequency switching. By utilizing these technologies, Diamond Electric expects to downsize the final product to 25% of the size of existing models.

www.diaelec.co.jp/en

ON Semiconductor partners with Audi on electronics for autonomous and electric vehicles

ON Semiconductor of Phoenix, AZ, USA — which supplies power management, analog, sensors, logic, timing, connectivity, discrete, system-on-chip (SoC) and custom devices for automotive, communications, computing, consumer, industrial, medical, aerospace and defense applications — has unveiled a strategic relationship with Audi AG following its selection to become part of the German car maker's Progressive SemiConductor Program (PSCP).

The goal of the interdisciplinary semiconductor strategy is to foster innovation along with quality and make the latest technologies available for Audi models early on, satisfying the rapidly changing and developing expectations of customers in terms of performance, reliability, safety and operating convenience.

Automotive innovations have increasingly been enabled by semiconductor-based solutions — a trend set to continue due to sophisticated powertrain electrification, Advanced Driver Assistance Systems (ADAS) and the progression towards autonomous driving. In addition, other applications such as those related to comfort and convenience, infotainment and vehicle connectivity are driving semiconductor use in the automotive sector. A high priority is therefore being placed on establishing programs and standards in alignment with leading semiconductor suppliers to create a mutual understanding of technology innovation and quality.

ON Semiconductor provides image sensors, power management and connectivity for automated driving systems. The firm has a portfolio of power solutions including modules and silicon carbide (SiC)/gallium nitride (GaN) wide-bandgap devices that enable the development of highly efficient, next-generation electric vehicles (EVs) and hybrid electric vehicles (HEVs).

"With semiconductors being so vital to recent and future developments on our vehicle platforms, we recognized that traditional automotive innovation cycles were no longer appropriate for keeping pace with consumer demand for exciting new technologies in all areas of the vehicle," says Dr Thomas M. Mueller, Audi's head of electrics/electronics. "Partnering with a market leader like ON Semiconductor on our PSCP will provide the perfect framework for close collaboration and help speed the realization of innovative, high-quality and highly efficient systems for our vehicles."

Currently, 80–90% of all car innovations are based directly or indirectly on semiconductors. This is why Audi is developing a core competency in the semiconductor area with its Progressive SemiConductor Program, which is designed to rapidly make the latest semiconductor technologies available in cars while increasing reliability. The aim is to transfer progress in microelectronics more effectively to the car. A key part of the program involves being in direct contact with the semiconductor manufacturers and working with them on joint development.

www.onsemi.com

SDK to expand high-grade SiC epi capacity further to 7000 wafers per month by September

Tokyo-based Showa Denko K.K. (SDK) has decided to further expand its capacity for producing high-quality-grade silicon carbide (SiC) epitaxial wafers for power devices, which are already marketed under the trade name High-Grade Epi (HGE). This is in addition to an existing, ongoing expansion of the HGE production facilities announced last September.

After the initial expansion work (scheduled to be finished in April), SDK's HGE production capacity will rise from 3000 wafers per month (equivalent, for 1200V-breakdown power devices) currently to 5000 wafers per month. After the further expansion (to be completed in September), capacity will rise to 7000 wafers per month.

Compared with the mainstream silicon-based devices, SiC-based power devices can operate under high-temperature, high-voltage and high-current conditions while conserving energy substantially. These features enable device makers to produce smaller, lighter and more energy-efficient next-generation power control modules. SDK says that, in addition to the traditional use as power sources, SiC-based power devices are now replacing conventional silicon-based power devices for on-board use, such as inverter modules for railcars, on-board battery chargers, and rapid charging stations for electric vehicles (EVs) in parallel with the rapid expansion of the EV market.

SDK says its SiC epiwafer business has been achieving above-market growth rates because power device makers appreciate that HGE achieves what it claims is the world's lowest crystal defect density and highest wafer homogeneity. The firm has hence decided to expand HGE production facilities further since the initial HGE production expansion is expected to reach full-capacity operation by mid-2018.

www.sdk.co.jp

Qualcomm agrees increased offer price of $127.50 per share for NXP

Qualcomm Inc of San Diego, CA, USA says that indirect subsidiary Qualcomm River Holdings B.V. has agreed an increase to $127.50 per share of its cash tender offer to purchase NXP Semiconductors N.V. The amended agreement (approved by the Qualcomm and NXP boards of directors) also lowers the minimum tender condition from 80% of NXP's outstanding shares to 70%, and extends the expiration time for the offer to the end of 5 March (New York City time).

In addition, Qualcomm River Holdings B.V. has entered into binding agreements with nine NXP stockholders who collectively own over 28% of the firm's outstanding shares (excluding additional economic interests through derivatives) to tender their shares at $127.50 per share. These stockholders include funds affiliated with Elliott Advisors (UK) Ltd and Soroban Capital Partners LP.

Qualcomm intends to fund the additional consideration with cash on hand and new debt. The amended tender offer is not subject to any financing condition.

The revised price reflects enhanced current value drivers for NXP, including:

- NXP's recent performance, including calendar 2017 results that exceeded Qualcomm's transaction model on revenue, gross margin and EBIT. NXP's non-GAAP operating income (excluding Standard Products) rose by 20% from calendar 2016 to 2017.
- Strong market dynamics and positive outlook for key segments. NXP's Auto business has increased revenues by 11% year-over-year. Qualcomm has also significantly improved its own capabilities in key industry segments such as Auto ($3bn revenue pipeline), IoT ($1bn in fiscal-year 2017 sales) and Networking, further enhancing the value proposition of the combined company.
- High confidence in annualized cost synergies of at least $500m resulting from insights gathered during integration planning.

"Qualcomm's leading SoC [system-on-chip] capabilities and technology roadmap, coupled with NXP's differentiated position in Automotive, Security and IoT, offers a compelling value proposition," believes Qualcomm's CEO Steve Mollenkopf. "We remain highly confident in our fiscal 2019 non-GAAP EPS target of $6.75–7.50, which includes $1.50 per share accretion from the acquisition of NXP. With only one regulatory approval remaining, we are working hard to complete this transaction expeditiously. Our integration planning is on track."

"The acquisition of NXP will enable us to accelerate our growth strategy... This is an attractive acquisition at this price for Qualcomm stockholders based on NXP's recent strong financial performance, the growth in key strategic areas such as Auto and IoT and our high confidence in management's ability to execute upon the synergy opportunities," says Tom Horton, presiding director of Qualcomm's board.

"NXP is a highly strategic and attractive acquisition for Qualcomm that enhances the value of our leading 5G technologies," says Qualcomm's chairman Dr Paul E. Jacobs. "The revised agreement provides certainty for both Qualcomm and NXP stockholders," he believes.

Qualcomm's acquisition of NXP has received antitrust clearance from eight of the nine required government regulatory bodies around the world. The transaction remains contingent on clearance from the Ministry of Commerce (MOFCOM) in China. Qualcomm is optimistic it will receive MOFCOM clearance in the near term.

www.nxp.com
www.qualcomm.com

MACOM and ST to develop GaN-on-Si manufacturing for mainstream RF applications

ST licenses MACOM technology to supply GaN-on-Si RF power products

MACOM Technology Solutions Holdings Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for RF, microwave, millimeter-wave and lightwave applications) and STMicroelectronics of Geneva, Switzerland have agreed to develop gallium nitride on silicon (GaN-on-Si) wafers to be manufactured by ST for MACOM's use across an array of RF applications.

While expanding MACOM's source of supply, the agreement also grants to ST the right to manufacture and sell its own GaN-on-Si products in RF markets outside of mobile phone, wireless base-station and related commercial telecom infrastructure applications.

MACOM hence expects to access increased silicon wafer manufacturing capacity and improved cost structure, aiming to displace incumbent silicon LDMOS and accelerate the adoption of GaN-on-Si in mainstream markets. ST and MACOM have been working together for several years to bring GaN-on-Si production up in ST's CMOS wafer fab. Sample production from ST is expected to begin this year.

"To date, MACOM has refined and proven the merits of GaN-on-silicon using rather modest compound semiconductor factories, replicating and even exceeding the RF performance and reliability of expensive GaN-on-SiC alternative technology," says MACOM's president & CEO John Croteau. "We expect this collaboration with ST to bring those GaN innovations to bear in a silicon supply chain that can ultimately service the most demanding customers and applications," he adds.

"ST's scale and operational excellence in silicon wafer manufacturing aims to unlock the potential to drive new RF power applications for MACOM and ST as it delivers the economic breakthroughs necessary to expand the market for GaN-on-silicon," says Marco Monti, president of the Automotive and Discrete Product Group at STMicroelectronics. "While expanding the opportunities for existing RF applications is appealing, we're even more excited about using GaN-on-silicon in new RF energy applications, especially in automotive applications, such as plasma ignition for more efficient combustion in conventional engines, and in RF lighting applications, for more efficient and longer-lasting lighting systems," he adds.

"Once the $0.04/watt barrier for high-power RF semiconductor devices is crossed, significant opportunities for the RF energy market may open up," believes Eric Higham, director of the Advanced Semiconductor Applications Service at market research firm Strategy Analytics. "Potential RF energy device shipments could be in the hundreds of millions for applications including commercial microwave cooking, automotive lighting and ignition, and plasma lighting, with sales reaching into the billions of dollars."

www.st.com
www.macom.com

Advantech launches second-generation GaN-based 1kW X-band SSPA for radar systems

Advantech Wireless Inc of Montreal, Canada (which makes satellite, RF equipment and microwave broadband communications systems) has launched its second-generation GaN-based 1kW X-band pulse amplifier, designed for radar systems.

The new 1kW X-band indoor solid-state pulse amplifier is fully integrated and operates over the 8.9–9.6GHz band. The GaN-based systems are built for high reliability and include features such as duty-cycle monitor and pulse width monitor to ensure trouble-free operation. The 1kW APRA X-band solid-state pulse amplifier is designed to replace aging traveling-wave tubes (TWTs) and Klystrons with solid-state technology.

The new pulse amplifier is designed to be used in radar systems as a direct replacement for older-generation Klystrons or TWTs. Key features include small form factor and increased range.

Advantech Wireless says that its second-generation GaN technology reduces power consumption and operating costs due to its high reliability. Because of its linearity, the amplifier also produces a cleaner pulse, resulting in better range and resolution of the radar system.

"The advantage of solid-state design over tubes and klystron technology is that this technology is much better suited for mobile radar applications," says Cristi Damian, VP business development. "These new GaN-based solid-state pulse amplifiers for radars exhibit very high spectral purity, linearity and low phase noise," he adds. "The radar pulse processing allows for very high pulse fidelity and sharpness, which translates into longer ranges and higher detection capabilities."

The 1kW X-band indoor SSPA's design is based on Advantech Wireless' industry-proven reliable SSPAs and over 25 years of experience with high-reliability systems.

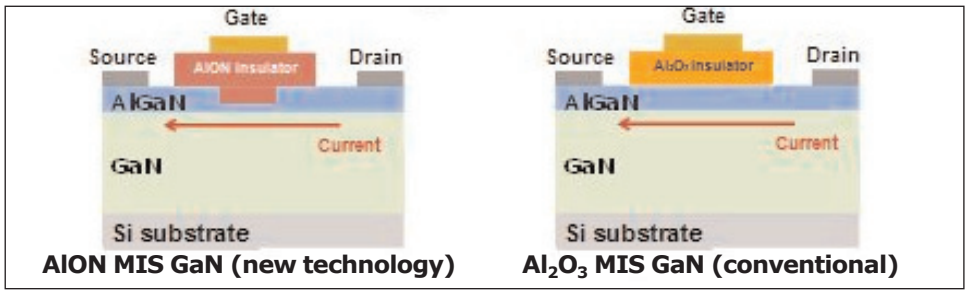
www.advantechwireless.com

Panasonic develops insulated-gate MIS GaN power transistor capable of continuous stable operation

Panasonic Corp of Osaka, Japan has developed an insulated-gate metal-insulator-semiconductor (MIS) gallium nitride (GaN) power transistor capable of continuous stable operation with no variation in its threshold gate voltage. This makes it possible to further increase GaN power transistor speed, enabling the miniaturization of electronic equipment, says the firm.

MIS-type GaN power transistors are expected to be practical for use as next-generation ultrafast power devices. Meanwhile, Panasonic has been researching MIS gate structures as a future technology for further increasing operation speed. However, conventional MIS-type GaN power transistors suffer from hysteresis, and high-speed switching operation with high current and high voltage has not previously been achieved.

Panasonic has now confirmed the first continuous, stable operation of MIS-type GaN power transistors, at a drain current of 20A and with a breakdown voltage of 730V. With a significant increase in switching frequency (an OFF operation time of 1.9ns and ON operation time of 4.1ns), the miniaturization of peripheral passive components becomes possible. Using this technology, highly efficient operation and miniaturization of various power conversion circuits (such as power supplies for servers and base stations) can be achieved. Enabling operation at higher frequencies leads to further miniaturization of equipment, expanding the GaN power transistor market, it is expected.



AlON MIS GaN (new technology) Al_2O_3 MIS GaN (conventional)

The use of a novel gate insulator of aluminum oxynitride (AlON, in which electrons are not easily trapped) suppresses hysteresis (in which the relation between gate voltage and drain current varies when the gate voltage is enhanced or applied repeatedly). This leads to continuous stable operation with a gate voltage up to +10V (maximum) for high-speed switching.

The crystal growth technique enables the formation of a recessed gate structure without process damage, making it possible to achieve a high drain current while maintaining normally-off operation (in which no current flows between the source and the drain when no voltage is applied to the gate).

The high current and high breakdown voltage were achieved by applying Panasonic's proprietary technologies featuring process uniformity over large areas, which have been acquired through the mass production of GaN-on-Si power devices.

The new transistor is the result of collaborative research with assistant professor Takuji Hosoi and professor Heiji Watanabe of Osaka University, and professor Tamotsu Hashizume of Hokkaido University, partly supported by Cross-ministerial Strategic Innovation Promotion Program (SIP), 'Next-Generation Power Electronics' (funding agency: NEDO) of Council for Science, Technology and Innovation (CSTI) of the Cabinet Office, Government of Japan.

http://panasonic.net

Comtech wins $1.3m solid-state power amplifier order

Comtech Telecommunications Corp says that during fiscal second-quarter 2018 its subsidiary Comtech Xicom Technology Inc of Santa Clara, CA, USA — 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 — received an order worth more than $1.3m for solid-state power amplifiers (SSPAs) for use in an airborne in-flight connectivity (IFC) system.

"This order is for the increasingly active IFC market, and further extends an ongoing production run," notes Comtech Telecommunications' president & CEO Fred Kornberg. "Customers have embraced the high reliability and efficiency of our GaN [gallium nitride] technology and value the added benefit of small size and weight, especially for airborne systems."

In mid-December, Comtech Xicom received a separate SSPA order worth more than $9.4m, also for airborne IFC (enabling high-speed satellite connectivity in the cabin). "Travelers expect fast and reliable broadband satellite connectivity in the air," says Kornberg. The order supports continued production of this product through the latter part of 2018.

Comtech Xicom's product range spans power levels from 8W to 3kW, with frequency coverage in sub-bands within the 2–51GHz spectrum. Amplifiers are available for fixed and ground-based, ship-board and airborne mobile applications.

www.xicomtech.com

Akash raises $3.1m in seed round funding led by Khosla

GaN-on-diamond MMIC power amplifiers on market; phase 2 aims to co-design small-satellite systems and transmitters by 2019

Akash Systems Inc of San Francisco, CA, USA — which was founded in 2016 by Felix Ejeckam and Ty Mitchell — has raised $3.1m and closed its seed round funding, led by Khosla Ventures and including Social Capital, Data Collective, Ruvento Ventures, Sriram Krishnan, and Backstage Capital.

The funding will allow Akash to further its development of the next generation of small satellites and the RF power amplifiers that power them.

Foreseeing the limitations of existing satellite capacity and networks, Akash is targeting fast, affordable satellite communications using gallium nitride (GaN)-on-diamond technology. "Today's worldwide data demand is outpacing the bandwidth and power capabilities of our current communication infrastructure," says co-founder, CEO & gallium nitride (GaN)-on-diamond inventor Felix Ejeckam. "We have the technology and innovation to look beyond current satellite systems in order to enable the design of small satellite (Cubesat) systems and subsystems in the very near future," he adds. Akash says that its patented GaN-on-diamond science is enabling smaller, lighter and higher-performing satellites that will pave the way to lower launch costs, reduced cost-per-bit, more launch cycles, and increased communications access and throughput.

Ejeckam invented the GaN-on-diamond technology in 2003 while at Group4 Labs Inc by lifting GaN epitaxy from its original growth substrate (for example, silicon) and transferring it to a synthetic CVD diamond substrate. Group4 Labs' assets were acquired in 2013 by Element Six Technologies (a member of the De Beers Group of Companies).

In 2016, Ejeckam, together with Akash co-founder & chief operating officer Ty Mitchell, entered into an agreement with RFHIC Corp of Anyang, South Korea (which designs and makes active RF & microwave high-power components and hybrid modules) to jointly negotiate the repurchase of the GaN-on-diamond intellectual property (IP), with Akash acquiring all patents and other IP rights related to GaN-on-diamond technology for use in satellite communications and related markets.

"The constant use of communication strains our satellite infrastructure more each year," comments Sven Strohband, a partner at Khosla. "Akash Systems is here to revolutionize satellite communications by creating high-performance components to get ahead of current satellite limitations such as heat generation and efficient cooling."

Phase one of Akash's business plan includes GaN-on-diamond monolithic microwave integrated circuit (MMIC) power amplifiers (currently on the market). The firm plans to move into phase two, working with satellite system makers to design small-satellite (Cubesat) systems and their transmitters, by 2019.

www.AkashSystemsInc.com

Mission Microwave ramps production deliveries of 200W Ka-band GaN-based solid-state power amplifiers

Mission Microwave Technologies of Santa Fe Springs, CA, USA, which makes solid-state power amplifiers (SSPAs) and block up-converters (BUCs), has completed the initial delivery and acceptance testing of its 200W Ka-band (30GHz) gallium nitride (GaN)-based products for a US-based technology integrator.

Mission Microwave is providing individual amplifiers and redundant systems based on its Titan Ka-band BUC. Both Ku-band and Ka-band systems are being delivered in support of mobile SatCom deployable systems. The 200W Ka-band Titan BUC produces over 100W of linear radio-frequency power in a 10kg package to support mission-critical communications while the Ku-band configuration delivers 200W of linear Ku-band RF power.

"Our customer needed a very high-power Ka-band solution within a very constrained size, weight and power (SwaP) budget," says president & CEO Francis Auricchio. "The Titan amplifier system was a clear choice for their design with efficiency, SwaP and performance well beyond anything else available in the commercial market," he claims. "The Titan BUC is less than half the weight of competing products and uses significantly less power while providing the linear performance and reliability needed."

Tactical and commercial customers and their end-users can benefit from continued releases of new Mission Microwave RF products as satellite communications systems suppliers incorporate them in their designs for X-, Ku- and Ka-band uplinks for commercial and MilSatCom applications, says the firm. The GaN-based Ka- and Ku-band BUCs are based on a family of proprietary components and design elements that ensure the products are predictable and reliable in manufacture, operation and support, it adds.

www.missionmicrowave.com

VisIC samples first 1200V GaN power module

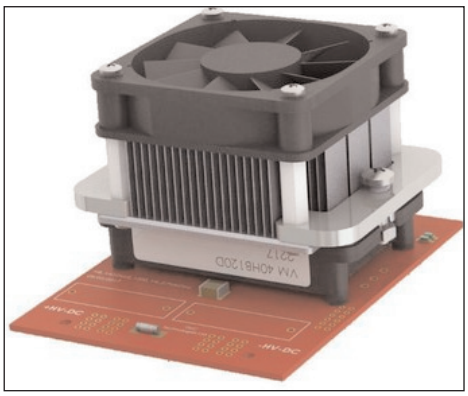
Manufacturing partnership uses TMSC 650V GaN-on-Si process

VisIC Technologies Ltd of Nes Ziona, Israel — a fabless developer of power conversion devices based on gallium nitride (GaN) metal-insulator-semiconductor high-electron-mobility transistors (MISHEMTs) — is sampling what are claimed to be the first 1200V GaN modules, and is announcing a manufacturing partnership with Hsinchu-based Taiwan Semiconductor Manufacturing Corporation (TMSC, the world's biggest semiconductor wafer foundry) on their GaN-on-silicon technologies that were announced last year. Engineering samples are now in design with lead customers, and trade demonstrations will take place during PCIM Asia (Power conversion and Intelligent Motion) 2018 in Shanghai, China (26–28 June).

The fast power switch module performs with what is claimed to be the highest efficiency in the industry, enabling small but efficient electric vehicle (xEV) chargers and uninterruptible power supply (UPS) systems.

The new VisIC module is based on TSMC's 650V GaN-on-silicon process, which provides high yield and fast ramp-up capabilities, while VisIC's GaN high-electron-mobility transistor (HEMT) design provides a switching time below 10ns.

With 1200V ratings, the GaN module offers typical on-resistance of just 40mΩ. Target applications are power converters for motor drives, three-phase power supplies and other applications requiring current switching up to 50A.



VisIC's 1200V GaN device is a half-bridge module that integrates GaN HEMTs with push-pull and over-current and over-temperature protection in a single package. The design takes advantage of VisIC's Advanced Low Loss Switch (ALL-Switch) technology, which uses a patented, high-density lateral layout that results in fast switching performance and low $R_{DS(on)}$.

The high-voltage GaN module offers reduced gate charge and capacitances with low $R_{DS(on)}$, so the switching energy for the GaN device is as low as 140µJ. Consequently, switching losses are 3–5 times lower than comparable silicon carbide (SiC) MOSFETs.

VisIC says that, with its 1200V GaN module, designers can greatly reduce system size without compromising performance, yielding ultra-small EV chargers for electric cars or highly efficient motor drives for industrial applications.

The GaN power device market rise to more than $332.5m in 2022, forecasts market research & strategy consulting company Yole Développement in its 'GaN Power Epitaxy, Devices, Applications and Technology Trends' report last November (based on products rated for blocking voltages 650V and below). VisIC says that its new module opens up a wider market of devices with 1200V blocking voltage, currently serviced by silicon insulated-gate bipolar transistors (IGBTs) and silicon carbide (SiC) MOSFET devices.

"TSMC has made significant capital and engineering investment in our GaN manufacturing capability, which makes this platform well suited to support VisIC and its customers' demands," says Maria Marced, president of TSMC EMEA (Europe, Middle East and Africa).

In addition to UPS and xEV chargers, 1200V GaN technology enables a wide range of inverter applications, which require high current (hundreds of Amperes). Such high-current applications require a high-volume GaN manufacturing capability, which TSMC provides.

"GaN has better fundamental physical properties, such as maximal breakdown field and current density, than those of silicon or SiC," notes VisIC's chief technology officer Gregory Bunin. "There are no fundamental limitations for GaN products to address the high-voltage, high-current space," he adds. "This manufacturing partnership allows VisIC to ramp capacity very quickly."

www.visic-tech.com
www.tsmc.com
www.mesago.de/en/PCC/home.htm

Navitas showcasing GaNFast power ICs at APEC

As a 'Diamond' sponsor at the Applied Power Electronics Conference (APEC 2018) in San Antonio, Texas (4–8 March), Navitas Semiconductor Inc of El Segundo, CA, USA is showcasing both its own gallium nitride (GaN) power ICs as well as GaN-enabled power systems in a private demo suite and on the exhibition floor (booth #1341).

"Many commercial uses of GaNFast Power ICs are rapidly advancing," says chief technology officer/chief operating officer Dan Kinzer. "We are pleased to demonstrate how monolithic GaN integration has overcome both engineering and commercial hurdles to enable a new class of high-frequency, high-efficiency & high-density power systems."

At APEC, Navitas is showcasing how its latest GaNFast devices and reference designs achieve what is claimed to be unprecedented small size, low weight and high efficiency levels, with fast-charging speeds for end-products ranging from smartphones and tablets to laptops, monitors and gaming systems. Last September, Navitas launched what is claimed to be the smallest 65W USB-PD laptop adapter reference design, supporting the size and weight reductions demanded by consumers.

"This is a dynamic time for Navitas and the industry, as GaN power systems graduate from academic curiosity to real-life commercial applications," says Stephen Oliver, VP of sales & marketing. "Navitas will showcase a new series of GaN platforms that are the result of close collaboration with our customers and partners."

At APEC, Navitas will present or be featured in the following conference papers and events:

6 March (8:30am, room 206) — Paper 1180 'GaN Power ICs Enable Breakthroughs in Adapter Performance' by Dan Kinzer (Navitas);

6 March (5pm, room 217D) — Rap Session 1 'Biggest Impact on Power Consumption—Devices or Magnetics?' (moderator: Kevin Parmenter, VP of applications engineering, Excelsys) by Dan Kinzer (Navitas);

7 March (2:20pm, room 214A) — Paper 1736 'A Single-Stage Bi-directional Dual-Active-Bridge AC–DC Converter Based on Enhancement Mode GaN Power Transistor' by Tianxiang Chen, Ruiyang Yu, Qingyun Huang and Alex Q. Huang (University of Texas, Austin);

7 March (2pm, room 214B) — Paper 2018 'Design Considerations of Highly-Efficient Active Clamp Flyback Converter Using GaN Power ICs' by Lingxiao Xue and Jason Zhang (Navitas);

7 March (2:20pm, room 214B) — Paper ID#: 1171 'Design Consideration of Active Clamp Flyback Converter with Highly Nonlinear Junction Capacitance' by Pei-Hsin Liu (Texas Instruments);

8 March (8:30am, room 206) — Paper ID#: 1179 'GaN Reliability Through Integration and Application Relevant Stress Testing' by Nick Fichtenbaum (Navitas).

www.apec-conf.org

Navitas' GaN Power ICs at Taiwan power electronics technology forum

At the Micro Electronics 2018 Power Design and Power Components Technology Forum in Taiwan (30 January,), Navitas' director field application & technical marketing Peter Huang delivered a keynote presentation 'GaN Power ICs Enable Next Generation Power Adaptor Design'.

Huang shared new insights on how what is claimed to be the industry's first gallium nitride (GaN) power ICs create dramatic increases in speed, efficiency and densities for a broad range of power systems.

Navitas was the silver sponsor of the conference, which presents an interactive forum for innovative manufacturers, partners and customers to share expertise in accelerating adoption of new GaN and SiC devices.

GaN integration enables a new class of faster-charging, smaller, lighter power systems.

"After 40 years of slow, inefficient silicon devices, the power electronics industry is entering an exciting era of new materials, new devices, new magnetics, new controllers and imaginative topologies," says Huang. "Navitas looks forward to demonstrating how monolithic integration of power, drive and logic — all in GaN — leads to a new generation of high-efficiency, high-density chargers and adapters for smartphone, laptop, consumer, TV, and new energy applications."

www.mem.com.tw/meeting_arti.php?sn=1712190001

www.navitassemi.com

Transphorm highlighting high-voltage GaN in production at Applied Power Electronics Conference

At the Applied Power Electronics Conference & Exposition (APEC 2018) San Antonio, Texas (4–8 March), Transphorm Inc of Goleta, near Santa Barbara, CA, USA — which designs and manufactures JEDEC- and AEC-Q101-qualified high-voltage (HV) gallium nitride (GaN) field-effect transistors (FETs) for high-voltage power conversion applications — is highlighting how high-voltage GaN is now in production.

"After years of R&D, manufacturing excellence and customer development, GaN has arrived, as evidenced by remarkable customer products harnessing its benefits," says Philip Zuk, VP technical marketing. "We have the diverse product portfolio, quality and reliability, production scale, and design tools to enable cross-market high-voltage applications requiring greater power efficiency," he adds.

Transphorm says that 2017 marked the first year of HV GaN end-product releases as customers set new benchmarks in the broad industrial, PC gaming, and server industries. Demonstrating GaN's impact with such products, Transphorm is offering new information and design resources for reducing development time:

- Reference Design: Prior to APEC, Transphorm is announcing a key development platform that kick starts newcomers to GaN technology.
- Education Session: 'Reference Designs Kick Start Reliable High-voltage GaN Application Development' — Philip Zuk details the reference design's key features and design techniques for optimal performance.
- Evaluation Platforms:

— 3.3kW phase-shifted full-bridge DC-to-DC converter for HV battery applications such as electric vehicle on-board chargers.

— 500W and 800W LLC DC-to-DC converters equipped with a 12V output for applications such as server power supplies and other AC-to-DC merchant power supplies.

Power supply manufacturer and early GaN innovator Telcodium is again joining Transphorm to showcase new power building blocks intended to speed GaN development.

Also, CORSAIR's GaN-based AX1600i power supply unit is on display, demonstrating how GaN helped it to break its own industry-leading records for the PC gaming product.

Also, attendees have a first opportunity to source the Q+R (quality and reliability) expert (an integral part of the team responsible for Transphorm earning JEDEC and AEC-Q101 qualifications).

www.transphormusa.com

EPC showcasing performance of eGaN FETs and ICs in high-power-density DC–DC conversion and high-frequency applications at APEC

At the Applied Power Electronics Conference & Exposition (APEC 2018) in San Antonio, Texas (4–8 March), 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 — is delivering seven technical presentations on GaN technology and applications:

- Education Seminar: 'Maximizing GaN FET and IC Performance, Not Just a Drop in Replacement of MOSFETs', by Alex Lidow, Michael de Rooij, David Reusch and John Glaser;
- Exhibitor Seminar: 'GaN Transistors for Efficient Power Conversion', by Alex Lidow;
- 'Moving Up in Voltage with eGaN FETs', by John Glaser;
- 'Amplifier Design Challenges for Large Area Highly Resonant Wireless Power Systems', by Michael de Rooij and Yuanzhe Zhang;
- 'Evaluation of Measurement Techniques for High-Speed GaN Transistors', by Suvankar Biswas and Tom Neville (Tektronix);
- 'Design Considerations for GaN Transistor Based Synchronous Rectification', by David Reusch and John Glaser; and
- 'System Optimization of a High-Power Density Non-Isolated Intermediate Bus Converter for 48 V Server Applications', by David Reusch, Suvankar Biswas and Yuanzhe Zhang.

In booth #1255, EPC is demonstrating its latest eGaN FETs and ICs in customers' end-products enabled by eGaN technology. These include a high-power-density 48–12V non-isolated converter capable of delivering over 700W. In addition, a range of 3D real-time LiDAR imaging sensors used in autonomous vehicles is being displayed. Also, a single desktop is implementing a high-power resonant wireless charging solution capable of generating 300W to wirelessly power a wide range of devices including cell phones, notebook computers, monitors, wireless speakers, smart watches, and table lamps.

www.apec-conf.org
www.epc-co.com

Renesas Electronics ships space industry's first rad-hard low-side GaN FETs for power supplies

Tokyo-based Renesas Electronics Corp has announced what is claimed to be the space industry's first radiation-hardened, low-side gallium nitride (GaN) field-effect transistor (FET) driver and GaN FETs that enable primary and secondary DC/DC converter power supplies in launch vehicles and satellites, as well as downhole drilling and high-reliability industrial applications. The devices power ferrite switch drivers, motor control driver circuits, heater control modules, embedded command modules, 100V and 28V power conditioning, and redundancy switching systems.

The ISL7023SEH 100V, 60A GaN FET and ISL70024SEH 200V, 7.5A GaN FET use the base die manufactured by Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA. The GaN FETs are said to provide up to 10 orders of magnitude better performance than silicon MOSFETs while reducing package size by 50%. They also reduce power supply weight and achieve higher power efficiency with less switching power loss. At 5mΩ (R_{DSON}) and 14nC (Q_G), the ISL70023SEH enables what is claimed to be the industry's best figure of merit (FOM).

Both GaN FETs require less heat sinking due to reduced parasitic elements, and their ability to operate at high frequencies allows the use of smaller output filters, which achieve what are said to be excellent efficiencies in a compact solution size. Manufactured using a MIL-PRF-38535 Class V-like flow, the ISL70023SEH and ISL70024SEH offer guaranteed electrical specifications over the military temperature range and lot-by-lot radiation assurance for high dose rate 100krad(Si) and low dose rate 75krad(Si).

The ISL70040SEH low-side GaN FET driver powers the ISL7002xSEH GaN FETs with a regulated 4.5V gate drive voltage and splits the outputs to adjust FET turn-on and turn-off speeds. Operating with a supply voltage of 4.5V to 13.2V, the FET driver provides high current source and sink capability for high-frequency operation, while offering both inverting and non-inverting gate drive to provide flexibility in power supply designs. Its fail-safe protection on the logic inputs eliminates unintentional switching when they are not actively driven. The ISL70040SEH provides reliable performance when exposed to total ionizing dose (TID) or heavy ions, and is immune to destructive single event effects (SEE) up to 16.5V with linear energy transfer (LET) of 86MeV•cm^2/mg. The GaN FET driver uses a MIL-PRF-38535 Class V manufacturing flow and wafer-by-wafer radiation assurance testing.

"We are pleased to see Renesas Electronics continue Intersil's six decades of spaceflight product development and leadership," comments EPC's co-founder & CEO Alex Lidow. "It is especially gratifying and exciting to see our innovative enhancement-mode gallium nitride-on-silicon (eGaN) FET technology at work with Renesas' new radiation-hardened GaN FET driver. These products demonstrate how eGaN technology increases the performance and reduces the cost for applications currently being served by MOSFETs," he adds.

"Size, weight and power efficiency mean everything to designers and manufactures of launch vehicles and satellites," says Philip Chesley, vice president of Renesas Electronics' Industrial Analog and Power Business Division. "The new ISL7002xSEH GaN FETs and ISL70040SEH GaN FET driver represent the most meaningful power management innovation we've seen in a long time for the spaceflight industry."

The ISL70023SEH 100V, 60A GaN FET or ISL70024SEH 200V, 7.5A GaN FET can be combined with the ISL70040SEH low-side GaN FET driver and the ISL78845ASEH PWM controller to create launch vehicle and satellite switched-mode power supplies.

The rad-hard ISL70023SEH 100V, 60A GaN FET and ISL70024SEH 200V, 7.5A GaN FET are available now in hermetically sealed 4-lead 9.0mm x 4.7mm SMD packages. The rad-hard ISL70040SEH low-side GaN FET driver is available now in a hermetically sealed 8-lead 6mm x 6mm SMD package.

www.renesas.com

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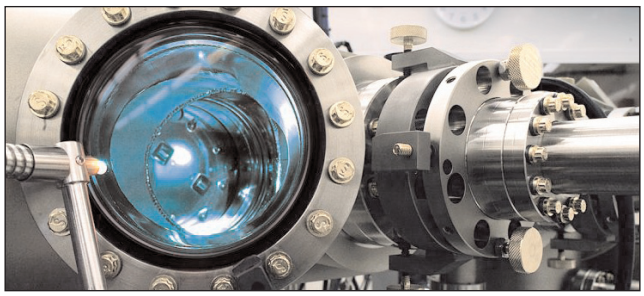
or contact us: x-fea-fuji-dc@fujielectric.com

HRL offering new GaN MMIC foundry service for low-cost design and fabrication of custom ICs

HRL Laboratories LLC of Malibu, CA, USA has announced a new shared foundry service, offering millimeter-wave (mmW) gallium nitride (GaN) technology for fabrication of monolithic microwave integrated circuits (MMICs) through multi-project wafer (MPW) runs.

"Eligible customers will be able to design into our world-class, state-of-the-art mmW T3-GaN fabrication process and receive custom, tailored circuits for their specific applications at a price much lower than a dedicated foundry run," says Shawn Burnham, the HRL scientist in charge of the GaN foundry service. "They will be given access to a process design kit, which has already been used to demonstrate world-record power amplifier and low-noise amplifier performance."

HRL T3-GaN is a mmW high-electron-mobility transistor (HEMT) technology for applications such as next-generation high-data-rate wireless communications and high-resolution radar imaging. HRL processes GaN wafers in a 10,000ft^2 ISO Class 4 cleanroom, and is a US Department of Defense Trusted Foundry.



Epi growth and thermal processing are integral to HRL Labs' T3 GaN foundry services.

HRL will begin an open subscription period soon for customers with verified US government end-use of the foundry product. Interested customers seeking information on pricing or scheduling can e-mail GaNFoundry@hrl.com.

For customers that do not want to perform custom MMIC designs themselves, HRL also continues to offer related T3-GaN MMIC design services to US Government customers, which could then be used on MPW runs. HRL has over 25 years of experience designing MMICs from UHF to mmW, including low-noise amplifiers, power amplifiers, mixers, switches, attenuators, and phase shifters, and the expertise to package the fabricated MMICs.

www.hrl.com

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Fine tuning boron content in nitride alloys can further development of optical and electronic interface devices

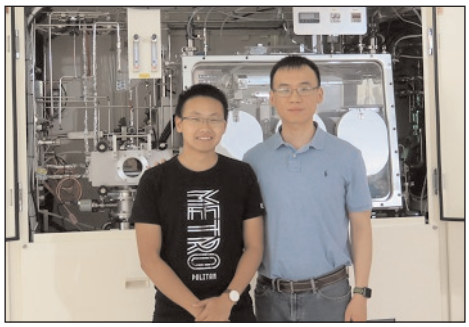
Large range of spontaneous and piezoelectric polarization constants could aid development of optical and electronic junction devices

On the basis that controlling the electronic properties at the interface between materials can help in the quest for improvements in computer memory, King Abdullah University of Science and Technology (KAUST) has shown that varying the atomic composition of boron nitride (BN)-based alloys enables the tuning of electric polarization.

Some materials exhibit spontaneous polarization, even without an external electric field. Such materials have potential uses in computer memory, but this application requires a material system in which the polarization is controllable. Visiting Student Research Program (VSRP) student Kaikai Liu, his supervisor Xiaohang Li and coworkers investigated one approach to polarization engineering at the interface between BN-based alloys.

Spontaneous polarization is strongly dependent on the structure and composition of the atomic crystal. Piezo-electric materials can change polarization when physically deformed.

The KAUST team used software (the Vienna ab-initio Simulation Package) to investigate electronic properties of the ternary alloys boron aluminum nitride and boron gallium nitride, looking at how they change as boron replaces aluminum and gallium atoms, respectively. "We calculated the spontaneous polarization and piezoelectric constants of boron nitride alloys within a newly proposed theoretical framework and the impact of the polarization at junctions of these two materials," says Liu.



The KAUST team includes Kaikai Liu (left) and Xiaohang Li (right).

The team showed that the spontaneous polarization changes very nonlinearly with increasing boron content, contradicting previous studies that assume a linear relationship.

The reason for this nonlinearity is attributed to volume deformation of the alloy's wurtzite crystal structure. The nonlinear change in the piezoelectric polarization is less pronounced, but evident. This arises because of the large difference in atomic spacing between boron nitride and both aluminum nitride and gallium nitride. Furthermore, boron aluminum nitride or boron gallium nitride can become non-piezoelectric when the boron content is more than 87% and 74%, respectively.

The work shows that a large range of spontaneous and piezoelectric polarization constants could be made available simply by changing the boron content. This could be useful for developing optical and electronic junction devices formed at the interface between conventional nitride semiconductors and either boron aluminum nitride or boron gallium nitride.

"Our next step will be to experimentally test the proposed junctions, which our theory predicts could have much better device performance than current approaches," says Liu.

AXT's Q4/2017 revenue grows a more-than-expected 30% year-on-year, driven by InP and germanium

InP capacity being increased to meet demand, while GaAs being qualified at new plant for 3D sensing applications

For fourth-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 $26.3m, down 6.7% on $28.2m last quarter. This included $20.5m from substrate sales (down 8.5% on $22.4m last quarter) and $5.8m from raw material joint ventures (level with last quarter). However, Q4 revenue is up 30% on $20.3m a year ago and above the $26–27m guidance, driven by strength in InP and germanium (for solar cells, as the satellite industry continued its potential positive trend).

Of total revenue, North America comprised 9%, Asia Pacific 67% and Europe 24%. Again, two customers generated more than 10% of revenue, while the top five customers generated about 36% of revenue (down from 39% last quarter), reflecting continuing diversification of both products and customers.

Full-year revenue grew by 21% from $81.3m in 2016 to $98.7m in 2017, driven by record InP revenue (comprising about 30% of total revenue) and solid performance across the firm's product portfolio, including 30% year-on-year growth in germanium substrate revenue.

Q4 gross margin was 37.2%, down from 39.5% last quarter but up slightly from 37.1% a year ago. Full-year gross margin has risen from 32.4% in 2016 to 34.9% in 2017.

Operating expenses have grown further, from $5.2m a year ago and $5.9m last quarter to $6.1m, pushing full-year OpEx from $20m in 2016 to $21.8m in 2017.

Net income was $3.1m ($0.08 per diluted share), down from $4.4m ($0.11 per diluted share) last quarter but up from $2.2m ($0.06 per diluted share) a year ago. Full-year net income has risen by 80% from $5.6m ($0.17 per diluted share) for 2016 to $10.1m ($0.26 per diluted share) for 2017.

During Q4, depreciation & amortization was steady at $1.1m. Capital expenditure (CapEx) has dropped back to $4.7m from a spike to $15m last quarter (mostly furnace systems for AXT's new GaAs manufacturing facility in Dingxing, China, about 90 miles south of the existing Beijing plant). Accounts receivable (net of reserves) rose from $20.9m to $22.3m. During the quarter, cash reserves (cash, cash equivalents and investments) fell by $1.3m from $78.3m to $77m.

Net inventory rose from $40.8m to $45.8m (consisting of 51% in raw materials, 44% in work-in-progress, and only 5% in finished goods). "Both work-in-progress (WIP) and raw materials increased, and this is intentional as we see raw material prices increasing and as we build inventory during the relocation," notes VP & chief financial officer Gary Fischer. "Recently we have begun to see an increase in raw material pricing, particularly gallium, largely a result of overall improvement in commodity pricing," says CEO Dr Morris Young. "The increase to-date remains modest, and on the whole has served to bring suppliers close to breakeven levels, following a very significant decline in pricing over the last two years," he adds.

"We also made good progress on the relocation of our gallium arsenide manufacturing facility and we are on track with our stated goal to provide qualification wafers [the firm's first for 3D sensing applications] in Q1," says Young. "Once submitted, the length of qualification process will depend on the sense of urgency within the supply chain," he adds. "We could see modest amount of incremental opportunity from this application [3D sensing] in 2018, but with more meaningful contribution in 2019."

For Q1/2018, AXT expects revenue of $26–27m (up 29% year-on-year) and profit of $0.07–0.09 per share.

"With the transition of our new factory now well underway, we are gaining a bit more clarity on our headcount requirements and other relocation-related expenses, including training and travel," notes Fischer. "As such, we are anticipating that our quarterly OpEx in 2018 will remain at approximately the Q4/2017 level."

"As we move into 2018, we are excited to see a resurgence of demand for compound semiconductor substrates in new applications across our product portfolio that have the power to reshape the technology landscape over the coming decades," says Young. "We continue to invest in the advancement of our products and customer support capabilities, and believe that we are positioning the company well for continued growth and new opportunities in 2018 and beyond," he adds.

"We are in an early stage of a multi-year opportunity for our indium phosphide business," Young continues. "This is a highly specialized material in which AXT has made considerable market progress, both in terms of outstanding technical properties of our material as well as our customer traction. As a result, we are currently increasing our indium phosphide capacity in a meaningful way in order to meet the expected increase in demand for our product in 2018 and beyond."

www.axt.com

Riber reports full-year 2017 revenue up 86% to €30.6m, driven by evaporators

Order book up 44% year-on-year at end-2017

For full-year 2017, Riber S.A. of Bezons, France — which makes molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells — has reported revenue growth of 86% from 2016's €16.5m to €30.6m (49% from Asia, 33% from Europe and 18% from North America).

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

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

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

The order book has risen by 44% from €18m at the end of 2016 to €25.8m at the end of 2017 (excluding three orders this January: for major accessories for Asia; a research MBE system for the USA; and a production MBE system for China, all for delivery in 2018).

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

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

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

Given the order trends, Riber expects another growth year in 2018.

www.riber.com

Riber receives order for research MBE system from USA

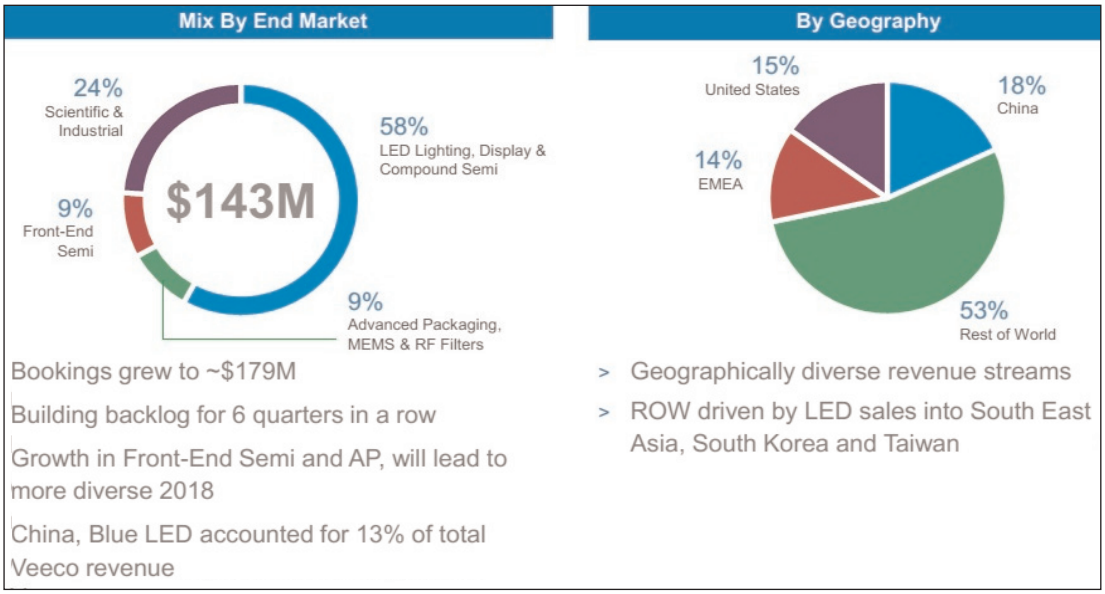
Riber has received an order for a research MBE system from the USA.

Described as a world leader in instrumentation, the customer has ordered the system for the manufacturing of infrared imaging sensors for the aerospace industry.

The system will be delivered in second-half 2018.

Veeco's revenue rises 9% in Q4/2017, driven by rebound in GaN MOCVD sales to China

Revenue diversification to aid margin growth in second-half 2018



Epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA has reported revenue for full-year 2017 of $484.8m, up 46% on $332.5m for 2016, aided by a good year for the blue LED market, despite a competitive environment that saw the firm's share of the metal-organic chemical vapor deposition (MOCVD) market for gallium nitride (GaN) blue LEDs trimmed to 55% reckons market research firm IHS (compared with about 75% previously). However, revenue growth is partly due to the acquisition in late May of Ultratech Inc of San Jose, CA, USA (which designs and makes lithography, laser-processing and inspection systems used to manufacture microelectronic devices and LEDs).

Fourth-quarter 2017 revenue was $143.4m (a sixth consecutive quarter of growth), up 9% on $131.9m last quarter and up 53% on $93.6m a year ago, driven by MOCVD and laser anneal system shipments.

Of total revenue, the LED Lighting, Display and Compound Semiconductor segment has jumped from 45% last quarter to 58%, due mostly to shipments to LED customers in Malaysia, Korea and Taiwan, as well as new sales to China (for expansion of GaN blue LED manufacturing capacity), which comprised 13% of total revenue.

The Advanced Packaging, MEMS & RF Filter segment comprised 9% of revenue (down from 17%). The Front-End Semiconductor segment (formerly part of the Scientific & Industrial segment, before the Ultratech acquisition) also comprised 9% of revenue (down from 13%).

The Scientific & Industrial segment comprised 24% of revenue (roughly level with 25% last quarter), driven by strength in shipments of ion beam tools to the data storage industry and SPECTOR System to the optical coatings market.

Geographically, 18% of revenue came from China (rebounding from 12%), USA 15% (down from 18%) and 14% from Europe, Middle East & Africa (EMEA, rebounding slightly from 13%), with the rest of the world rising further, from 49% to 53%, driven by MOCVD sales for blue LED makers' capacity expansions in Malaysia, South Korea and Taiwan.

On a non-GAAP basis, full-year gross margin fell from 40.8% in 2016 to 40.6% for 2017. Q4 margin of 41.5% is down from 42.3% last quarter but up on 39.2% a year ago (and above the 39–41% guidance), reflecting a favorable product mix and ongoing cost-reduction efforts.

Full-year operating expenditure (OpEx) rose from $143.6m in 2016 to $165.5m, but Q4 OpEx of $49m (up from $32.9m a year ago but roughly level with $48.9m last quarter) was at the low end of the expected range of $49–51m.

Quarterly net income rose further, from $3.8m ($0.09 per diluted share) a year ago and $4.3m ($0.09 per diluted share) last quarter to $9.1m ($0.19 per diluted share, above the $0.00–0.16 guidance range) in Q4/2017. Full-year net income was $23.4m ($0.53 per diluted share), compared with a net loss of $11.3m ($0.29 per diluted share) in 2016.

Operating cash flow was $19m. On 11 December Veeco announced a share repurchase program of $100m, and in the last few weeks of December it bought $3m worth of shares. Overall, during Q4, cash and short-term investments rose by $7m, from $321m to $328m.

"2017 was a transformational year for Veeco. We completed the acquisition of Ultratech, which is providing us with a more diversified revenue stream, and the integration is proceeding well, with greater synergies than we originally expected," says chairman & CEO John R. Peeler. "We also completed the manufacturing consolidation in our New Jersey facility, generating good annual savings [of $4m annually]," he adds.

"We ended the year with strong bookings and historically high backlog," notes Peeler. Q4 order bookings were $179m, up 10% sequentially (growing for a third consecutive quarter, with backlog building for a sixth consecutive quarter, up by $35m on Q3 to $334m).

"The markets with most growth in bookings were Front-End Semiconductor and Advanced Packaging," notes chief financial officer Sam Maheshwari. "In Advanced Packaging, MEMS and RF Filter markets, we are beginning to see a recovery, as orders more than doubled in Q4. We booked multiple Lithography tools, as well as a multi-tool order for our wet etch PSP [Precision Surface Processing] tools supporting UBM etch and RDL etching," he adds. In Front-End Semiconductors, bookings growth was driven by capacity orders for two laser spike annealing (LSA) systems.

In Lighting, Display & Compound Semiconductor markets, Veeco received multiple large multi-system orders from customers in China (including EPIK 868 MOCVD systems for high-volume LED maker Focus Lighting, announced in December). "Since we introduced the EPIK 868 last September, we've shipped several large orders to Chinese customers, as our platform enables greater productivity and lower cost of ownership," says Peeler. "Outside of China and general lighting, we're seeing increasing strength in areas such as photonics and RF devices," he adds, with orders tied more to the prior EPIK 700 model than the EPIK 868. Veeco also received several orders for MOCVD and PSP products to support production of red, orange and yellow (ROY) LEDs, laser diodes and vertical-cavity surface-emitting lasers (VCSELs). In January, Germany's Osram Semiconductors GmbH placed follow-on orders for K475i and Propel MOCVD systems, which are designed for high-volume production of power electronics, laser diodes, RF semiconductor devices, and LEDs. "VCSELs is another area within photonics where we're gaining traction. Our PSP systems, in addition to our MOCVD systems, are used in VCSEL manufacturing," notes Peeler.

"Backlog gives us a good visibility for first-half 2018," says Maheshwari. "In MOCVD, most regions are reporting fab utilization rates of over 85%, and we expect the market to remain robust," adds Peeler. For first-quarter 2018, Veeco expects revenue of $140–165m, gross margin of 34–36%, OpEx of $46–48m, and earnings per share ranging from a loss of $0.04 to a profit of $0.14.

"Entering 2018, we expect to grow in all of our target markets, and we are seeing particularly healthy demand in Advanced Packaging, MEMS & RF Filter and Front-End Semiconductor markets," says Peeler. This should lead to a more balanced revenue mix for 2018, targeting 40–50% in LED Lighting, Display and Compound Semiconductors, and 15–20% in Advanced Packaging, MEMS & RF Filters, 15–20% in Front-End Semiconductors and 15–20% in Scientific & Industrial.

"We are expecting strong growth in 2018 sales over 2017," says Maheshwari. "We see first-half gross margin coming in towards the higher end of the previously guided 30–35% range [i.e. 34–35%]." Additionally, Veeco continues to expect second-half gross margin to be higher than the first half, exiting the year at 40% or more.

www.veeco.com

Veeco, AMEC and SGL settle MOCVD wafer carrier patent litigation

Veeco, Advanced Micro-Fabrication Equipment Inc (AMEC) of Shanghai, China and its wafer carrier supplier SGL Carbon have mutually agreed to settle their pending litigation and resolve all pending disputes, including AMEC's lawsuit against Veeco before the Fujian High Court in China and Veeco's against SGL before the US District Court for the Eastern District of New York.

On 23 January, the Patent Re-examination Board (PRB) of China's State Intellectual Property Office (SIPO) ruled that all claims relating to Veeco's patent number ZL 01822507.1 ('Susceptorless reactor for growing epitaxial layers on wafers by chemical vapor deposition') were invalid, citing "lack of novelty and non-obviousness". On 12 January, Chinese customs had temporarily detained two EPIK700 MOCVD systems (shipped by Veeco Asia) upon arrival in China, due to alleged infringement of AMEC's patent CN 202492576 (with AMEC saying that it was contemplating further legal action including possibly filing a patent infringement lawsuit with the Chinese court). That followed a ruling on 7 December by the Fujian High Court granting AMEC's motion (filed on 13 July) for an injunction prohibiting Veeco Shanghai from importing, manufacturing, selling or offering for sale to any third party any MOCVD systems (and wafer carriers used in the MOCVD systems) that would infringe AMEC's China patent.

Veeco's ZL 01822507.1 patent is the Chinese counterpart of US patents 6506252 and 6726769 asserted by Veeco in an infringement action filed in the US District Court for the Eastern District of New York (EDNY) last April against SGL Carbon. On 2 November, the EDNY granted Veeco's motion for a preliminary injunction prohibiting SGL from shipping wafer carriers without Veeco's express authorization. On 16 November, the EDNY denied SGL's motion to suspend the preliminary injunction pending an appeal to the US Court of Appeals for the Federal Circuit (CAFC).

"We have reached a mutually agreed settlement of the pending IP disputes and we are back to normal business operations in our MOCVD business," says Veeco's chairman & CEO John R. Peeler.

All legal actions worldwide (in court, patent offices and otherwise) between Veeco, AMEC and SGL and their affiliates are dismissed and/or withdrawn. All business processes, including sales, service and importation, hence continue.

www.amec-inc.com

SPTS receives $37m in etch & dep system orders from two GaAs foundries to expand RF device production capacity

SPTS Technologies Ltd of Newport, Wales, UK (an Orbotech company that manufactures etch, PVD and CVD wafer processing solutions for the MEMS, advanced packaging, LED, high-speed RF on GaAs, and power management device markets) has received about $37m in etch and deposition system orders from two gallium arsenide foundry customers. For delivery in first-quarter and second-quarter 2018, the Omega plasma etch, Delta PECVD and Sigma PVD systems will be used to manufacture radio-frequency devices for 4G and emerging 5G wireless infrastructure and mobile device markets.

"RF devices are entering another exciting phase of growth with the proliferation of 4G mobile communications and preparation for 5G," says Kevin Crofton, corporate executive VP at Orbotech and president of SPTS Technologies. "IDMs and foundries are looking to add capacity to existing fabs to meet the growing demand, while new entrants are establishing new lines to address future demand for the 5G rollout. Our lead customer has been at the forefront of GaAs foundry services for almost two decades, and their repeat orders are a testament to the production advantages that our etch and deposition solutions continue to deliver to their core business."

Since power amplifiers (PAs) are among the most critical RF components in mobile communications, and virtually all PAs in a modern smartphone are made from circuits built on GaAs semiconductors, analysts are predicting that the growth of 4G communications, gigabit LTE (Long Term Evolution) and emerging 5G will be the growth engine to drive the RF GaAs device market from $8.1bn in 2017 to over $9bn by 2021 ('RF GaAs Device Forecast and Outlook: 2016 – 2021', Strategy Analytics, October 2017).

"Our latest forecast shows that PAs for cellular applications will continue to account for more than half of the RF GaAs device market," comments Eric Higham, director of the Advanced Semiconductor Applications service at Strategy Analytics. "Despite smartphone growth slowing, the added complexity in mobile devices to support gigabit LTE and the emergence of 5G points to continuing growth in RF GaAs production."

www.spts.com

EXALOS orders Veeco's Propel GaN MOCVD platform for R&D on superluminescent LEDs

Epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA says that EXALOS AG of Schlieren, Switzerland has ordered a Propel gallium nitride (GaN) metal-organic chemical vapor deposition (MOCVD) system (for delivery in third-quarter 2018) for R&D on broadband superluminescent light-emitting diodes (SLEDs).

As a hybrid between LEDs (which emit broadband light from a surface in all directions) and laser diodes (which emit narrowband light from a waveguide with a well-defined laser beam), superluminescent LEDs emit broadband light in a highly directional beam through electrical current injection, and are used in medical and industrial imaging, motion control detectors, navigation, optical sensing and metrology applications.

"With over 400,000 SLED units shipped and strong technical expertise, EXALOS is a proven leader in this space," comments Peo Hansson Ph.D., senior VP & general manager of Veeco MOCVD Operations. "We are looking forward to working with them closely as the capability of our Propel platform, which serves a wide range of specialized applications, complements their technology and advanced product roadmap," he adds.

Propel Power GaN MOCVD system.

"Veeco's Propel platform is uniquely qualified to provide the most capable process flexibility with the best results, all while maintaining the lowest cost-of-ownership," comments EXALOS' CEO Christian Velez.

The Propel GaN MOCVD system is designed to provide a wide process window and flexible configurations that result in handling a wide range of GaN applications, from power/RF to advanced LEDs, including µLEDs, laser diodes, UV-LEDs and SLEDs. The system has the versatility to process 6" and 8" wafers in a single-wafer mode, as well as 2–4" wafers in a mini-batch mode. The Propel reactor is based on Veeco's TurboDisc technology including IsoFlange and SymmHeat technologies, which provide homogeneous laminar flow and uniform temperature profile across the entire wafer.

www.exalos.com
www.veeco.com

CS Clean Solutions opens modernized refill facility for waste gas treatment columns

After completing a 12-month trial phase, CS Clean Solutions AG has opened a new, modernized facility for the refurbishment and service of waste gas treatment columns at its headquarters in Ismaning (near Munich), Germany.

Unused process gases and hazardous by-products from plasma etch, chemical vapor deposition (CVD) and similar semiconductor processes must be removed efficiently and safely from exhaust lines to ensure safety of personnel and compliance with regulatory emission standards. For over 30 years, users of the CLEANSORB range of dry scrubber products in Germany, Austria and Switzerland have benefited from a comprehensive maintenance package comprising a unique take-back and disposal service for the spent absorber material. Similar customer support is available in other countries through CS Clean Solutions' network of local service centres.

Close-up of modernized Refill Center.

The firm says that expansion of the service centre in Munich was needed to increase throughput and keep pace with the steady growth in semiconductor research and processing in recent years, particularly in the III–V sector. The modernized facility has been re-built from scratch in a dedicated building equipped to the highest standards of operator safety and materials handling, the firm adds.

The CLEANSORB waste gas abatement system removes hazardous process gases by chemical conversion to stable solids at ambient temperature (chemisorption). No external heating, waste water or other facilities are required for operation. The CLEANSORB system is hence fully passive and is permanently on standby, even in the event of a power- or other facilities failure.

www.csclean.com

DISCO completes construction of new Kyushu building

Applications lab expanded more than three-fold from old building

Tokyo-based DISCO Corp — which makes manufacturing equipment including chemical-mechanical polishing (CMP) systems and laser-based ingot slicing equipment and processes for silicon carbide (SiC) — has completed construction of a new, two-storey building in Kyushu, Japan, that will begin operation on 29 January.

Built on a site covering about 4772m^2, the building's total floor space is 1381m^2. Of this, the applications laboratory (in which processing tests are performed) is about 249m^2 (expanding more than three-fold from the old building's 68m^2). Construction began in March 2017 and was completed on 15 January. Relocation should be completed at the beginning of February. Total investment in the site and building amounts to about 1 billion yen.

Disco's new Kyushu Branch building.

DISCO says that it has not only established an environment capable of quickly supporting customer requests but it has also enhanced its BCM (business continuity management) support capabilities by adopting seismically isolated reinforced-concrete structures.

www.disco.co.jp

Picosun establishes new business unit focused on customer service and support

Atomic layer deposition (ALD) thin-film technology firm Picosun of Espoo, Finland has established a new business unit to further reinforce and streamline its service and support operations, targeted at maximizing customer satisfaction and uptime of its production ALD systems worldwide.

Picosun says that new orders rose by 68% year-on-year during 2017 to €24.4m. Demand for industrial ALD systems is growing rapidly, and repeat sales of P-series high-throughput batch ALD tools and PicoPlatform vacuum cluster systems underline the need for a strong service organization able to provide all-inclusive around-the-clock response worldwide, every day of the year, says the firm.

To meet this demand, Picosun has strengthened its service and support division by several new hirings in both the Finnish headquarters and subsidiaries in Europe, North America and Asia. The service products are tailored for the needs of industrial customers, ranging from PicoSupport maintenance contracts (with 24/7 service) to PicoDevelopment process consultancy and PicoTraining advanced training programs for ALD tool operators. The new business unit will manage all service operations and products globally and collectively.

www.picosun.com

Axus hires vice president of sales & marketing

Axus Technology of Chandler, AZ, USA (which provides CMP, wafer thinning and wafer polishing surface-processing solutions for semiconductor, MEMS/nanofabrication and substrate applications) says that Jim Kelly has joined it as VP of sales & marketing, providing management, sales, marketing and business development support to the global customer base and sales team.

Due to Axus' growth with customers in the Silicon Valley area, Kelly will be based at the firm's facility in the Richmond, CA, in order to give additional support and focus to that region, creating a new sales and support office to expand Axus' previous system repair facility there.

Kelly has more than 20 years of experience in semiconductor automation, particularly in wafer handling. He was VP of sales & marketing at Isel Robotik USA for five years before its sale to Moog, after which he stayed on for three additional years as market manager for worldwide sales of Moog's semiconductor portfolio of products. Prior to joining Axus, Kelly was director of global sales at Metlsaw.

"Jim's vast experience in global semiconductor equipment sales will help Axus penetrate into new markets worldwide," believes president Dan Trojan. "We are looking forward to being better equipped to support our existing Silicon Valley customers and to gain new ones by his presence in the area," he adds.

www.axustech.com

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CRAIC's microspectrophotometers offered with enhanced PL microspectroscopy

CRAIC Technologies Inc of San Dimas, CA, USA is now offering enhanced photoluminescence (PL) microspectroscopy.

Users of the 20/30 PV and Apollo II microspectrophotometers now have the ability to acquire PL spectra and images of microscopic sample areas throughout the ultraviolet (UV), visible and near-infrared (NIR) regions. Additionally, PL-equipped CRAIC microspectrophotometers can be used to monitor the time dependences of these spectra using the firm's kinetic software TimePro or map the PL emission from large-scale objects with microscopic spatial resolution.

Apollo II microspectrophotometer.

"Many of the novel nanoparticles and films being developed are characterized by their photoluminescent microspectra. New microscopic devices utilizing photoluminescence are also under development," says president Dr Paul Martin. "As such, the ability to test those devices with ultra-high spatial resolution and fidelity becomes increasingly important," he adds. "Microspectrometers can quickly characterize and qualify photoluminescence so as to allow for researchers and manufacturers to develop ever better devices."

www.microspectra.com

CRAIC receives ISO 9001:2015 certification

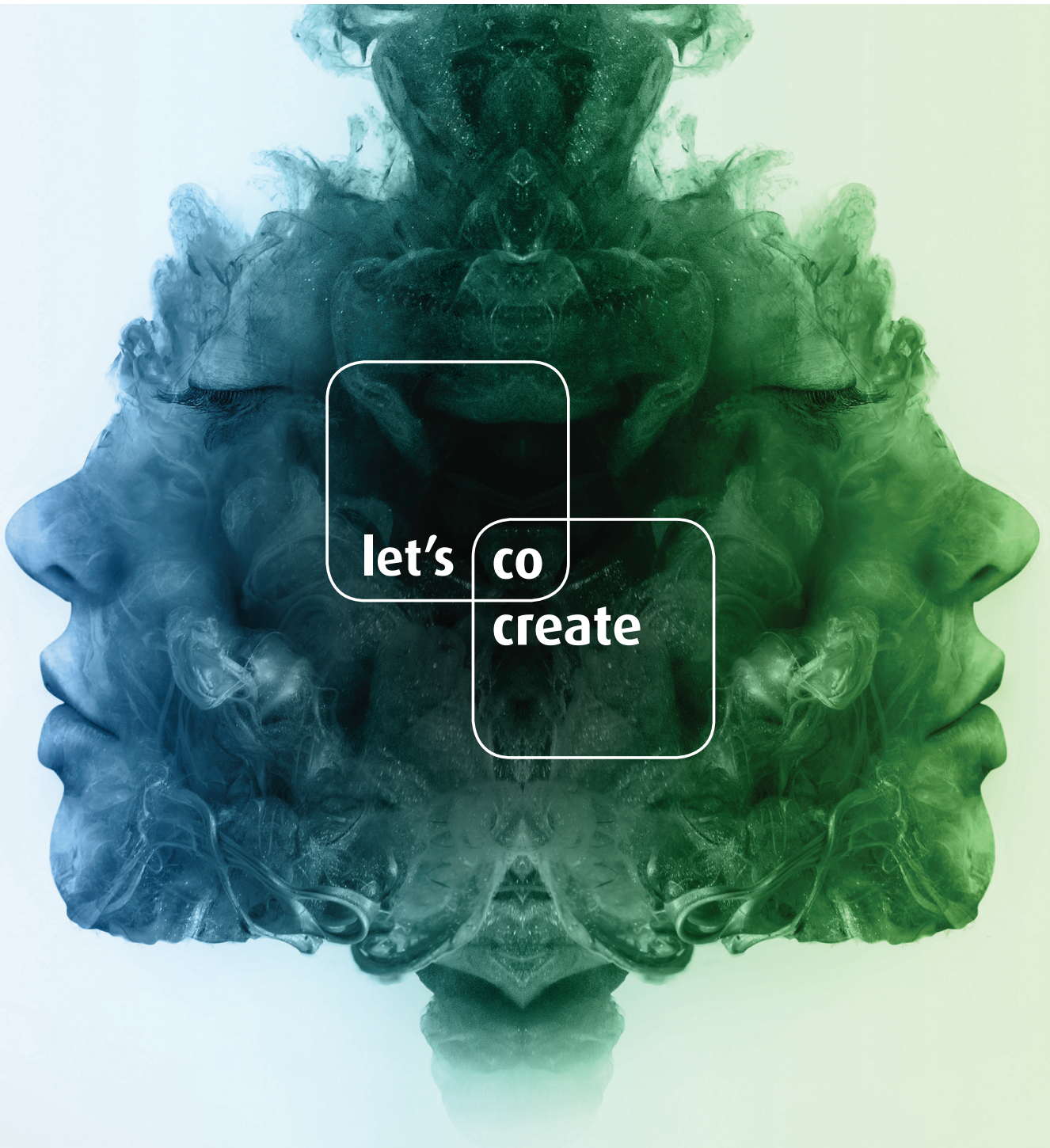
UV–visible–NIR microscope and microspectrometer manufacturer CRAIC Technologies Inc of San Dimas, CA, USA has been certified under ISO 9001:2015 as of January.

The firm previously earned certification under ISO 9001:2008 and is audited and registered annually. The updated International Organization for Standardization (ISO) 9001:2015 Quality Management System assists companies in developing a management system that combines quality with their wider business strategy. There is a focus on risk-based thinking and accountability in all organizational processes that helps to improve communications, efficiency and implementation of continuous improvement. It also acts as a tool to streamline processes and to make them more efficient. Finally, the ISO 9001:2015 standard demonstrates to customers that CRAIC offers products and services that are consistently of the highest quality, the firm adds.

Upgrading the firm's certification to ISO 9001:2015 will "provide evidence to our customers that we remain focused on continuous improvement and customer satisfaction," says president Dr Paul Martin. "Our move from ISO 9001:2008 to the updated standard ISO 9001:2015 demonstrates our desire to always perform at the highest levels of quality and efficiency," he adds. "It's essential for us in delivering innovative, high-quality and customer-focused scientific solutions."

ISO 9001:2015 is process based in that the certification recognizes organizations that link business objectives with operating effectiveness. Companies that achieve management systems certification to ISO 9001:2015 have demonstrated effective implementation of documentation and records management, management's commitment to their customers, establishment of clear policy, good planning and implementation, good resource management, efficient process control, measurement and analysis. Continual improvement has been institutionalized.

www.microspectra.com



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DOWA develops DUV LEDs with record 90mW output for resin curing and medical care

Mass production to begin in April

Dowa Holdings Co Ltd subsidiary Dowa Electronic Materials Co Ltd of Tokyo, Japan has developed a deep-ultraviolet LED chip featuring what is claimed to be record output power of 90mW, with a peak wavelength of 310nm, and dimensions of 1mm x 1mm.

Deep-ultraviolet light with a wavelength of 310nm is used for curing and skin therapy. Replacing conventional mercury and excimer lamps with such LEDs enables equipment to be smaller and mercury-free. With the advantages of long life time and power saving, the LED is expected to find new applications.

Combining a high-quality aluminium nitride (AlN) template with unique crystal growth technology, Dowa Electronic Materials is already equipped for mass production for deep-ultraviolet LED chips with record output power at the 280nm disinfection wavelength. For the 310nm wavelength, by combining this technology with fine-structured sapphire substrates developed by Tokyo-based Oji Holdings Corp, Dowa has improved luminous efficiency, boosting output power by 20% (compared with existing products) to a record 90mW for 310nm. The firm will begin to mass produce the new 310nm DUV LEDs in April.

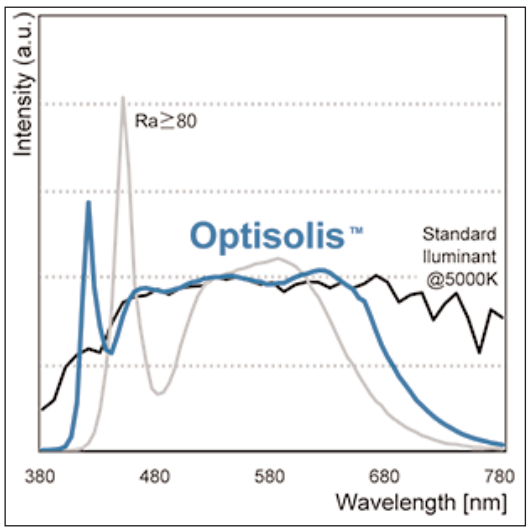
www.dowa.co.jp

Nichia launching Optisolis ultra-high-CRI white LED

In February Japan's Nichia Corp launched the Optisolis white LED (first presented at The Phosphor Global Summit in 2016).

Using Nichia's own blue chip and phosphor technology and optimized for the general lighting market, Optisolis has an ultra-high color rendering index (CRI) with a spectrum that is claimed to demonstrate the closest match to that of the standard illuminant (so all colors are reproduced to the color seen under a standard light).

Most importantly, since UV emission is essentially non-existent in the spectrum, the degradation of irradiated materials can be reduced dramatically compared with that of other light sources containing UV emission, including other LEDs on the market, it is claimed.



Example spectrum (T_S 25°C).

Target applications of Optisolis include museum and art gallery lighting, where the highest CRI is preferred but UV radiation and light sources can be detrimental. Additional applications could include color evaluation (e.g. in painting, printing), commercial lighting (e.g. retail etc.) or wherever an ultra-High CRI is desired.

www.nichia.co.jp

Seoul Semi's annual revenue hits record $1.04bn

For full-year 2017, South Korean LED maker Seoul Semiconductor Co Ltd has reported revenue of $1.04bn, up 16% (far exceeding the industry average of just 2%) due to both general lighting sales and IT product-related sales growing in the mid-teens, as well as the automotive lighting business growing by more than 20%. This was a result of the firm's efforts to stay ahead of the competition by continually investing in R&D as well as strengthening its global sales organization, believes chief financial officer Sangbum Kim.

The growth for general lighting was due largely to an increase in sales of 220V and 370V Acrich MJT products for household and industrial applications. Other notable revenue increases were reported for the WICOP line of packageless LEDs, as well as for the Acrich NanoDriver, which incorporates step drive methods that achieve results said to be greater than those of conventional SMPS technology.

Operating profit of $92m, up 71% as a result of rising sales across all business divisions.

For first-quarter 2018, Seoul Semiconductor expects revenue of KrW270–290bn, up 5–13% year-on-year, despite the first quarter normally being considered to be an off-season. The firm hence has a positive outlook for full-year growth in 2018.

To accelerate revenue growth further into the double-digit range for 2018, the firm plans to drive sales of differentiated products such as its SunLike natural-spectrum LED technology while also shifting focus more to its rapidly growing automotive lighting business.

www.SeoulSemicon.com

Seoul Semiconductor files third patent infringement lawsuit against Mouser for sale of Everlight LEDs in Italy

On 2 February, South Korean LED maker Seoul Semiconductor Co Ltd filed a patent infringement lawsuit in Italy in the Court of Milan against global electronic components distributor Mouser Electronics Inc as well as its Italian subsidiary for the sale of certain LED products made by Taiwan-based Everlight Electronics Co Ltd.

Seoul asserts that Mouser is liable for selling LED products that infringe its patent rights. Seoul has sought a permanent injunction, damages, withdrawal from the market, and destruction of the products.

Seoul previously filed two patent infringement lawsuits against Mouser in Germany in the District Court of Düsseldorf in 2017, alleging infringement by high-power and mid-power LED products made by Everlight.

Despite such lawsuits, Mouser has continued to sell allegedly infringing products in other countries. Seoul has hence launched its third patent infringement lawsuit against Mouser for the sale of Everlight LED products in Italy.

Seoul says that it has invested 10% of its revenue (over $100m per year) in R&D to develop technology and to strengthen its patent portfolio since its inception. The firm has also made committed to protecting its intellectual property rights against suspected infringement since it obtained a preliminary injunction order against Taiwan LED maker AOT in 2005. For example, in 2014 it filed patent infringement lawsuits against two North American TV makers, resulting in a judgment based on one manufacturer's admissions of infringement, and royalty-bearing licenses by both. In 2016, Seoul secured a willful infringement judgment from the US district court for its LED lens patent against Japanese LED lens maker Enplas. In 2017, Seoul resolved patent infringement litigation against Kmart, which agreed to stop selling certain filament LED bulbs. Seoul also recently began an enforcement campaign for protecting its Acrich technology, and has filed a patent lawsuit against a US lighting maker for infringement of 12 Acrich patents. Throughout this period, Seoul has continued to put other companies on notice that it suspects of patent infringement.

Seoul plans to continue and expand its patent enforcement worldwide against firms suspected of infringement, until they cease and Seoul secures court remedies to address harm caused by the infringement. "To fundamentally block distribution of suspected infringing products, we will have to expand our enforcement efforts to include direct manufacturers, secondary product manufacturers who have purchased or used suspected-infringing components, as well as their distributors," says a member of Seoul's IP team.

www.SeoulSemicon.com
www.everlight.com

Seoul Semiconductor invalidates Everlight's patent in UK

South Korean LED maker Seoul Semiconductor Co Ltd says that it has won the patent invalidity litigation action that it filed against Everlight Electronics Co Ltd in the UK.

Purchased by Everlight from a US company in 2017, patent EP (UK) 1169735 relates to an LED package structure for thermal dissipation. Recently, Everlight filed patent infringement litigation based on a foreign counterpart of this patent against its competitor Bridgelux Inc in a US federal court.

Last year, Seoul filed invalidation litigation against this Everlight patent in the Patent Court of the UK. Subsequently, Everlight abandoned its defense and acknowledged in the court proceeding that its patent is invalid and that it is responsible for reimbursing Seoul for its litigation costs.

Based on Everlight's admissions, on 14 February the UK Patent Court issued an order declaring that the patent should be revoked. It also ordered that Everlight must pay about $1m (£712,247.10) in litigation costs to Seoul based on Everlight's stipulation.

Currently, Seoul is also enforcing certain of its patent rights against a distributor of Everlight LED products. During the past year, it has launched two patent infringement lawsuits in Germany against Mouser Electronics, a global distributor of Everlight LED products. In addition, in early February Seoul filed a new patent litigation against Mouser for the sale of allegedly infringing Everlight products in Italy. Mouser subsequently appears to have removed all Everlight products from its distribution list worldwide, says Seoul.

McClear delivering plenary address at Strategies In Light

Seoul Semiconductor says that, at the Strategies in Light 2018 conference & exhibition in Long Beach, CA, USA (13-15 February), its president for the Americas, Mark McClear, is delivering a plenary address on 'The LED Supply Chain – Past, Present and Possible Future' (14 February).

Aledia completes €30m Series-C financing

Intel invests in commercializing 3D GaN nanowire-on-silicon LEDs

Aledia S.A of Grenoble, France, which is developing light-emitting diode for display applications based on 'WireLED' three-dimensional (3D) nanowire GaN-on-silicon technology that is claimed to cut manufacturing costs compared to conventional planar (2D) LEDs, has closed a €30m ($36m) Series C financing round with Intel Capital as a new investor, joined by most existing investors including Braemar Energy Ventures, Demeter, the Ecotechnologies Fund of Bpifrance (the French national industrial bank), IKEA Group, Sofinnova Partners and Supernova Invest.

"Today more than 3 billion people interface to the Internet with mobile displays, and LED technology is expected to be used in a majority of these displays in the next few years," notes Aledia's CEO, chairman & co-founder Giorgio Anania. "The unique advantages that 3D LED technology delivers position it as the driver of a once-in-a-generation shift," he reckons. "This financing round and collaboration with Intel reflect this potential and underscores the interest that our 3D nanowire-on-silicon technology is getting in the mobile-display market and from leading global technology-investment firms."

Based on technology originally developed by the CEA-Leti nanotech research institute in Grenoble, Aledia is developing a new generation of LEDs manufacturable on large-diameter silicon wafers (200mm/8", scalable to 300mm/12") in existing microelectronics foundries and targeted at mobile display applications. The technology is expected to lead to displays that are more energy-efficient, much brighter and more manufacturable at moderate cost. The silicon-based technology is also well suited to the integration of microelectronics, the firm says.

Aledia is working on next-generation displays with several large industrial partners. It is also developing large/existing displays (smart phones, laptops, tablets, etc) as well as smaller, newer displays for VR/AR/MR and smartwatch applications, using its megapixel integrated silicon chips.

Anania says the Series C financing will support its plans to significantly accelerate the speed of its LED technology development, including acquiring critical equipment.

"Energy efficiency, display quality and cost are three critical characteristics of mobile consumer electronics displays, and we feel Aledia's 3D LED technology, based on large-area silicon fabrication, can impact this space," says Gregory M. Bryant, senior VP & general manager of the Client Computing Group at Intel. "We're excited to work with Aledia to innovate display technologies across client platforms."

www.aledia.com

Seren completes first tranche of £1m investment round

Funds to aid scale-up of template technology for μLED displays

Seren Photonics Ltd of Pencoed Technology Park, Bridgend, Wales, UK — which develops semi-polar and non-polar GaN-based products — has completed the first tranche of a £1m investment round, including £250,000 from the Development Bank of Wales along with matching investment from private investors.

Funds will be used to continue the manufacturing scale-up of its template technology along with further developing green LED epi structures.

The evolution of the firm's product offering towards semi-polar green LED epitaxy is driven by increasing demand for improved-efficiency wavelength-stable green LEDs for micro-LED display applications, where each pixel is represented by an individual red, green or blue micro-LED. Whereas individual red and blue LED efficiencies are already in the 60–70% range, green LEDs still remain at <20% wall plug efficiency (WPE). Poor efficiency results in increased power consumption and sometimes a need for additional green LED pixels, which also acts to reduce overall screen resolution as well as to increase cost.

The overall market for next-generation displays using micro-LEDs could be $30-40bn, it is forecasted, if micro-LEDs become the display technology of choice. Applications include large, high-resolution indoor displays, 4k and 8k TVs, augmented reality (AR)/virtual reality (VR) headsets, automotive head-up displays (HUDs), smartphones and wearables.

"Seren's semi-polar and non-polar technologies make InGaN/GaN-based LEDs significantly more wavelength stable over a wide range of operating conditions, enable an order-of-magnitude higher switching speeds and also deliver the potential for improved efficiency through superior electron–hole recombination rates," says chief development officer Dr Bedwyr Humphreys. "This is a truly versatile technology, having the potential for reducing droop in high-brightness blue LEDs, enhancing the performance of longer-wavelength GaN LEDs and enabling high-speed LED-based communication systems such as visible light communication (VLC) as well as short-range plastic optical fiber (POF) communication," he adds.

"The high level of interest for this technology in next-generation displays and high-speed communication endorses the importance of semi-polar GaN in enabling leading-edge LED performance," says Steve Smith, technology ventures director at the Development Bank of Wales.

www.serenphotonics.co.uk

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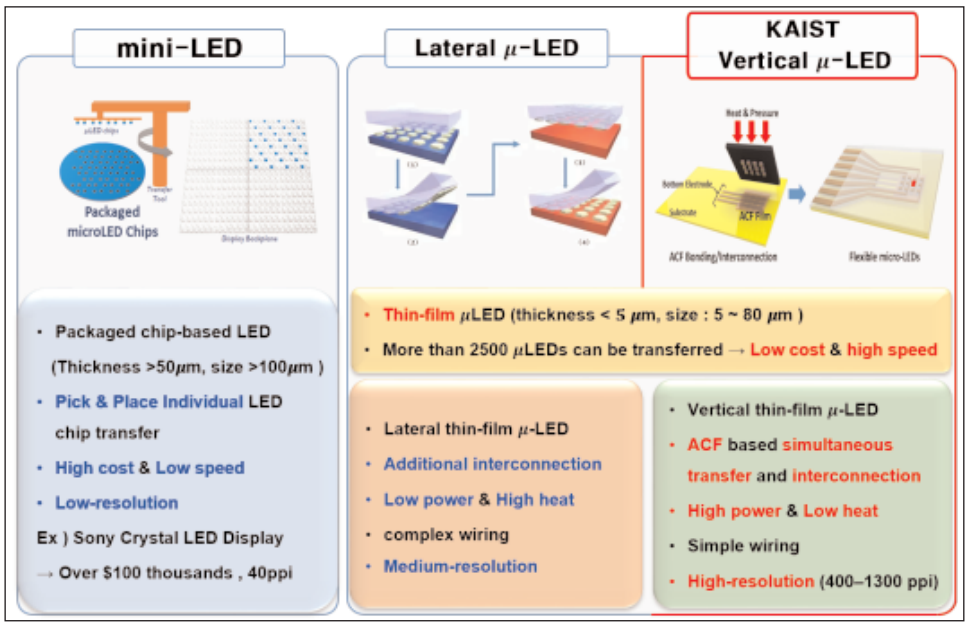
KAIST develops flexible vertical micro-LEDs with three times optical power density of lateral micro-LEDs

Simultaneous transfer and interconnection enabled by precise alignment of anisotropic conductive film bonding process

A research team at the Korea Advanced Institute of Science and Technology. (KAIST) led by professor Keon Jae Lee of the Department of Materials Science and Engineering and professor Daesoo Kim of the Department of Biological Sciences has developed flexible vertical micro-LEDs (f-VLEDs) using anisotropic conductive film (ACF)-based transfer and interconnection technology (Lee et al, 'Optogenetic Control of Body Movements via Flexible Vertical Light-Emitting Diodes on Brain Surface', Nano Energy February 2018 issue). The team also succeeded in controlling animal behavior via optogenetic stimulation of the f-VLEDs.



Flexible micro-LEDs have become a strong candidate for next-generation displays due to their ultra-low power consumption, fast response speed, and excellent flexibility, says KAIST. However, previous micro-LED technology had critical issues such as poor device efficiency, low thermal reliability, and the lack of interconnection technology for high-resolution micro-LED displays.

The team has designed new transfer equipment and fabricated a f-VLED array (50x50) using simultaneous transfer and interconnection through the precise alignment of the ACF bonding process. These f-VLEDs achieved optical power density of 30mW/mm^2 (three times higher than that of lateral micro-LEDs), improving thermal reliability and lifetime by reducing heat generation within the thin-film LEDs.

These f-VLEDs (5μm thick and less than 80μm square) can be applied to optogenetics for controlling the behavior of neuron cells and brains. In contrast to the electrical stimulation that activates all of the neurons in the brain, optogenetics can stimulate specific excitatory or inhibitory neurons within the localized cortical areas of the brain, which facilitates precise analysis, high-resolution mapping, and neuron modulation of animal brains (ACS Nano, 'Optogenetic Mapping of Functional Connectivity in Freely Moving Mice via Insertable Wrapping Electrode Array Beneath the Skull').

In this work, they inserted the f-VLEDs into the narrow space between the skull and the brain surface and succeeded in controlling mouse behavior by illuminating motor neurons on two-dimensional cortical areas located deep below the brain surface.

"The flexible vertical micro-LED can be used in low-power smart watches, mobile displays, and wearable lighting," says Lee. "In addition, these flexible optoelectronic devices are suitable for biomedical applications such as brain science, phototherapeutic treatment, and contact lens biosensors."

Lee recently established a startup company (FRONICS Inc) based on micro-LED technology and is looking for global partnerships for commercialization.

www.kaist.ac.kr

Lumileds appoints senior VP & general counsel

LED maker Lumileds of San Jose, CA, USA has appointed Silicon Valley veteran Cheree McAlpine as senior VP, general counsel. She joins from global electronic components and services provider Avnet Inc, where she was VP & general counsel.

"She brings extensive legal and business expertise, which will be extremely valuable to Lumileds," comments CEO Mark Adams.

Previously, McAlpine was VP & general counsel of Wyse (acquired by Dell in 2012). She was also a senior legal leader at Sun Microsystems. Her expertise includes advising executive leaders on strategic and corporate governance matters, as well as providing counsel and management of M&A activities, intellectual property transactions and operations. McAlpine holds a Law Degree from the Suffolk University.

www.lumileds.com

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FerroTec

Cree's growth in Wolfspeed Power & RF products and LED products offsets drop in Lighting revenue

Wolfspeed capacity expansion to hit gross margin in near term

For fiscal second-quarter 2018 (ended 24 December 2017), Cree Inc of Durham, NC, USA has reported revenue of $367.8m, down 8% on $401.3m a year ago but up 2% on $360.4m last quarter — and exceeding the targeted $340–360m — driven by strong demand for Wolfspeed and LED Products.

Revenue for the Wolfspeed business (Power & RF devices and silicon carbide materials) was an above-target $70.6m (19% of revenue), up 7% on $66.2m (18% of revenue) last quarter and up 30% on $54.4m (14% of revenue) a year ago. "While we were capacity constrained during the quarter, we achieved the higher revenue by managing our front-end wafer factory capacity between Wolfspeed and LED production," says chief financial officer Mike McDevitt.

Revenue for LED Products (chips and components) was an above-target $152.7m (42% of revenue), up 6% on $144.5m (40% of revenue) last quarter and up 11% on $138m (34% of revenue) a year ago, due to strong demand in the automotive after-market, video screen, general lighting and specialty lighting applications.

Revenue for Lighting Products (mainly LED lighting systems and lamps) was $144.6m (39% of revenue), at the upper end of the targeted range but down 3% on $149.7m (42% of revenue) last quarter and down 31% on $208.9m (52% of revenue) a year ago. Commercial lighting revenue was down a little less than targeted, despite continued weakness in the North American market. Consumer sales were in line with target.

Wolfspeed gross margin was 48.4%, down from 49% last quarter but up from 47.7% a year ago.

LED product gross margin was a below-target 25.3%, down from 26.9% last quarter, due mainly to higher chip costs resulting from managing the front-end wafer factory production between Wolfspeed and LED.

Lighting Product gross margin has fallen further, from 35.8% a year ago and 21.3% last quarter to 15.9%, due mainly to larger-than-expected warranty reserves (for quality issues identified on certain products) and lower commercial factory utilization.

Overall company gross margin has fallen from 35% a year ago and 27.8% last quarter to 25.2%. On a non-GAAP basis, gross margin has fallen from 35.8% a year ago and 28.3% last quarter to 25.7% (below the targeted 28.5%).

Operating expenses (OpEx) were $97m (below the targeted $100m), due mainly to lower-than-expected variable performance-based compensation and lower IP litigation spending, as activity in some cases was delayed to fiscal Q3.

Net loss was $0.66m ($0.01 per diluted share, at the low end of the targeted range), compared with net income of $4.1m ($0.04 per diluted share) last quarter and $29.9m ($0.30 per diluted share) a year ago. However, excluding the additional warranty costs (for quality issues identified for certain commercial lighting products), earnings would have shown a profit of $3m ($0.03 per share, at the top end of the targeted range).

Cash flow from operations was $51.7m (down from $54.1m last quarter and $101.6m a year ago). Spending on property, plant & equipment (PP&E) has risen further, from just $15.9m a year ago and $36.5m last quarter to $48.8m, while patent spending was steady at about $2.5m. So, total capital expenditure (CapEx) was $51.3m. Free cash flow was hence just $461,000 (down from $15.2m last quarter and $82m a year ago).

However, Cree received $46m from the exercise of employee stock options. Hence, during the quarter, cash and investments (net of line of credit borrowings) rose by $42m from $484m to $526m. At the end of the quarter, Cree had $124m outstanding on its line of credit.

For fiscal third-quarter 2018 (ending 25 March), Cree expects revenue to fall to $335–355m, as 5% sequential growth for Wolfspeed (as additional wafer capacity starts to come online) will be offset by LED Product revenue being seasonally lower by 10% (due to the timing of the Chinese New Year, Christmas and New Year's holidays), and Lighting Product revenue falling by 10% (due to outdoor product seasonality and continued North American market softness).

Nevertheless, gross margin should rise to 28%, due to Lighting being targeted to have more normal warranty reserves, cost improvements, and a more favourable product mix. Gross margin will be positively impacted by higher Wolfspeed revenue mix, despite lower targeted Wolfspeed margins associated primarily with the cost of ramping the new wafer capacity. LED Product margin should be slightly lower due to lower seasonal factory utilization.

Operating expenses should rise by $1m to $98m, including incremental spend related to the delayed IP legal costs, Wolfspeed R&D and trade show costs, partially offset by lower variable sales costs.

Net income should range from a loss of $3m ($0.03 per diluted share) to a profit of $3m ($0.03 per diluted share).

Capital priorities remain focused on expanding capacity in the Wolfspeed business, where demand exceeds the firm's current ability to supply. The initial set of tools for wafer capacity expansion came online as Cree exited fiscal Q2.

"We are on target with our plan to double wafer capacity for external material customers by the end of calendar 2018," notes McDevitt. "We were also on target with our additional Power & RF device capacity starting to come online in fiscal Q4. This plan is intended to double our power device capacity by the end of calendar 2018 from where we exited fiscal 2017," he adds. "As we ramp this new capacity, we anticipate we could have some variability in our initial production yields and factory utilization that may reduce our near-term Wolfspeed gross margins."

For full-year fiscal 2018, Cree continues to target CapEx of $220m, driven mainly by expanding Wolfspeed's production capacity to support forecasted customer demand.

Due to accelerating the Wolfspeed capacity investments to support the substantial growth opportunity forecasted over the next several years, Cree continues to target overall fiscal 2018 free cash flow being negative $20m.

The plan is to double power device capacity by the end of calendar 2018 from where we exited fiscal 2017

Last quarter Cree announced that it was implementing a strategic review of its businesses, aiming to determine which areas offer the best opportunities for growth in both revenue and profitability. "We have a few more things to work through, but I believe we'll be in a good position to roll out our direction before the end of this quarter," says CEO Gregg Lowe. "Over the last few months, I've traveled extensively to meet with customers, partners and employees, and I come away from that convinced there is meaningful upside

Cree appoints senior VP of global sales & marketing

Cree has appointed Thomas Wessel as senior VP of global sales and marketing, reporting to Gregg Lowe and overseeing sales & marketing for the Wolfspeed power & radio frequency (RF) and Cree LED components businesses.

Wessel has more than 20 years of global sales and marketing leadership experience in the semiconductor industry, serving the automotive, industrial, electronics and communications markets. He joins Cree from NanoSemi Inc., a venture-funded spinoff from the Massachusetts Institute of Technology (MIT) and MIT Lincoln Laboratory, where he served as VP of sales & marketing. Prior to that, he was senior VP of worldwide sales & marketing at Analog Devices Inc, a multi-national semiconductor company specializing in data conversion and signal processing technology, where he led the organization to eight consecutive quarters of growth. His career also spans sales and marketing management roles at Texas Instruments and Atlantik Elektronik.

"Thomas has a history of success in sales, marketing and business leadership within the markets Cree serves," comments CEO Gregg Lowe. "Cree's Wolfspeed power & RF and LED component technologies are critical to the success of today's most in-demand and evolving markets, such as the automotive industry's transition to electric vehicles… Thomas will help us unlock Cree's potential."

Wessel holds an engineering degree in physics from the University of Applied Sciences Lübeck and completed the advanced management program at IESE Business School. He is a Stevie Awards finalist for 'Best Turnaround Executive', recognized by the industry's only global, all-encompassing business awards program honoring performance in business.

www.cree.com

Osram launches Synios P2720 940nm-wavelength IR LED to reduce red glow in 2D facial recognition

Osram Opto Semiconductors GmbH of Regensburg, Germany says that, by using a wavelength of 940nm, its new Synios P2720 LED reduces the red glow that can occur with light sources in the short-wave infrared range. Up to now, the sensitivity of IR cameras for 2D facial recognition was only good if the light source had a wavelength of 850nm. The cameras have been further developed to give them greater sensitivity in longer-wavelength ranges, so 940nm light sources can now be used — which in turn improves the overall performance of the system.

Bright and uniform illumination of the user's face or eyes is particularly important for facial recognition and also for eye-tracking systems. The Synios P2720 offers an output of 1150mW at 1A. Due to this high overall output, it has a radiant intensity of 360mW/sr.

The Synios P2720 has the same footprint as the 850nm version. Measuring only 2.0mm x 2.75mm x 0.6mm, the IRED is therefore suitable for space-critical applications. Since the new IRED has no optics, its compact dimensions mean that users can install secondary optics in line with their requirements.

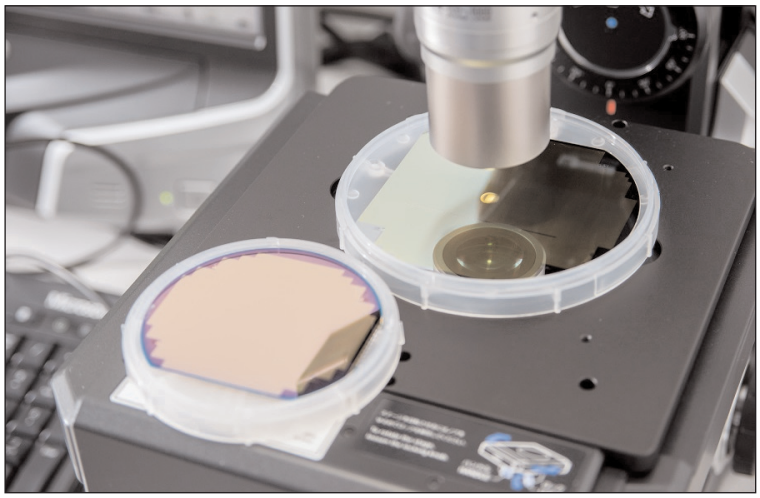
Already available for initial customer projects, the new Synios P2720 IRED for 2D facial recognition is the latest addition to Osram Opto's existing portfolio for biometrics.

www.osram.com

CST Global profiles CoolBlue and MacV quantum technology development projects at Photonics West

At SPIE Photonics West 2018 in San Francisco (27 January — 1 February), III-V optoelectronic foundry Compound Semiconductor Technologies Global Ltd (CST Global) of Blantyre, near Glasgow, Scotland, UK (a subsidiary of Sweden's Sivers IMA Holdings AB) gave an update on two of its government-funded quantum technology development projects.

'CoolBlue' is developing next-generation distributed feedback (DFB) gallium nitride (GaN) laser diodes for quantum sensing systems, and Dr Thomas Slight is presenting a paper on the project's findings at the conference. The project 'MacV' (VCSELs for miniature atomic clocks) is developing a commercially viable mass-produced coherent population trapping (CPT)-based miniature quantum atomic clock, for submarine or military applications (where a GPS signal is not available). MacV is very relevant to attendees and has many other potential market applications, says CST Global.



"CPT-based miniature atomic clocks require extremely stable single-mode laser diodes for direct modulation at the resonant frequency of the gas cell," says research engineer Dr Iain Eddie, MacV project leader at CST Global. "The MacV VCSELs (vertical-cavity surface-emitting lasers) will provide low power consumption, stable wavelength, high reliability and a small footprint," he adds. "A volume-produced VCSEL source with these specific characteristics is not currently manufactured in the UK and there are potential applications for chip-scale atomic clocks worldwide. This gives the MacV project participants, and the UK, a strategic and commercial opportunity in the emerging atomic clock market."

The MacV project runs from March 2017 until February 2019, and has a budget of £1,234,392, including a government funding contribution of £705,287. CST Global is a participant member of the project and will receive £202,056. Cardiff University and NPL Management Ltd are also participant members, with Cardiff-based Compound Semiconductor Centre Ltd as lead participant.

www.CSTGlobal.uk

Kyle Kennedy appointed as staff engineer in Sales & Marketing

CST Global has appointed Kyle Kennedy as staff engineer in the Sales & Marketing department. He reports to VP sales & marketing Euan Livingston, and joins Karen Rodger, sales & marketing support, and Nick Bowden, PR & digital marketing.

"Kyle started at CST Global three years ago as a process engineering technician. This promotion takes him out of the production department and into frontline, technical sales," notes Livingston. "Kyle has first-hand experience of process design and manufacture of complex VCSEL, FP and DFB semiconductor lasers, from quality testing, through to dry and wet etching, oxidation, thinning and polishing processes. Such a high level of production knowledge is proving invaluable when liaising with customers and partner companies. It not only helps us understand customers' needs more accurately, but also allows constructive input on design at the start of projects, positively affecting cost, production time and yield," he comments.

CST Global's new staff engineer Kyle Kennedy.

"I am the prime point of contact for the sales and marketing aspects of the New Product Introduction (NPI) process," says Kennedy. "My responsibilities include developing technical specifications for new products, competitive analysis, resolution of NPI tactical issues, technical literature management, volume pricing, stock recommendations and regular communication with customers and staff. I will also provide additional technical and commercial backup to Euan and Karen."

www.CSTGlobal.uk

CST Global receiving £151,699 of UK government funding to lead HELCATS atomic clock project

III-V opto foundry working with NPL and University of Glasgow

III-V optoelectronic foundry Compound Semiconductor Technologies Global Ltd (CST Global, a subsidiary of Sweden's Sivers IMA Holdings AB) is to lead the project HELCATS (High-power phosphorous-based, DFB lasers for cold atom systems) from its facility in Blantyre, Glasgow, Scotland, UK.

The project will enable miniaturized atomic clock systems using strontium ions. Atomic clocks are critical in determining position in navigation and defence applications and core to powering next-generation telecommunications systems.

CST Global is working with research partner National Physical Laboratory Ltd (NPL) and academic partner the University of Glasgow on the project. Running from March 2018 to February 2019, the project will cost a total of £497,574, with government funding of £396,441, of which CST Global will receive £151,699.

Olek Kowalski.

"Currently, there are no commercially available semiconductor lasers developed for use in miniature strontium atomic clock applications," says research engineer Dr Olek Kowalski (who leads the project). "The strontium atomic clock system we are targeting requires four phosphorous-based gallium arsenide (GaAs) distributed feedback (DFB) laser sources, operating between 690 to 710nm," he adds.

"We will use a low-loss waveguide approach to enable narrow emission linewidths and photonic integration for on-chip manufacturing of separate DFB and amplifier elements," Kowalski continues. "This design will not only help reduce the size, weight and cost of the quantum clock light sources, but also improve reliability and output power. We are expecting a 10,000-fold improvement in accuracy when compared to current systems."

CST Global achieves 88% growth in 2017 to £6.7m, triggering issue of new shares in owner Sivers IMA

CST Global has reported revenue of £6.7m for 2017, up 88% year-on-year.

"The merger between CST Global and Sivers IMA in May 2017 allowed us to invest heavily in the automation of our production facility and quality processes," says CEO Neil Martin. "This was essential to meeting the escalating demand," he adds.

"Our investment has included the introduction of 4" wafer processing, increased MOCVD [metal-organic chemical vapor deposition] capability, a ground-breaking, automatic bar stacker machine, and automatic visual inspection and sorting. This is supported by a team of 59 world-class design, engineering and production staff. We also introduced ISO 9001:2015 quality and Telecordia certification, ITU GR 468 qualification testing, and ISO 14644-1 class 4 cleanroom conformance. These investments proved essential to accessing a new, world-class customer base," continues Martin. "CST Global's membership and support of the UK and European Technology Consortium Program means we have 14 active government co-funded projects feeding our technology capability pipeline."

CST Global agreed to be acquired on 19 May for an initial purchase price of 27,924,998 shares in Sivers IMA. By exceeding £6.5m turnover, as part of the original agreement, CST Global shareholders are entitled to an additional 13,962,499 newly issued shares. During its annual general meeting (AGM) on 14 February, Sivers IMA's board of directors agreed to authorize the issue of the new shares. These are expected to be traded on Nasdaq First North on 21 February. Following completion, Sivers IMA shares will total 107,045,825.

www.CSTGlobal.uk
www.siversima.com

GCS, Intengent and VLC Photonics partner on one-stop fabless development services for InP PICs

VLC providing PDK for Intengent's Taper Assisted Vertical Integration platform based on foundry GCS' regrowth-free process

Compound semiconductor wafer fabrication foundry Global Communication Semiconductors (GCS) of Torrance, CA, USA, independent III-V photonics consultancy Intengent of Ottawa, Canada, and photonic integrated circuit (PIC) design house VLC Photonics of Valencia, Spain, are partnering to jointly offer fabless development and production services for customized PICs in indium phosphide (InP).

GCS provides wafer foundry services based on a proprietary regrowth-free process in InP. Originally developed as optoelectronic and heterojunction bipolar transistor (HBT) processes, it also allows prototyping and volume-scalable production of PICs. The key enabler is a photonic integration platform that is compatible with the foundry's regrowth-free process and yet is suitable for a variety of applications.

Intengent has developed such a platform, termed Taper Assisted Vertical Integration (TAVI), which is regrowth-free, based on the GCS process, and enables decoupling of epitaxial growth and wafer fabrication. TAVI covers many PIC applications, including those in growing and emerging markets, like optical interconnects and switching markets. It also offers complementary solutions to silicon photonics, which is considered by many to be the technology of choice for high-scale integration but lacks amplifying, lasing and other functions that are naturally implementable in InP. In a three-way partnership with GCS and VLC, Intengent is working towards making TAVI a generic platform while preserving its flexibility and openness to PIC customization.

VLC Photonics has expertise in generic photonic integration platforms and, as a fabless and independent design house for PICs, has been developing design libraries and process design kits (PDK) for different foundry platforms and customers. A PDK for the TAVI platform reduces the PIC design effort and risk, by shifting the focus towards circuit-level simulations. The evolving PDK is based on verified active and passive building blocks, and is already used in commercial PIC designs carried out by the partnership.

"Our well-established opto and RFIC processes have great synergies with the TAVI PIC platform," says GCS' CEO Brian Ann. "Our 4" and 6" wafer capability as well, based on a commercially supplied one-step-growth epitaxy, creates a unique opportunity for PICs in InP," he adds. "The GCS–Intengent–VLC partnership can fully utilize this opportunity and generate a significant business for PICs in various markets. By leveraging the infrastructure and expertise that we have gained through years of serving high-volume RF electronics and optoelectronics markets, this partnership offers time- and cost-efficient PIC development into production," he states.

"GCS is an advanced III-V foundry with a high InP wafer throughout both in RF electronics and optoelectronics markets," comments Intengent's CEO Valery Tolstikhin. "The TAVI platform takes advantage of GCS' process maturity and extends it to PICs in InP," he adds. "To make the technology suitable for a fabless PIC development, one more thing is needed: the PDK. This is where VLC comes in, bringing a wealth of experience in PIC design and characterization. The fabrication process, the integration platform, and the PDK, together, make a versatile generic platform for PICs in InP that allows the end users to access the commercial-grade technology under the fabless model," he adds.

"VLC has a solid approach to working with foundries, EDA [electronic design automation] partners and customers on PDK development, based on its commercial and proprietary design tools, characterization techniques, and in-house test & measurement capabilities," says VLC's CEO Iñigo Artundo. "TAVI implemented over the GCS process has a great potential as a generic platform for PICs in InP, enabling both customization and volume scalability in an environment of industrial-grade wafer fabrication," he adds.

www.gcsincorp.com
www.intengent.com

AIM Photonics and Analog Photonics unveil silicon photonics PDK

Combined with MPW runs, PDK to give partners access to components for developing 100G, 200G and 400G+ transceivers or systems

The Rochester-based consortium AIM Photonics (American Institute for Manufacturing Photonics), an industry-driven public-private partnership advancing the USA's photonics manufacturing capabilities, and Analog Photonics of Boston, MA, USA (which has expertise in the design and verification of silicon photonics components and systems with the capability of industry-oriented custom optical solutions) have announced the release of the AP SUNY Process Design Kit v2.0a (APSUNY_PDKv2.0a).

Analog Photonics (AP) has expanded the comprehensive set of silicon photonics integrated circuit (PIC) component libraries within SUNY Poly's process to address the high-speed optical communication needs. Combined with multi-project wafer (MPW) runs, this process design kit (PDK) will give AIM Photonics' members access to silicon photonics components for the development of 100G, 200G and 400G+ optical transceivers or systems used in data centers, metro and long-haul optical networks.

"AIM Photonics is laying a strong foundation for enabling next-generation photonics-based capabilities, and we anticipate that this latest PDK version will provide even further incentive for members of the photonics industry to collaborate with AIM Photonics to leverage the updated PDK, especially for high-speed communications technologies, and join the more than 80 signed members and additional interested collaborators from across the USA, including industrial, academic and governmental members who have found incredible value in this growing national initiative," says Dr Michael Liehr, AIM Photonics' CEO and SUNY Poly's VP for research.

The PDK includes a silicon photonics library of interfaces, passive and active components, schematics and models for the development of optical modules and system.

The key features of the APSUNY_PDKv2.0a are:

- 50Gbps modulation with less than 1V peak-to-peak drive (low-voltage drive at high bandwidth is key to enable low-power applications and work with CMOS/BiCMOS drivers);
- digital detectors with greater than 45GHz bandwidth and high responsivity (suitable for C-band receivers);
- both polarization support for standard and low-cost single-mode fibers (eliminating the need for expensive polarization-maintaining fibers);
- lower-loss crossings and propagation with seamless dielectric transitions and <1% mismatch between the outputs of a 3dB splitter (leading to a high common mode rejection ratio, CMRR); and
- continued multi-vendor electronics-photonics design automation (EPDA) support with integrated EPDA PDK flow for schematic driven layout and system-level simulation.

"We listened to the AIM Photonics community and improved the performance and quality significantly from the first release of the PDK in 2016," says director of PDK development at Analog Photonics, Dr Erman Timurdogan. "The updated PDKv2.0a with the verified high bandwidth and low-power performance will enable quick succession of complex silicon photonics integrated circuits, empowering a number of our current and future partners," he adds.

The combined AP SUNY PDKv2.0a and MPW offering provides access to PIC systems for companies wanting a reduction in the time to market, product development risk, and investment. By incorporating design, verification and process development within the PDK, firms can rapidly modify their designs while reducing the cost per gigabit.

"With the recent ratification of the IEEE 802.3bs standards for 200G and 400G and the ever-increasing demand for data, transceiver manufacturers will need to keep up with the data-center requirements of lower cost, lower power and smaller-size transceivers while data rates continue to increase," says Analog Photonics' CEO Michael Watts. "To accomplish this, optical integration and silicon photonics is a key technology. The recent release of the PDKv2.0a, which now includes 50Gbps, supports the industry's efforts down this path."

In the near future, the PDK will be empowered by laser and CMOS integration with an interposer, a capability that will be made possible at AIM Photonics' Test, Assembly and Packaging (TAP) facility in Rochester, NY. Additional releases of the AP SUNY PDK are planned over the next several years with improved statistical models, optical components and PIC systems.

AIM Photonics is planning to conduct PDK updates in February, June and October and is ready for three total full-build/passive MPW runs to take place February, May and September, with an interposer MPW run scheduled for June. To ensure space for all interested parties, AIM Photonics is accepting reservations for these MPW runs. Those interested in participating in any of the AIM Photonics 2018 MPW silicon photonics runs can e-mail Chandra Cotter at ccotter@aimphotonics.com.

PDK and MPW fab access is solely available through the AIM Photonics MPW aggregator MOSIS.

www.mosis.com/vendors/view/AIM
www.aimphotonics.com/mpw-schedule
www.analogphotonics.com/pdk

POET introduces Optical Interposer Platform for co-packaging of electronic and optical components

Optical engines for single-mode transceiver modules targeted as initial high-volume application

POET Technologies Inc of Toronto, Canada and San Jose, CA, USA — a designer and manufacturer of optoelectronic devices, including light sources, passive waveguides and photonic integrated circuits (PIC) for the sensing and datacom markets — has unveiled an Optical Interposer Platform that facilitates the co-packaging of electronics and optics in a single multi-chip module (MCM).

Based on its previously announced dielectric waveguide technology, POET's Optical Interposer provides the ability to run electrical and optical interconnections side-by-side on the same interposer chip at the micron scale. It represents an integral part of POET's hybrid integrated optical engines and leverages the manufacturing processes and unique capabilities of its dielectric waveguides.

As the need for higher data transfer speeds at greater baud rates and lower power levels increase, optics will move increasingly closer to the source of the data, whether it be a processor, application-specific integrated circuit (ASIC) or field-programmable gate array (FPGA), says POET. The Optical Interposer Platform enables an optoelectronic interconnect fabric to interface directly with the source of data to support high-speed optical data transfer from within the MCM. Additionally, the technology is projected to offer cost-efficient optical interconnects, allow for a reduction in components, and reduce test & assembly steps to decrease manufacturing costs.

POET believes that its Optical Interposer Platform, targeting 100G transceiver applications, is readily scalable to 200G and 400G transceiver products with minimal incremental cost. Also, its scalable architecture (in reach and speed) has the potential to provide a highly differentiated competitive advantage in leading-edge datacom transceivers, reckons the firm.

The Optical Interposer has applications in a wide range of high-growth markets, primarily high-performance computing, networking, optical transceivers and transponders, and automotive LiDAR (light detection and ranging) systems. The platform technology is applicable to both gallium arsenide (GaAs)- and indium phosphide (InP)-based optical components. Optical engines for single-mode transceiver modules represent the initial high-volume application.

POET also says that it has completed development of its low-loss dielectric waveguide stack and is readying the technology for transfer to manufacturing. As part of its continued technology development, POET has demonstrated a 10x improvement in the optical loss of its waveguide stack compared with the performance publicly disclosed at the Photonics Integrated Circuit (PIC) conference in March 2017. Optical transmission loss within the dielectric stack has now been measured to be below 0.2dB/cm, which renders the stack virtually loss-less for most practical applications. The ability to deposit low-loss and low-stress dielectric waveguides is the first critical step to enabling complex functionality of these waveguides in key applications, such as arrayed-waveguide gratings (AWGs), échelle gratings, laterally coupled gratings, multi-mode interference (MMI) couplers and splitters, and pass-through waveguides. These functional features are integral to enabling the performance of a transceiver optical engine and essential to the performance of the multiplexer/de-multiplexer component required in wavelength-division multiplexing (WDM) systems.

Consistent with prior expectations, POET continues to work toward providing engineering samples of a receive optical engine to customers by mid-2018. The device will be fabricated leveraging the Optical Interposer Platform.

Through its subsidiary DenseLight Semiconductors, POET participated at SPIE Photonics West 2018 in San Francisco (27 January – 1 February).

http://spie.org/photonics-west.xml
www.poet-technologies.com

POET demos functionality of PIN photodetector targeting 100–400G optical transceivers

POET Technologies Inc of Toronto, Canada and San Jose, CA, USA — a designer and manufacturer of optoelectronic devices, including light sources, passive waveguides and photonic integrated circuits (PIC) for the sensing and datacom markets — has demonstrated a high-frequency waveguide-integrated PIN photodiode targeting 100G and 400G data-center applications.

The firm's PIN photodetector has demonstrated a 3dB optical bandwidth of 37GHz, which is a typical requirement for achieving 50GBaud data rates. The achieved native bandwidths are more than capable of supporting the requirements of 100G receive optical engines (4 lanes at 25Gb/s each) and they can be extended to support 200G/400G engines. Unlike more conventional top-entry PIN photodiodes, POET utilizes an evanescently coupled twin-waveguide structure with integrated spot-size converters that is compatible with the firm's new Optical Interposer Platform and is designed to operate at wavelengths of 1310–1550nm.

The waveguide-integrated PIN diode is said to provide good responsivity with superior flatness of the RF response. Additionally, the integrated spot-size converter increases fiber-coupling efficiency as well as alignment tolerance. This key differentiating feature of the technology and product enables the PIN detectors to be passively placed on the receive side of an optical interposer without compromising coupling efficiency, says POET Technologies. This approach is expected to result in lower production costs during volume manufacturing.

The firm has been able to demonstrate fiber-coupled responsivity in excess of 50%, meeting the initial requirements for a receive optical engine. The integrated waveguides are also engineered to exhibit low polarization-dependent loss (PDL) — a key requirement for PIN photodiodes.

POET is working to provide engineering samples for its PIN photodetectors by mid-2018 for use in its receive optical engines. Engineering samples of its receive optical engines will utilize the new Optical Interposer Platform.

www.poet-technologies.com

Lumentum's record quarterly revenue driven by VCSEL array ramp for 3D sensing in consumer mobile

VCSEL and edge-emitting laser capacity being expanded to meet expected demand in second-half 2018

For fiscal second-quarter 2018 (to 30 December 2017), optical and photonic optical component and subsystem maker Lumentum Holdings Inc of Milpitas, CA, USA has reported record revenue of $404.6m, up 66.4% on $243.2m last quarter and 52.7% on $265m a year ago (and well above the $345–375m guidance). Growth was driven by the ramp of 3D sensing vertical-cavity surface-emitting laser (VCSEL) arrays, telecom pump lasers and reconfigurable optical add-drop multiplexers (ROADMs), and strong demand for commercial lasers (both micro-machining and kilowatt laser products). There was record revenue for nearly all laser product lines.

Optical Communications revenue was $360.1m (89% of total revenue), up 73.2% on $207.9m (85.5% of total revenue) last quarter and up 52.2% on $236.6m (89.3% of total revenue) a year ago.

Of this, Telecom revenue was $110.2m, flat sequentially and down 31% on $160.1m a year ago. However, revenue for ROADMs rebounded by 22% quarter-on-quarter (with North American customers having worked down their inventories from prior quarters, and China rising to about 20% of shipment volume). Also, Telecom pump laser sales achieved record revenue. Datacom revenue was $34.4m, down 24% on $45.2m last quarter and 49% on $68.1m a year ago (with coherent components and datacom transceivers declining sequentially). Consumer & Industrial revenue was $215.5m (including over $200m in 3D sensing — well above expectation, after rapidly expanded 3D sensing VCSEL capacity and production volumes). This is up 312% on $52.3m last quarter (about $40m in 3D sensing) and over 2000% on just $8.4m a year ago. This also includes record revenue for industrial diode lasers, driven by strong demand from customers building material processing tools (including kilowatt glass-fiber lasers using Lumentum's pump lasers).

Commercial Lasers revenue was a record $44.5m (11% of total sales), up 26.1% on $35.3m (14.5% of total sales) last quarter and up 56.7% on $28.4m (10.7% of total sales) a year ago, driven by both micro-machining and kilowatt laser products (due to strong demand from equipment used in the production of next-generation consumer electronic devices such as new smartphones and wearables, which are increasingly using components that require laser-based processing).

"The steep production ramp and our consistently high yields were enabled by our proprietary laser design and production capabilities that have taken us years to develop," says president & CEO Alan Lowe. "We have irreplaceable learnings and volumes of field data from multiple high-volume 3D sensing ramps. This, along with our decades of experience supplying laser diodes into the industrial and subsea communication markets, allows us to produce high-performance, highly reliable volumes of lasers," he adds. "Our laser chip and manufacturing processes are specifically designed to enable the short-design cycles and high-volume production ramps needed by the fast pace of consumer electronics customers. These requirements are quite different from those of other customers in the industrial and communications market. We spent nearly a decade developing unique capabilities to address the 3D sensing market."

Laser chip and manufacturing processes are specifically designed to enable short-design cycles and high-volume production ramps

Gross margin (on a non-GAAP basis) was 44.9%, up from 34% last quarter and 36.9% a year ago. This was particularly due to the favorable product mix and improved operating leverage from higher volumes in Optical Communications, for which gross margin was 45%, up from 34.7% last quarter and 36.6% a year ago (driven by 3D sensing gross margin significantly above the historical corporate average). Commercial Lasers gross margin was 44.7%, up from 30% last quarter and 39.4% a year ago (returning to the mid-40% level, consistent the longer-term target of 50%).

Operating expenses were $67.2m, up from $54.1m last quarter and $58.9m a year ago, due mainly to investments in new product programs, infrastructure investments to support growth, and variable incentive compensations, with research & development (R&D) expense rising from $35.4m to $38.9m and selling, general & administrative (SG&A) expense rising from $23.5m to $28.3m. However, as a percentage of revenue, operating expenses been cut from 22.2% to 16.6%.

Demonstrating the strength of the firm's operating model as volume increases, operating income was $114.6m (operating margin of 28.3% of revenue), up from $28.6m (11.8% margin) last quarter and $39m (14.7% margin) a year ago.

Likewise, net income was a record $107.8m ($1.67 per diluted share), up from $27.8m ($0.43 per diluted share) last quarter and $35.9m ($0.57 per diluted share) a year ago.

Capital expenditure (CapEx) was $26m (level with last quarter but down from $35m a year ago). During the quarter, cash and short-term investments hence rose by $92m, from $532.5m to $624.5m.

During the quarter, Lumentum continued to book new 3D sensing orders and exited the quarter with a solid order backlog for deliveries through June.

However, given the company's consumer electronics-oriented 3D sensing customer mix, for the seasonally lower fiscal third-quarter 2018 (to end March) Lumentum expects revenue to fall to $280–305m, with 3D sensing down significantly. Non-3D sensing revenue should rise by $25m sequentially to $35m, including $20m growth for ROADMs and telecom pump lasers plus (with demand outstripping what the firm can supply) $5m growth for Commercial Lasers to exceed $50m (a target that's been pursued for a long time). ROADM revenue will be up for both the USA and China.

Lumentum expects operating margin to fall to 15.5–18% and diluted earnings per share to fall to $0.65–0.80.

Revenue should include contributions from new 3D sensing customers in the Android space, including some who have designed in Lumentum's newest high-performance edge-emitting lasers. "These new opportunities are in the early stages and are only expected to contribute a few million dollars," notes Lowe. "These new customers are expected to drive far more business as we look to our fiscal 2019 and beyond," he adds. "Our proven capabilities position us well for the future as demand for our industrial lasers and ROADMs is strengthening, and 3D sensing opportunities are broadening to more customers and end markets… Consumer electronic manufacturers throughout China, Korea and North America are looking to 3D sensing to enhance security, to enable augmented and virtual reality and to add other new functionality. Given the volume that these manufacturers produce, it is not difficult to imagine the annual market for 3D sensing lasers to exceed $1bn in the next year or two. To capitalize on these market opportunities, we are rapidly ramping our R&D investment in 3D sensing and in additional manufacturing capacity for VCSELs and edge-emitting lasers. Given the lengthy qualification times, we are already in the process of qualifying new equipment to permit even higher production starts in our fourth quarter for first-half fiscal 2019 deliveries."

"We expect strong North American ROADM demand to continue in the quarters ahead. Chinese demand for ROADMs will grow throughout calendar year 2018 and 2019 as China continues its march towards large-scale domestic deployments [building out networks in many of the large cities]," says Lowe. "We are adding capacity for ROADMs today, so I would expect our ability to get a new peak level of ROADM revenue this year is very highly likely."

Finally, demand continues to be strong for both micromachining and kilowatt fiber laser product lines, so Lumentum expect Commercial Lasers to be on a growth trajectory over the coming quarters.

Lumentum showcases 3D sensing solutions at Photonics West

At the SPIE Photonics West 2018 event in San Francisco (30 January – 1 February), Lumentum showcased its latest photonics-based products supporting the dynamic 3D sensing, industrial diode laser and commercial laser markets.

3D sensing

Lumentum has a wide range of diode laser products for 3D sensing applications and has developed partnerships with companies supporting the growing 3D sensing market. Several of these had information and displays of products incorporating Lumentum's diode lasers in the Lumentum booth.

Lumentum partner Himax, with its SLiM module for mobile device platforms, incorporates a Lumentum diode laser, wafer-level optics (WLO), laser drivers, diffractive optical elements (DOE) and additional semiconductor components for Face ID facial authentication.

Another 3D sensing partner, Orbbec, uses Lumentum diode lasers in its Astra Mini camera. This highly compact platform is suitable for a wide range of settings, including gesture control, robotics, 3D scanning, and point cloud development for mobile devices ranging from schools to industrial environments, and even retail locations.

Lumentum diode lasers support Occipital's Structure Sensor for mobile devices and enable applications such as 3D scanning, large-scale 3D mapping of rooms and buildings, and inside-out positional tracking for AR/VR headsets. Occipital also uses Lumentum diode lasers for its Bridge headset for mixed-reality, where users can see virtual content mixed seamlessly with their real-world environment.

Pump lasers

Lumentum's fiber-coupled pump lasers are used worldwide in demanding industrial applications including fiber-laser pumping and materials processing.

The ST2 200W fiber-coupled diode pump laser is now in high-volume production and deployed at customers globally. Introduced at Photonics West 2017, the ST2 recently completed a 10,000-hour reliability test ensuring endurance and power stability to withstand prolonged use in harsh manufacturing settings. Lumentum also has a full portfolio of fiber-coupled devices leveraging the low-cost L4 platform.

www.lumentum.com/en/3d-sensing
www.lumentum.com/en/products

Oclaro's quarterly revenue falls 10% driven by CFP and QSFP client-side 100G transceiver modules

Revenue to bottom in March quarter before June-quarter recovery led by CFP2-ACO sales

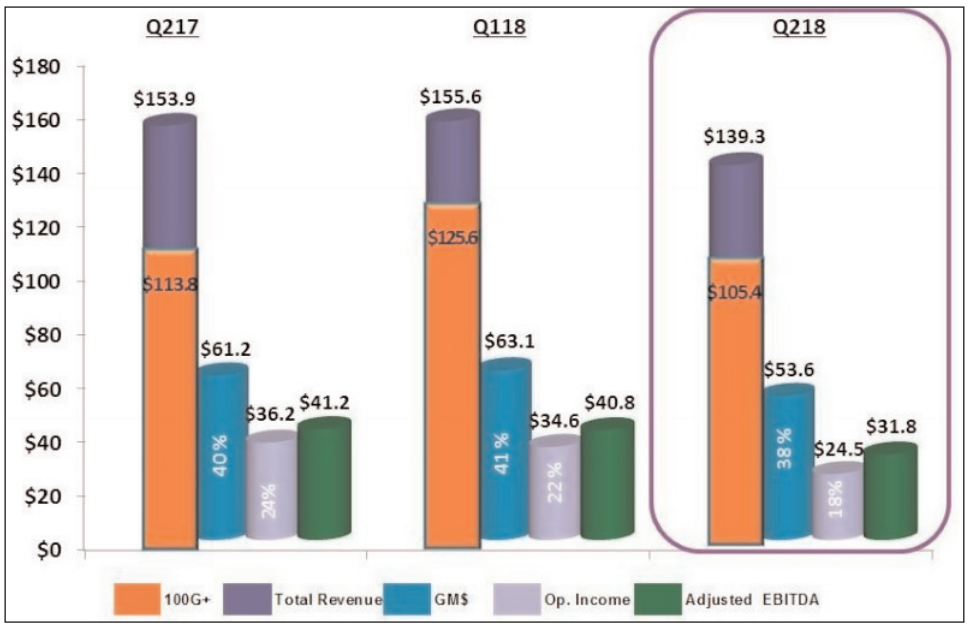
For its fiscal second-quarter 2018 (ended 30 December 2017), Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications) has reported revenue of $139.3m (split about 47%:53% between client-side/datacoms and line-side/telecoms). This is down 10% on $155.6m last quarter and 9.5% on $153.9m a year ago.

Sales of 100G-and-above products fell by 16% from $125.6m (81% of total revenue) last quarter to $105.4m (76% of total revenue). Client-side 100G transceiver modules fell, with both the CFPX and QSFP families down by $7m each (after peaking last September with sales to a web-scale customer). Revenue for the CFP2-ACO (analog coherent optics) family was down by about $12m (although most of this should recover in the March quarter).

Sales of 10G & 25G products grew by 13% from $30m (19% of total revenue) to $34m (24% of revenue).

After falling for three consecutive quarters, China has rebounded from 27% of total revenue last quarter to 37%, while Europe, the Middle East & Africa (EMEA) rose from 11% to 17% as the Americas fell back from 47% to 32% and Southeast Asia was roughly level at 14%.

"China was a bright spot in the quarter, as we saw sequential revenue growth there for the first time in a year," says CEO Greg Dougherty. Sales in the region rose by 20% on last quarter, driven by three factors: (1) a large customer had a very strong December for vendor-managed inventory (VMI) pulls for several coherent components and tunable products (due to their desire to have inventory to carry them through Chinese New Year, so this level of demand is unlikely to continue in Q3 and Q4);



(2) there was an increase in non-Chinese customers using Hong Kong as a staging hub; and (3) there was increased demand from Chinese transceiver customers for 10G and 25G laser chips.

On a non-GAAP basis, gross margin was 38.4%, down from 40.6% last quarter and 39.8% a year ago (although towards the higher end of the 36-39% guidance).

Operating expenses have risen further, from $25m (16% of sales) a year ago and $28.5m (18.3% of sales) last quarter to $29.1m (20.9% of sales).

Operating income was $24.5m (operating margin of 17.6%), down from $34.6m (22% margin) last quarter and $36.2m (24% of sales) a year ago (although above the $19–23m guidance).

Likewise, net income has fallen further, from $36.3m ($0.21 per diluted share) a year ago and $34.5m ($0.20 per diluted share) last quarter to $23.1m ($0.14 per diluted share).

Adjusted EBITDA (earnings before interest, taxes, depreciation and amortization) was $32m (down from $40.8m last quarter and $41.2m a year ago). This was mostly offset by capital expenditure (CapEx) of $16m and working capital of $4m. Free cash flow was hence $10.3m. During the quarter, cash, cash equivalents and short-term investments therefore rose from $279.8m to $290.1m.

For fiscal third-quarter 2018 (ending 31 March), Oclaro expects revenue to bottom out at $120–128m (down from $164m a year previously), due to: (1) annual price negotiations taking effect (typically involving a 10–15% reduction); (2) a further $6m drop in client-side CFP family sales, levelling off at about $10m per quarter (compared with a peak of about $44m in the March 2017 quarter); (3) a drop of another $7m in sales for the QSFP28 family as demand from the web-scale customer falls again (due to their inventory situation) — amounting to a $13m drop for 100G client-side transceivers (CFP and QSFP families) collectively; and (4) a drop of about $10m in 10G and 100G telecom product revenue (as Chinese customers continue to burn off their inventory built up in the December quarter).

Countering these headwinds, the primary growth driver is expected to be a recovery in revenue for the CFP2-ACO family. "Some competitors have entered the market recently, but we have seen very little erosion of our market share," says Dougherty. "Our market position is solidified by the long-term contracts that we have signed with major ACO customers." Oclaro recently signed another contract extension with a key customer. Since fiscal Q2's drop in sales was primarily due to market conditions, Oclaro expects fiscal Q3 ACO revenue to return to September 2017 levels and to show year-on-year growth in calendar 2018 while maintaining good gross margins. "We are also hearing from our customers that Verizon's metro builds are accelerating," Dougherty notes.

Oclaro also expects to see initial revenue from its 200G ICT/ICR product (integrated coherent transmit/receiver components, currently used in-house in Oclaro's CFP2-ACO module) as it begins shipping to a large Chinese customer for their in-house DCO (digital coherent optics) builds. "By leveraging the performance and integrated small size of our components, we are enabling our customer to come to market with the DCO to be used within their communications equipment," says Dougherty.

In fiscal Q3, gross margin should fall to 34–37%. Operating income is expected to fall to $13–17m (12% of sales).

"As the headwinds facing the industry begin to subside, and we ramp new products, our revenue is expected to resume growth in the June quarter [up 5% sequentially]," says Dougherty. "We expect to see growth in a variety of products in both the telecom and datacom sectors."

"In telecom, we expect the major growth drivers to be our ACO and 400G families. These are used in metro in DCI [data-center interconnect] applications. Also, as China begins building their own DCO transceivers, we expect to see growth for our ICT/ICR and tunable laser components," says Dougherty. Revenue from the 10G and 25G product lines should remain at the $30m per quarter level for the next few quarters. "Support for this sales level comes from our industrial-temperature-range 25G transceivers for 5G front-haul applications and our tunable 10G SFP+ for cable remote 5 and metro. These products are expected ramp over second-half 2018," he adds.

"In Datacom, we expect high-speed laser chip sales and the introduction of our new 400G PAM4 transceivers to be the major growth elements," says Dougherty. Oclaro expects revenue for 100G client-side transceivers (CFP and QSFP families) to remain sequentially flat for the balance of calendar year 2018. "The vast majority of our QSFP28 revenue currently comes from the 100GBASE-LR4 products. For QSFP CWDM4, we continue to see very unhealthy pricing practices in the market from many of the lower-spec variants. As a result, we have decided that we will focus only on supplying our existing customers. By eliminating our exposure in this market, we do not expect to add any more capacity for CWDM," he adds. "Instead, we will try more focus on selling high-speed laser chips to strategic customers. We expect to see solid growth in 25G chip sales, in second-half 2018, benefiting our gross margin profile with a much richer product mix."

Oclaro also expects to start seeing revenue for 400G intra-datacenter transceivers. The global market for 400G QSFP56-DD (double density) transceivers is projected to be $280m in 2019 and to grow to $720m in 2020. "By leveraging our EMLs, we will have a very strong market position in this emerging area," believes Dougherty. Oclaro aims to begin shipping PAM4-enabled QSFP56-DD transceivers later in calendar year 2018.

At the Optical Fiber Communication Conference & Exposition (OFC 2018) in San Diego (11–15 March), Oclaro will exhibit its new DCO modules, its 400G QSFP56-DD transceivers, its family of 400G and 600G coherent optical components, and its family of directly modulated lasers (DMLs) and electro-absorption modulated lasers (EMLs) for use in datacenters.

Oclaro continues to expect CapEx of $55–65m for fiscal 2018 (including about $16m in the March quarter), with an exit rate in June of about $10m per quarter with the completion of fab expansion work.

For calendar year 2018, Oclaro expects gross margin in the high 30s (37–39%), operating expenses of $30–32m per quarter, and double-digit percentage operating income.

"A bit further out to the end of 2018, we are developing a family of DCO modules that are expected to begin shipping for revenue early in calendar year 2019," says Dougherty.

www.oclaro.com

Oclaro hires Jankovic from Celestica to replace Optical Connectivity president Yves LeMaitre, promoted to chief strategy officer

Oclaro has promoted its Optical Connectivity president Yves LeMaitre to chief strategy officer.

Consequently, Walter F. Jankovic has been hired as president, Optical Connectivity. Previously, at design, manufacturing and supply chain solutions firm Celestica Inc, he served in financial and operational roles at the Cisco Global business unit from June 2005 to December 2008; as VP & general manager from January 2009 to April 2012; as senior VP, Communications and ISP Markets from May 2012 to December 2016; and as senior VP, Advanced Industrial and Health Tech Markets from December 2016. Prior to Celestica, he served in financial roles at Nortel Networks from July 1992 to December 2004.

Emcore's quarterly revenue down 17.6% while awaiting qualification of L-EML RFoG micro-nodes

Continuing inventory overhang at largest cable TV customer to impact March quarter

For its fiscal first-quarter 2018 (to end-December 2017), 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 $24m (at the low end of the $24–26m guidance range), down 17.6% on $29.2m last quarter and 20% on $30.2m a year ago.

Of total revenue, chips comprised 9%, navigation 4%, and broadband 87%, including 72% cable TV (down from about 80% last quarter). Of the remaining broadband business, Emcore saw steady demand for Satcom products. So, total non-cable TV revenue comprised 28% of overall revenue (up from 21% for full-year fiscal 2017).

"With the broadband market and specifically CATV, in the fourth quarter we made a decision to exit the RF-over-glass [RFoG] micro-node market, while we await qualification of our third-generation L-EML [linear externally modulated laser] RFoG micro-nodes," says president & CEO Jeff Rittichier. This action drove a drop of about $4m in cable TV product revenue (which is expected to continue through fiscal Q2).

In addition, at the end of the quarter Emcore saw delivery push-outs for some products due to an inventory bubble at one of its largest cable TV customers. "This situation resulted from a transition at one of our customers from EMS to in-house manufacturing," says Rittichier. "Significant transmitter buffer stock was built to mitigate the risks of moving the factory and several months' worth of laser inventory were also consolidated, resulting in a large overall inventory level," he adds.

"Our CATV business met some headwinds at the tail end of the quarter which damped down revenue, while our Chip and Navigation businesses performed well," says Rittichier. "Emcore made solid progress with increasing momentum in our end-market diversification strategy, offsetting a portion of the sequential CATV softness," he adds. "One of our most important objectives this year revolves around building revenue diversity, and this past quarter represented important evidence of our progress towards this goal."

Emcore saw accelerating demand for 2.5G and 10G chip products within China (expected to continue into fiscal Q2). Chip product revenue was above planned, with a projected return of certain telecom chips materializing as expected, driving fab utilization and contributing to corporate gross margin.

On a non-GAAP basis, gross margin was 33.6%, down from 36.9% last quarter, driven by lower volumes (which negatively impacted manufacturing overhead absorption), offset by a favorable mix shift of highly profitable cable TV products that began shipping last quarter. Also, this is level with a year ago, despite revenue falling 20% year-on-year, demonstrating the effectiveness of both cost-reduction efforts and operational improvements made over the last several years.

Operating expenses were $8.7m, down slightly from $8.9m last quarter but up on $7.8m a year ago. "We continue to invest in R&D [up from $2.2m a year ago to $3.8m] to accelerate delivery of new products across all three of our major product families," notes chief financial officer Jikun Kim. "We invested aggressively in new navigation, chips and cable TV products. The benefits of these investments are expected to meaningfully contribute to our revenues and gross margin percentage line in the future quarters," he adds. Otherwise, selling, general & administrative (SG&A) expenses have been cut from $5.6m a year ago and $5.2m last quarter to $4.8m, as Emcore works to hold down expenses while it works through the cable TV inventory headwind.

Operating income was $0.6m (operating margin of 2.5% of revenue), down from $3.3m (11.4% margin) last quarter and $3.5m (11.5% margin) a year ago.

Likewise, pre-tax income has fallen further, from $3.5m ($0.13 per diluted share) a year ago and $3.4m ($0.12 per diluted share) last quarter to $0.7m ($0.03 per diluted share). Capital expenditure (CapEx) was $2m (cut further, from $2.4m last quarter). Depreciation was $1.2m. During the quarter, cash and cash equivalents fell by $4.1m from $68.3m to $64.2m.

"At current demand levels, it will take about two quarters for our [CATV] customer to work through the inventory on hand," says Rittichier. "This will create a sequentially larger impact in the fiscal second quarter than the first, followed by shipments returning to normalized levels at some point during the fiscal third quarter."

Given the continuing RFoG market dynamics combined with the inventory overhang, for fiscal second-quarter 2018 (to end-March), Emcore expects revenue to fall further to $21–23m.

"While we still remain confident in our abilities to grow cable TV revenue on a sequential basis in Q3 and Q4 of 2018 through a combination of both average selling price (ASP) expansion with L-EML products and the resumption of RFoG shipments in the second half, we've

got to clear the inventory bubble first," says Rittichier. Emcore hence now expects cable TV revenue (including RfoG) to fall $23–27m year-on-year.

"The current inventory dynamic is in no way a reflection of the overall health of the cable TV market or the demand for our products," continues Rittichier. "Near-term demand volatility is a function of several factors: cable TV's high customer concentration, adverse weather (which limits installs in the winter) as well as infrastructure and CPE spending shifts. These factors combine to cause supply chain imbalances like the one we're experiencing now."

"Over the mid- to long-term however, big picture trends tend to hold, which is the case for DOCSIS 3.1 deployments and the migration to L-EML technology, which reflect quite favorably for Emcore," Rittichier believes. "End-market dynamics remain robust, with strong demand for transmission products as cable operators continue the deployment of DOCSIS 3.1 architectures, including transmitter, modules and receivers," he adds.

"Outside of the cable TV market, we continue to be enthusiastic about our revenue diversification initiatives," says Rittichier. "Emcore is taking important steps to be more than a cable TV business. The operational and technical foundations that we've built in the chip and navigation markets are ready to support rapid growth, and we've got the team that's necessary to build these businesses."

Emcore expects chip sales to be ahead of plan in fiscal Q2. "Sampling activity has also picked up with several different chips outside of the PON market, and several new development projects are moving forward for data -products with strong expressions of interest from customers," notes Rittichier. "The heart of the Emcore's business has always been optical semiconductor chips, and we're committed to driving growth in this business to make meaningful contribution to the business overall this year."

Emcore expects to see 33–37% of revenue come from non-cable TV products over the whole year, setting the stage for larger absolute growth in fiscal-year 2019. "We expect to do this while keeping our goal of 15% non-GAAP operating margin on a run-rate basis as we exit Q4."

www.emcore.com

Finisar demos VCSEL technology for 3D depth-sensing

At Photonics West in San Francisco (30 January – 1 February), fiber-optic communications component and subsystem maker Finisar Corp of Sunnyvale, CA, USA gave several demonstrations and product displays.

Finisar demonstrated vertical-cavity surface-emitting laser (VCSEL) arrays used in depth-sensing applications such as 3D facial recognition in consumer mobile devices. The firm also introduced a new high-speed photodetector and demonstrating WaveSource Programmable Laser technology from its test & measurement portfolio.

VCSEL technology offers advantages of superior performance over a large temperature range with a small footprint compared with traditional edge-emitting lasers, as well as high optical efficiency and fast response compared with LEDs. The technology has enabled many new applications including 3D facial recognition, augmented reality, automotive in-cabin sensing and LiDAR (light detection and ranging) for autonomous vehicles, using both structured light and time-of-flight (ToF) depth-sensing techniques.

Finisar's expertise in VCSELs stems from its roots with Honeywell when the technology was first commercialized in 1996. VCSEL reference designs will be released later in 2018.

"The adoption of VCSEL technology by the most successful companies in the world is extremely exciting, and, as the broadest-based optical company, Finisar is in the best position to capitalize on the opportunity," reckons Todd Swanson, executive VP of sales, marketing, and R&D. "With VCSEL advantages of superior performance and high optical efficiency, we have opened the doors to new market opportunities, specifically in consumer and automotive, that will transform security and safety."

New photodetector for high-power applications

Finisar introduced a new member of its high-speed photodetector product family. The 20GHz Ultra-high RF Power Detector features what is claimed to be the highest RF output power on the market for devices with a similar operating frequency. With ultra-high RF output power and uncooled operation, the product opens up new applications areas.

Typical applications include radio over fiber, analog photonic links, and microwave photonics. The device is based on an MUTC (Modified Uni-Traveling Carrier) photodetector chip capable of delivering up to 23dBm RF output power, and enables cost savings for the end-user by removing the need for expensive and power-hungry RF amplifiers, says Finisar.

WaveSource technology demonstration

Finisar also demonstrated its WaveSource Programmable Laser, which provides highly accurate wavelength scans as might be required in sensor systems and in optical component testing. Designed specifically for system integration as well as for applications in the optical lab, it covers the entire C-band and provides a high scanning speed beyond 300nm/s. The WaveSource Programmable Laser is demonstrated as part of a Terahertz Spectrometer System that has been set up in collaboration with the Fraunhofer Heinrich Hertz Institute (HHI) in Berlin, Germany.

www.finisar.com

Hanergy sets 25.1% efficiency record for GaAs solar production modules

Applications for thin, flexible solar power becoming broader and more critical

Hanergy Thin Film Power Group Ltd of Beijing, China says that German solar energy testing laboratory Fraunhofer ISE CalLab PV Modules has rated the newest solar production module of its US-based subsidiary Alta Devices of Sunnyvale, CA, USA as the highest-efficiency single-junction solar module ever produced.

With its record-setting 25.1% conversion efficiency, the module can be used to power a range of products such as unmanned aerial vehicles (UAVs), electric vehicles (EVs) and smart sensors that were previously limited by low-efficiency solar solutions.

The accelerating trend toward autonomous machines demands a power source that can be seamlessly recharged and has minimal impact on physical form, notes Hanergy. "Developing sources of power that can be replenished without interruption is increasingly important," says Alta Devices' chief marketing officer Rich Kapusta.

"Our goal with this module was to demonstrate world-record efficiency in mass production at commercial scale," says Dr Jian Ding, senior VP of Hanergy Thin Film and CEO of Alta Devices. "Applications for this type of thin and flexible solar power are becoming broader and more critical."

Alta's gallium arsenide (GaAs) modules perform at up to two times that of ordinary flexible solar cells, it is claimed, making them the current world leader in terms of module efficiency for thin-film solar technology. Since 2010, Alta's GaAs single-junction cells have broken conversion efficiency records four times and still hold the (lab) conversion efficiency record of 28.8%.

Alta's thin-film solar panels have been applied to a range of different products. On the transportation side, Alta Devices has worked with a European car maker to integrate solar cells into panoramic glass automobile roofs. Also, Alta Devices has made progress towards solving a 'pain point' of traditional UAVs by applying the highest-efficiency GaAs thin-film solar cell to develop a UAV with record flight time. In particular, as they are light and flexible, the thin-film panels were integrated into the drone without altering its aerodynamic profile.

www.altadevices.com

First Solar to build largest solar facility in Southeast USA

First Solar Inc of Tempe, AZ, USA — which makes cadmium telluride (CdTe)-based thin-film photovoltaic modules as well as providing engineering, procurement & construction (EPC) services — is set to proceed with development and construction of a 200MW$_{ac}$ photovoltaic (PV) solar power plant in Twiggs County, GA. First Solar was awarded the installation as part of a 525MW$_{ac}$ Request for Proposals for Georgia Power's Renewable Energy Development Initiative (REDI).

"Georgia Power's significant commitment to renewable energy, paired with Twiggs County's strong leadership and supportive business environment, combine to serve as a great example of how solar can be seamlessly included in the region's energy mix," says Kathryn Arbeit, First Solar's VP of project development – Americas.

The project is currently in an advanced development stage, and is being developed under a power purchase agreement (PPA) with Georgia Power for the electricity and renewable attributes generated by the facility. Construction is expected to begin in November. Upon completion and commissioning (in late 2019), this should be the largest stand-alone PV solar plant in the southeastern USA.

"We are committed to working with the Georgia Public Service Commission to create programs, like REDI, that help grow renewable energy in Georgia," says Wilson Mallard, Georgia Power's director of Renewable Development. "Recently completed large-scale solar projects across Georgia are serving customers today, and the Twiggs County project will be the latest addition," he adds.

The project will be built on 2000 acres of land near Warner Robins, GA. Using over half a million First Solar modules, the power plant is expected to generate more than 450GWh of electricity annually. It will also be the largest infrastructure project in Twiggs County, which will see the economic benefit of 300–400 jobs during construction and ongoing tax revenues from the project.

www.firstsolar.com

First Solar partnering with Arizona Public Service on 50MW solar-fueled battery storage project

Phoenix-based Pinnacle West Capital Corp subsidiary Arizona Public Service and cadmium telluride (CdTe) thin-film photovoltaic module maker First Solar Inc of Tempe, AZ, USA say they are bringing what is claimed to be a first-of-its-kind 50MW solar-fueled battery to the desert to provide renewable energy to Arizonans on hot summer days. The project will include one of the largest battery storage systems in the USA. The design models how the future of solar and storage can work together to supply power during peak hours.

First Solar will build and operate the flagship facility, which includes a 65MW solar field to charge the battery. A 15-year power-purchase agreement with First Solar will enable APS to use the stored battery power when energy use is at its peak later in the day.

By pairing solar energy with advanced battery technology, First Solar and APS will be able to store power when the sun is high in the sky and deliver it to customers at 3–8pm when the sun is on its way down but energy use is peaking, enabling APS customers to get more of their peak power from solar.

The project adds to the more than 1 million solar panels and three grid-scale batteries currently on APS's system. Over the next 15 years, the firm plans to adopt more than 500MW of additional battery storage.

By pairing solar energy with advanced battery technology, First Solar and APS will be able to store power when the sun is high in the sky and deliver it to customers at 3–8pm when the sun is on its way down but energy use is peaking

"Partnering with an Arizona company such as First Solar to pair solar power with advanced battery storage is good for our customers and continues our state's national leadership in clean energy innovation," says APS' chairman, president & CEO Don Brandt.

For First Solar, the addition of battery storage to utility-scale solar allows the sun's power to be used in the evening when the energy is needed most (logical use of technology in a state that sees nearly 300 days of sunshine per year).

The project was developed in response to APS's request for peaking capacity resources to serve customers between the peak hours of 3–8pm during the hot summer months. APS has full use of the 50MW battery and is able to maximize hourly capacity until it is fully discharged. The facility is set to begin service to customers in 2021 and will be built directly adjacent to the existing APS Redhawk Power Plant in western Maricopa County.

www.firstsolar.com

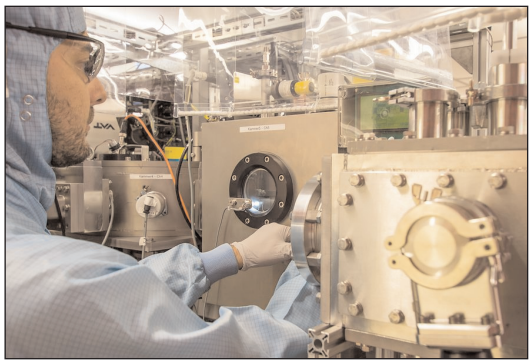
ZSW and IPVF agree five-year CIGS PV collaboration

Franco-German research alliance to boost efficiency and cut costs for flexible solar cells and modules

ZSW (Zentrum für Sonnenenergie- und Wasserstoff-Forschung — or Center for Solar Energy and Hydrogen Research — Baden-Württemberg) in Stuttgart, Germany and the Paris-based Institut Photovoltaïque d'Île de France (IPVF) have signed a deal (for an initial term of five years) forming a Franco–German alliance cooperating on energy research to develop the next generation of copper indium gallium diselenide (CIGS) thin-film solar cells.

ZSW has about 235 scientists, engineers and technicians employed at three locations in Stuttgart, Ulm and Widderstall, plus 90 research and student assistants. It is a member of the Innovationsallianz Baden-Württemberg (innBW), a group of 13 non-university, applied research institutes.

Founded in October 2013, IPVF is an industrial-academic partnership at the initiative of EDF and Total, CNRS and École polytechnique, and in association with Air Liquide, Horiba Jobin Yvon and Riber. It organizes partners' research activities in photovoltaic solar energy on a local, national and international level. With an initial budget of €150m, the project partly benefits from French public funding through the Investments for the Future Program under grant number ANRIEED-002-01. Within a new building on the Paris-Saclay campus, IPVF can host up to 200 PV researchers and offers 4000m^2 of lab space.



ZSW researcher in the CIGS lab.

The collaboration aims to optimize the upcoming thin-film photovoltaic technology, boost its efficiency and cut costs. CIGS cell efficiency has risen by 3.6 percentage points over the past five years. At 14–15%, CIGS thin-film solar modules sold today are challenging the silicon modules that dominate the market.

The researchers' agenda is to further exploit CIGS potential to strengthen and accelerate the deployment of photovoltaics. To reach climate protection targets, increasing the efficiency of PV modules at low costs in a short-term perspective is of key importance, they add.

The joint effort will focus on flexible solar cells and modules. The objective is to gain a deeper understanding of the processes in the solar cell and then increase cell efficiency. New materials and material combinations for flexible solar cells are also on the agenda, as is joint participation in research initiatives and an exchange program for the two institutes' researchers and doctoral students.

www.ipvf.fr/en
www.zsw-bw.de

XsunX expands direct marketing of solar + energy storage solutions to California's cannabis industry

XsunX Inc of Aliso Viejo, CA, USA, which designs and installs hybrid copper indium gallium (di)selenide thin-film (CIGS) photovoltaic (TFPV) solar power generation and energy storage technologies, says that, with the passage in January of California's Proposition 64 (Adult Use of Marijuana Act) legalizing recreational use of cannabis, it has begun work preparing a whole-facility energy management proposal for a grow operation preparing for its build-out, and is finalizing the launch of its direct marketing campaign to over 1000 additional cannabis operations in the state.

The legalization of cannabis has spurred an increase in grow operations in California, and XsunX aims to work with those operations interested in reducing their long-term energy costs. Creating more reason to reduce operating costs is the fact that, with legalization, wholesale cannabis rates have begun to dip.

"Cannabis operations, due to their inherent high power use, offer significant operating-cost-reduction opportunities for the use of solar + energy storage," says CEO Tom Djokovich. "We service all types of businesses, but the needs of the cannabis industry really excite us because our solar + energy storage managed solutions are so perfectly suited to help growers," he reckons.

XsunX says it is responding to the passage of California's Prop. 64, which legalizes recreational use of cannabis, and the anticipation that new cannabis operations will start plugging into the power grid. The California Public Utilities Commissions (CPUC) policy and planning division has engaged in research for the development of recommendations for its investor-owned utilities to prepare for a surge in energy use attributable to new cannabis cultivation.

www.xsunx.com

Ascent Solar's monolithically integrated thin-film PV modules selected by German Aerospace Center for further testing for deep space exploration

Ascent Solar Technologies Inc of Thornton, CO, USA - which makes lightweight, flexible copper indium gallium diselenide (CIGS) thin-film photovoltaic modules that can be integrated into consumer products, off-grid applications and aerospace applications - has been selected by the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt; DLR) for further testing to develop custom PV products designed specifically for its upcoming solar array deployment system.

DLR's new GOSOLAR project aims to test the deployment technology needed for a large-scale solar power generation system that will use a flexible photovoltaic membrane. Ascent's technology will allow DLR to address the challenging current requirements that come with this approach to solar-sail deployment in a gossamer formation. The use of Ascent Solar's patented monolithically integrated modules should allow DLR to implement their unique deployment design while maximizing the area that generates electrical power.

"We have been gaining traction in the deep space community, in part because we have a unique, lightweight and flexible product, but also because our monolithic integration offers greater design latitude that traditional crystalline products do not," says Dr Joseph Armstrong, chief technology officer and founding member of Ascent Solar. "We have demonstrated the ability to adjust the physical dimensions of our modules to meet the need of customers and, with unique deployment schemes employed by DLR, correctly sizing our solution to accommodate proper stowage and deployment is critical," he adds.

"Our design allows us to maximize the surface area of our award-winning solar technology while keeping the thin and lightweight profile of the deployed solar sails," says president & CEO Victor Lee. "We look forward to further development and testing with DLR in the coming years."

Ascent's modules selected by Japan Aerospace Exploration Agency for Jupiter deployment demo

Ascent Solar Technologies Inc of Thornton, CO, USA — which makes lightweight, flexible copper indium gallium diselenide (CIGS) thin-film photovoltaic modules that can be integrated into consumer products, off-grid applications and aerospace applications — has fulfilled a third order from the Japan Aerospace Exploration Agency (JAXA) for custom PV products designed specifically for JAXA's upcoming solar sail deployment demonstration project.

In this most recent purchase, JAXA placed the entire order, comprising of small area test cells and large, 19.5cm x 30cm monolithically integrated modules, all on a very thin, 25μm (0.001 inch) plastic substrate which is half the thickness of Ascent's production substrate for standard product. JAXA placed this order after achieving the desired experimental results from previous shipments and subsequent electrical, mechanical and environmental testing. The 19.5cm x 30cm module is a custom design to match the anticipated deployment mechanism and PV layout for the final Jovian spacecraft.

The deployment project is the next milestone of JAXA's evaluations of Ascent's PV in providing solar power for an upcoming mission to Jupiter and additional challenging missions under consideration. This decision followed earlier rounds of promising results, and the firm's flexible, monolithically integrated copper-indium-gallium-selenide (CIGS) solar module continued to operate well when being tested and subjected to the environmental extremes anticipated in deep space with significantly reduced solar insolation.

"JAXA's Jovian mission is a testament to the advancements being made in orbit, both in terms of its objectives, as well as the extremes in which the vehicle is required to operate," says CTO Dr Joseph Armstrong. "Our experience in fulfilling the latest order requires key process modifications that were necessary to provide those thinner modules in a production environment, and we are pleased to be able to successfully translate that into production. It is JAXA's intent to use the 19.5cm x 30cm modules in a deployment demonstration based on the agency's previous IKAROS (Interplanetary Kite-craft Accelerated by Radiation of the Sun) project that was demonstrated in orbit in 2010."

"Not only were we able to demonstrate a product of superior quality in the initial order, but we were able to take the challenge and deliver much thinner and lighter weight products in this order on the 25 micron substrate from our optimized production tooling to the same level of quality as our standard 50μm substrate product," says Ascent Solar's president & CEO Victor Lee.

www.isas.jaxa.jp/e/enterp/missions/ikaros/index.shtml

First perovskite solar cells applied to office buildings

Skanska Commercial Development Europe AB — a business unit of building and developer company Skanska Group of Stockholm, Sweden that develops sustainable, energy-independent office projects in Central Eastern Europe — reckons that, using technology provided by Saule Technologies of Warsaw, Poland, it will be the first developer worldwide to cover office buildings with semi-transparent perovskite solar cells on a commercial scale.

Established in 1887, Skanska employs 41,000 in Europe and the USA, working on 10,000 projects. Saule has pioneered the ink-jet printing of flexible, lightweight, semi-transparent perovskite solar modules.

With perovskite technology now ready to be integrated into building façades, Skanska will apply the test cells onto its projects in Poland in 2018. Under a license-based agreement, the developer has exclusive rights to use Saule's solar cell solutions in building façades and noise barriers across all Skanska markets worldwide (the Nordics, Europe and the USA). Skanska says that perovskite technology offers benefits for the developer, tenants and communities, such as favorable implementation costs, lower energy costs and consumption, and lower carbon footprints.

Saule has been working on ink-jet printing free-form perovskite solar modules since 2014. This technique allows the shapes and areas covered by each layer to be customized according to requirements. The stability and water resistance of the modules makes them suitable for the construction industry. Saule has conducted research on perovskite applications in solar energy harvesting and optoelectronics with universities in the UK, Israel, Germany, Italy and Spain. With a Japanese investor on board, along with support from the Polish National Centre for Research and Development and several research grants worth more than €20m, Saule is now working on a large-scale, prototype production line.

Example of Skanska's office building covered by semi-transparent perovskite solar modules. Perovskites are integrated into the property's façade without changing its design and aesthetics.

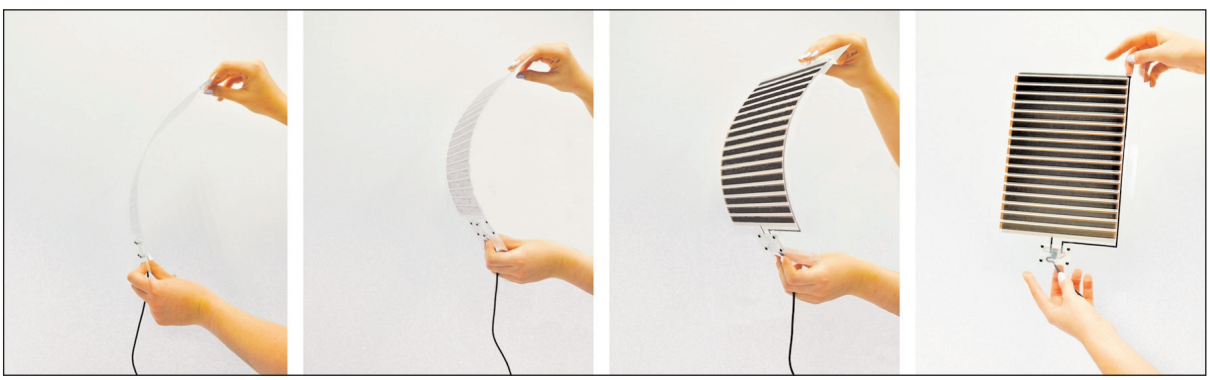
"Perovskite solar cells offer new opportunities to architects and construction companies willing to utilize solar power," says Saule's co-founder & chief technology officer Olga Malinkiewicz. "Our modules are lighter, thinner and much more design friendly than the most popular silicon solar cells," she adds. "We may customize the shape, color and size of the module depending on the needs of the customer and install them wherever there is a free area on the building. This also means not being limited to the roof."

While perovskite solar cell technology is being observed by organizations such as NASA, Skanska says that it has a chance to use it first to power office developments.

"Working with talented scientists from Saule, we are now turning fiction into reality and creating buildings which are more energy efficient and carbon neutral. Up to now this has not been possible on a large scale," comments Katarzyna Zawodna, CEO of Skanska's commercial development business in CEE. "Climate change is one of the biggest challenges the modern world is facing and it contributes to extreme weather events that are increasing in frequency and severity around the world. As such there is increasing legislative pressure to run businesses in a sustainable and attentive manner."

Skanska has been a signatory to the United Nations Global Compact since 2001. In 2009, as one of the first developers in CEE, Skanska introduced LEED certification to the office market, and announced the implementation of the WELL Building Standard in 2017. Usage of perovskite solar cells for zero-energy buildings is the latest innovation in Skanska's sustainable building strategy.

www.skanska.com/property



Printed, flexible, perovskite photovoltaics developed by Saule Technologies. The inkjet printing technique allows the design and production of free-form solar modules.

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Deep ultraviolet photonic crystal of AlGaN nanowires

Researchers hope structure will overcome poor light extraction of present light-emitting diodes with short wavelength less than 280nm.

Researchers based in the USA and Canada have used selective area epitaxy to develop arrays of aluminium gallium nitride (AlGaN) nanowires for deep ultraviolet (DUV) light emission [Xianhe Liu et al, Optics Express, vol25, p30494, 2017]. The team from University of Michigan in the USA and McGill University and McMaster University in Canada hope that their work will lead to more efficient DUV photonics. At present, AlGaN-based light-emitting diodes achieve external quantum efficiencies much less than 10%.

Applications of UV-C — less than 280nm wavelength — include water purification, disinfection, surface treatment, and medical diagnostics. AlGaN materials provide photon emissions in the energy range 3.4eV for pure GaN up to 6.2eV, corresponding respectively to wavelengths of 365nm and 200nm.

The researchers hope that regular 'photonic crystal' structures of AlGaN nanowires will boost efficiency, overcoming the unfortunate tendency of the light in high-Al-content AlGaN to be emitted with transverse magnetic (TM) polarization leading to in-plane propagation, inhibiting photon extraction. Theoretical studies suggest that light extraction efficiency can be increased to more than 70% with AlGaN nanowire photonic crystals.

Forming photonic crystals requires precise placement of nanowires through some form of selective-area epitaxy. The team comments: "To date, however, selective area epitaxy has not been successfully applied to Al-rich AlGaN nanowires, and there has been no demonstration of AlGaN nanowires emitting in the UV-C band by selective area epitaxy, which is partly limited by the high temperature (often >1000ºC) required for AlN epitaxy and the lack of a suitable growth mask."

Selective-area growth was performed on c-plane GaN-on-sapphire templates in a molecular beam epitaxy (MBE) system made by Veeco. A 10nm titanium mask was used with hexagonal apertures in a triangular lattice formation (Figure 1). After nitriding the mask, GaN nanowire templates were grown at 995ºC, according to sensors on the back-side of the substrate. The AlGaN part of the nanowire was grown at temperatures in the range 935–1025ºC. The shell of the nanowires was Al-rich, a feature expected to reduce non-radiative surface recombination of charge carriers.

By varying the AlGaN composition, a range of wavelengths — 210–327nm — was obtained in photoluminescence (PL) measurements.

LEDs with 280nm wavelength were fabricated from nanowires with 300nm of n-GaN, 80nm of n-$Al_{0.64}Ga_{0.36}N$,

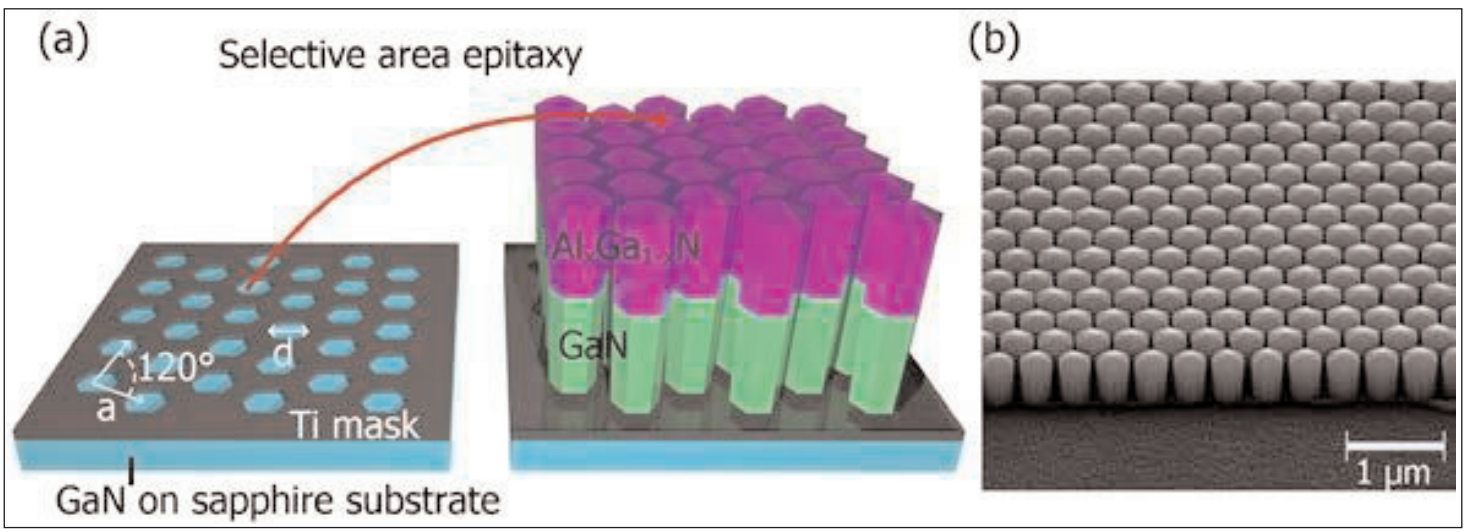


Figure 1. (a) Left: nanoscale aperture arrays defined by electron-beam lithography on 10nm thick titanium mask on c-plane GaN-on-sapphire substrate. Right: schematic of selective area epitaxy of GaN/AlGaN nanowires on patterned substrate. (b) Scanning electron microscope image of resulting GaN/AlGaN nanowire arrays.

Figure 2. (a) Current-voltage characteristics of AlGaN nanowire LED. Inset: same characteristics in semi-log scale. (b) Electroluminescence spectra of AlGaN nanowire LEDs measured under different injection currents. (c) Power density and peak position as a function of current density measured at room temperature under pulsed biasing condition.

30nm of undoped $Al_{0.48}Ga_{0.52}N$ and 60nm of p-$Al_{0.64}Ga_{0.36}N$. The undoped region constituted the active light-emitting part of the device. The growth used a substrate temperature of 1025ºC. The axial growth rate was ~150nm/hour. The nanowires also grew sideways, filling the air gaps of the lattice at a rate of ~20nm/hour.

The structure had a PL wavelength of 283nm and a linewidth of 11nm. The narrow width of the peaks indicates the improved uniformity over spontaneously grown nanowires. At higher excitation powers, the p-/n-AlGaN cladding layers contribute a peak around 255nm. Comparing low- and high-temperature PL responses suggested an internal quantum efficiency of 45% (or 49% at higher excitation power) at room temperature.

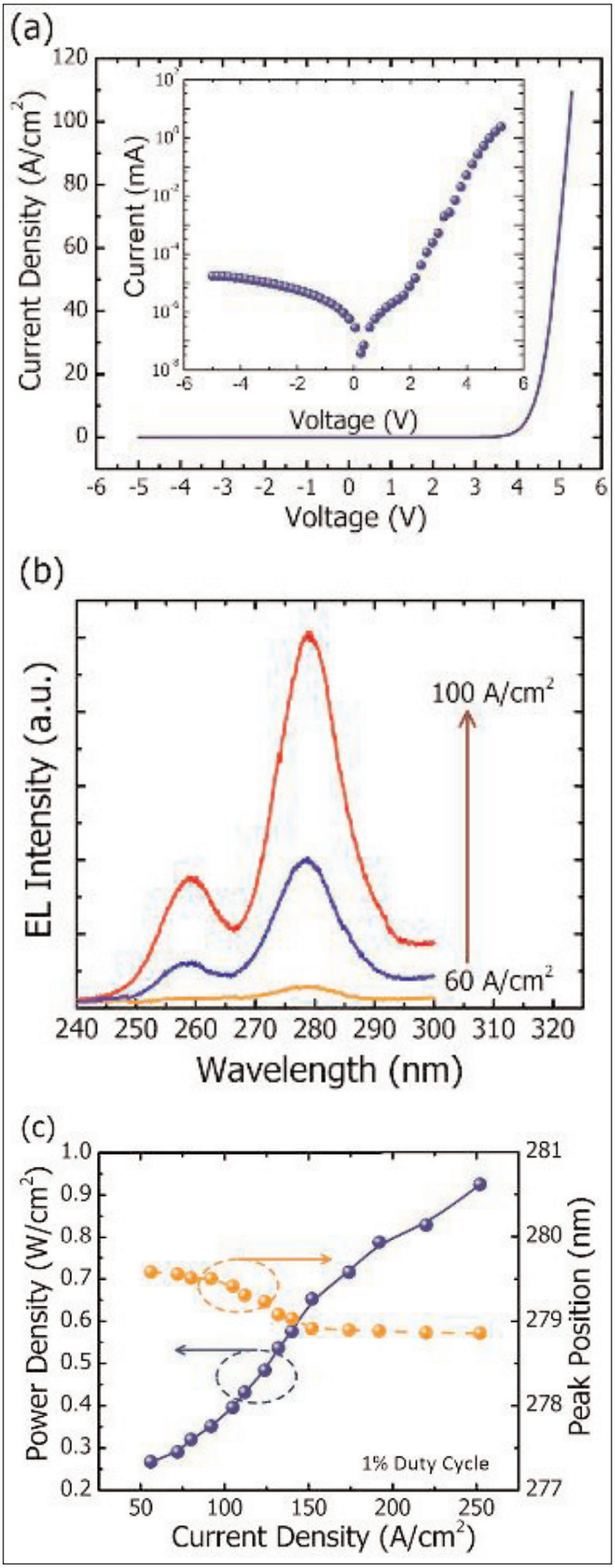
The LED fabrication consisted of spin-coating polyimide, etching back to reveal the tops of the nanowires, oxide removal with hydrochloric acid, and deposition, annealing and patterning of metal contacts — nickel/gold on the p-GaN and titanium/gold on the n-GaN layers. The p-contact metal was patterned into a grid.

A 50μmx50μm device had a turn-on voltage of 4.4V, and at 5V the current density was 100A/cm^2 (Figure 2). This performance is better than previously reported AlGaN quantum well LEDs operating at similar wavelengths, according to the team.

The peak wavelength was at 279nm with a very small blue-shift with increasing current — moving from 279.6nm at 50A/cm^2 to 278.9nm at 252A/cm^2. Some carrier overflow is evident in a weak emission peak at 260nm, which is attributed to recombination in the cladding (most likely on the p-side). The measurements avoided self-heating effects by pulsed operation.

The researchers estimate the output power at 0.93W/cm^2 with 252A/cm^2 injection. That would give a raw efficiency, not correcting for contact/series resistance, of the order 0.07% (0.93W/252A/5V), so much work needs to be done to get to 10% efficiencies.

The researchers comment: "The output power can be significantly increased by optimizing the nanowire size and spacing to achieve enhanced light extraction for TM polarized emission. Moreover, the device performance can be further improved by utilizing the scheme of tunnel junction to significantly enhance the hole injection and transport." ■



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Author: Mike Cooke

Reducing dislocations in GaAs on silicon templates

Researchers optimize GaAs grown by molecular beam epitaxy using on-axis gallium phosphide on silicon substrates.

University of California Santa Barbara (UCSB) in the USA has been working to optimize gallium arsenide (GaAs) molecular beam epitaxy (MBE) on gallium phosphide on silicon (GaP/Si) [Daehwan Jung et al, J. Appl. Phys., vol122, p225703, 2017]. Normally, growth of GaAs on Si uses off-axis substrates in efforts to avoid anti-phase domains. On-axis silicon is preferred for compatibility with CMOS processing foundries. The lattice mismatch between GaAs and silicon is ~4%, leading to dislocations.

The researchers managed to reduce threading dislocation densities (TDDs) to $7.2 \times 10^6/cm^2$, a factor of 40 lower than for an unoptimized process. They comment: "We believe that these high-quality GaAs buffer layers with low TDDs and smooth surfaces will serve as versatile templates for high-performance Si-based optoelectronic devices, including lasers and photodetectors as well as a myriad of photonic integrated circuits made from these devices."

The researchers used a commercial 300mm GaP/Si (001) template from NAsP III/V GmbH. The estimated unintentional miscut of the template was potentially only 0.1–0.2°. The silicon wafer was subjected to a special pre-epitaxial heat treatment designed to terminate anti-phase domains in the 45nm GaP layer.

The wafer was cut up into small pieces and put on molybdenum adapting plates in the Veeco MBE chamber. After oxide desorption, the growth began with 100nm GaAs at 400–550°C. The temperature was then raised to 600°C for 3μm GaAs layer growth.

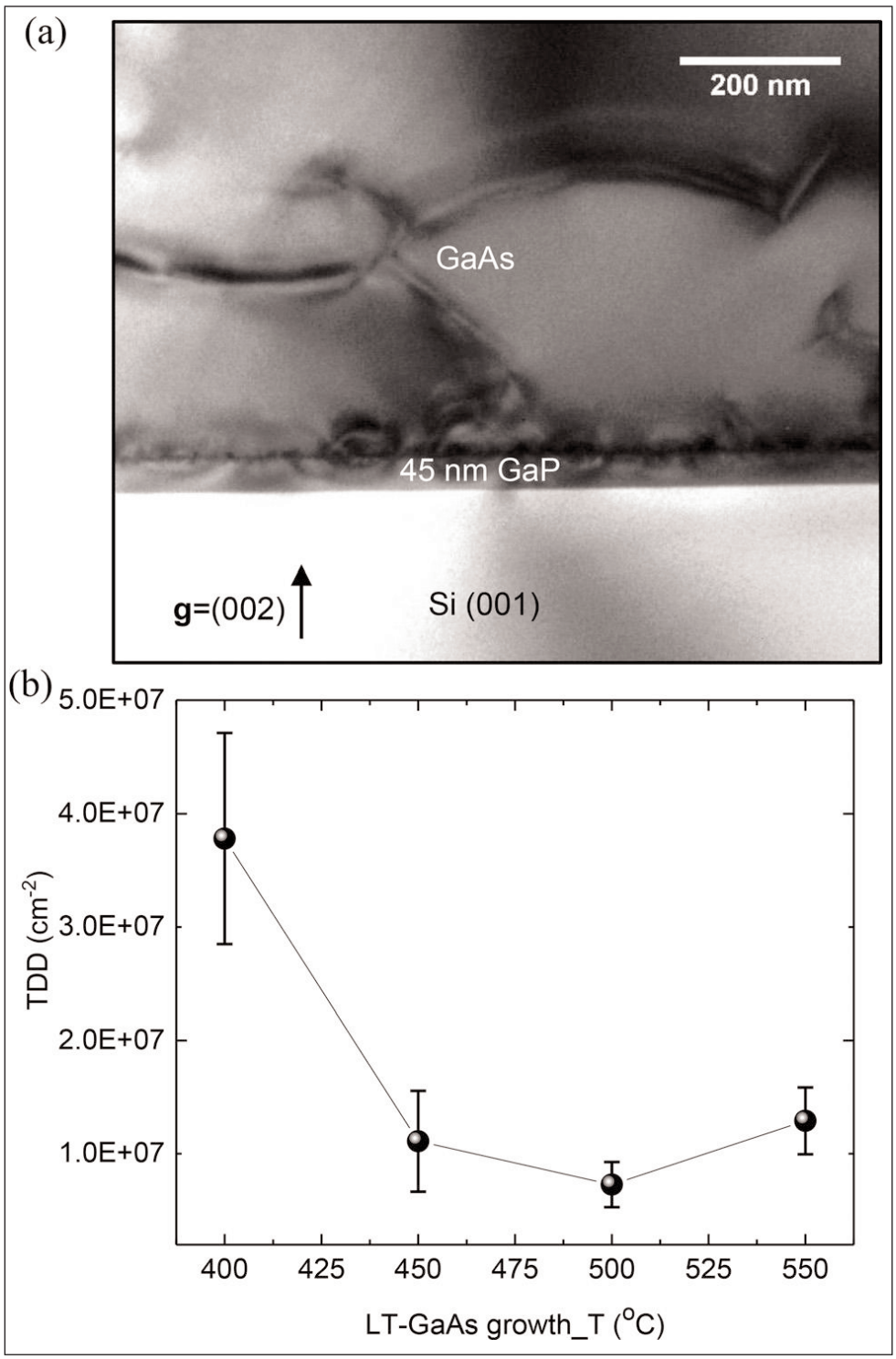

Figure 1, (a) Cross-sectional bright-field transmission electron micrograph of GaAs on GaP/Si. (b) TDD versus low-temperature-GaAs growth temperatures.

Electron channeling contrast imaging (ECCI) measurements gave a threading dislocation density (TDD) of ~$2.8x10^8$/cm^2 averaged over a 1800μm^2 area on a reference unoptimized GaAs/GaP/Si sample, which was consistent with results from more traditional plan-view transmission electron microscopy (TEM). ECCI allows dislocation density assessments over larger areas, reducing uncertainties. Root-mean-square (RMS) roughness of the reference was 7.8nm, according to atomic force microscopy (AFM) on 10μmx10μm fields.

Various optimizations were applied to the growth process: in-situ thermal cycle annealing, dislocation filter layers, and altering the growth temperature of the low-temperature GaAs layer.

The annealing consisted of 500°C low-temperature GaAs, 1.5μm high-temperature GaAs, 4x thermal cycling between 700°C and 320°C, and 1.5μm more high-temperature GaAs. ECCI measurements gave a TDD of $5.5x10^7$/cm^2. RMS roughness was 4.8nm. The team believes that the dislocations are removed by gliding and misfits fusing or annihilating.

A variety of dislocation filter layers were tested. The best involved 10 periods of 10nm indium gallium arsenide ($In_{0.1}Ga_{0.9}As$) and 10nm GaAs applied after thermal cycle annealing, giving $7.2x10^6$/cm^2 TDD and 2.9nm RMS roughness. The 200nm filter was capped with 1.3μm GaAs. The InGaAs was applied at 500°C. Somewhat lower TDDs of 1.2–$1.4x10^6$/cm^2 have been achieved with metal-organic chemical vapor deposition (MOCVD) on 4–6° offcut substrates. Also, higher annealing temperatures can be reached in MOCVD chambers.

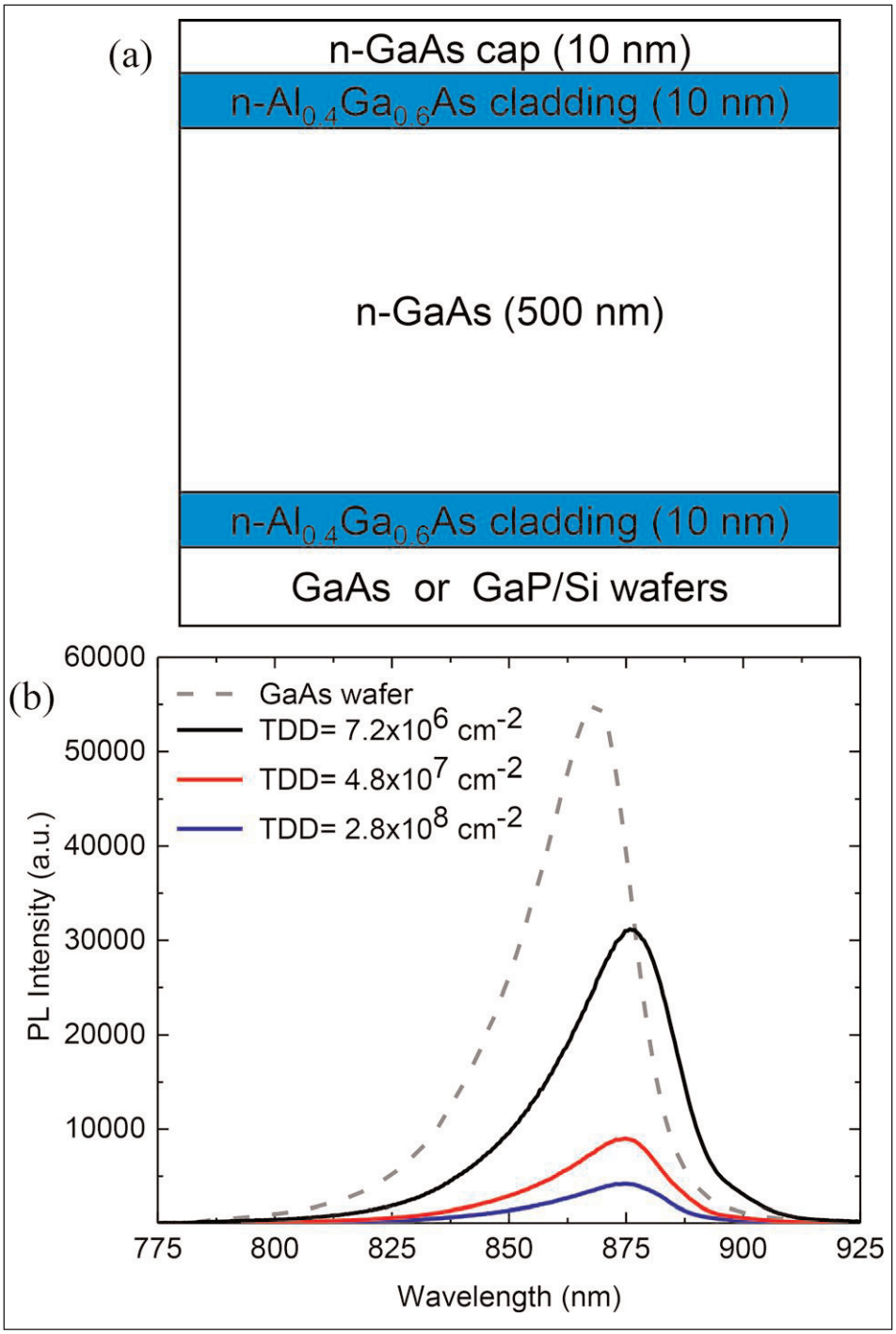

Figure 2. (a) Schematic of GaAs/AlGaAs PL structure. (b) Room-temperature PL spectra of GaAs PL samples grown on native GaAs, and three different GaAs/GaP/Si templates.

Variation of the low-temperature GaAs nucleation layer found that 500°C was optimal for a structure grown with thermal cycle annealing and InGaAs/GaAs dislocation filtering (Figure 1). Also adding extra dislocation filter layers (DFLs) increased the TDD level, while paradoxically decreasing roughness. The team explains: "We believe that adding more sets of DFLs nucleated more dislocations to relax the upper InGaAs/GaAs DFLs rather than recycling the pre-existing TDs."

Photoluminescence (PL) measurements were made on GaAs in aluminium gallium arsenide (AlGaAs) cladding structures grown on three GaAs/GaP/Si templates with TDDs varying between $2.8x10^8$/cm^2 and $7.2x10^6$/cm^2 (Figure 2). The researchers report: "It is noted that the integrated PL intensity from the optimized GaAs buffer layer is 7 times larger than the reference sample (TDD=$2.8x10^8$/cm^2). Compared with the GaAs layer grown on a native GaAs wafer, the optimized sample shows only ~40% reduction in the PL intensity at room temperature." ■

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Author: Mike Cooke

Integrating InGaAs transistor and III–V laser on silicon

Researchers in Singapore and the USA says that they have taken a step towards low-cost, low-power, high-speed optoelectronic integrated circuits.

Researchers based in Singapore and the USA have integrated indium gallium arsenide (InGaAs) transistors with aluminium gallium arsenide (AlGaAs) laser diodes (LDs) using molecular beam epitaxy (MBE) on silicon substrates [Annie Kumar et al, Optics Express, vol25, p31853, 2017].

The team from National University of Singapore, the Singapore–MIT Alliance for Research and Technology-Low Energy Electronic Systems, Nanyang Technological University in Singapore and Massachusetts Institute of Technology (MIT) in the USA are working towards low-cost, low-power, high-speed optoelectronic integrated circuits (OEICs). The same grouping of institutions reported in March 2017 transistor/LD integration on germanium substrate [www.semiconductor-today.com/news_items/2017/mar/nus_290317.shtml].

In their latest work, the Si (100) substrate was offcut 6°C in the (110) direction. The germanium (Ge) part of the buffer was grown in a three-step process, reducing the intentional doping to zero, which achieved a threading dislocation density of less than $5x10^6/cm^6$. The III–V layers were grown after 650°C annealing under ultra-high vacuum aimed at creating Ge double atomic steps on the surface of the buffer layer, designed to avoid anti-phase boundaries (APB).

The III–V growth was nucleated with 20 monolayers of GaAs grown at 300°C in low-temperature migration-enhanced epitaxy (MEE) to give good surface quality and to reduce APB-related defects. Further growth of the III-V heterostructure was carried out at 580°C. The laser active region consisted of a 5nm GaAs single quantum well with $Al_{0.3}Ga_{0.7}As$ barriers in graded-index separate-confinement heterostructures that varied in Al content between 30% and 60%, bridging across to the $Al_{0.6}Ga_{0.4}As$ crystal lattice of the cladding layers. Photoluminescence from the laser structure gave a peak wavelength of 788nm.

The transition to the transistor layers was achieved with an InAlAs buffer with indium content increasing from 0.1 to 0.52, giving a lattice matching with $In_{0.53}Ga_{0.47}As$ (the favored material for high speed transistors).

Device fabrication produced metal-first self-aligned gate transistors followed by laser diodes. The n^+ raised source drain contact metals were sputtered molybdenum and tungsten. Atomic layer deposition (ALD) formed

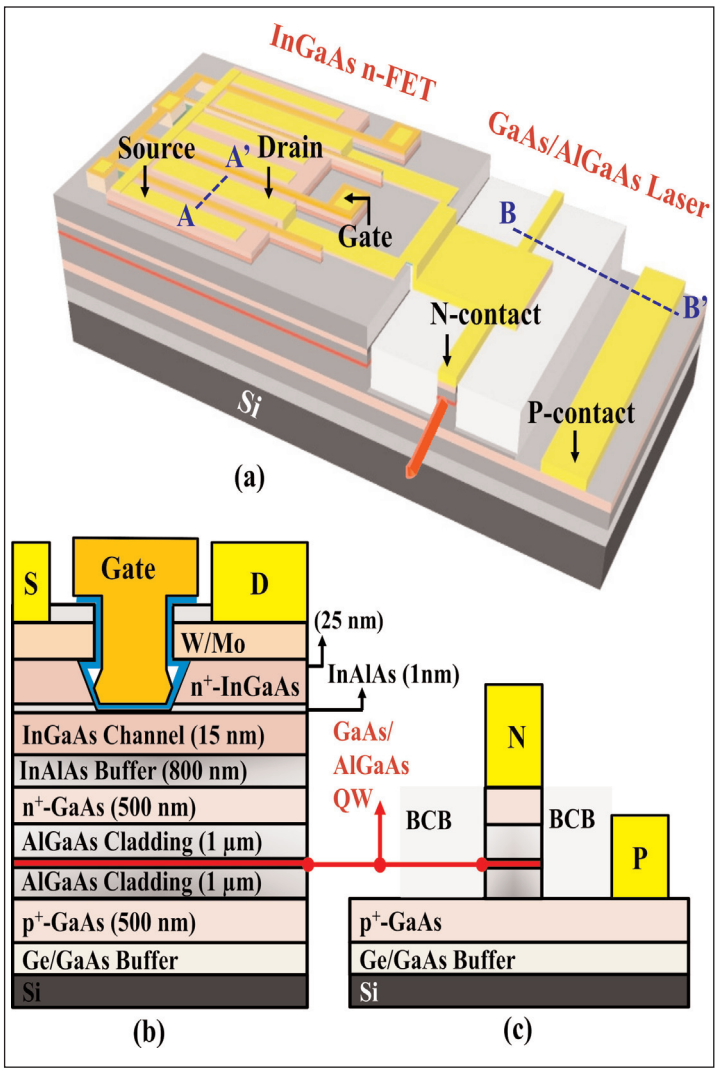

Figure 1. (a) Three-dimensional schematic of monolithic integration of self-aligned InGaAs MOSFETs and GaAs/AlGaAs QW laser on Si substrate. Drain of multi-finger transistor is connected to laser's n-contact. (b) Cross-sectional schematic of InGaAs metal-oxide-semiconductor field-effect transistors (MOSFETs) with detailed layer structure and thicknesses along line AA' in (a). (c) Cross-sectional schematic of GaAs/AlGaAs QW laser along line BB' of (a).

the high-k insulator part of the gate stack with 1.5nm aluminium oxide and 5.5nm hafnium dioxide. Molybdenum and tungsten were also used for the gate electrode. Mesa etching of part of the InAlAs buffer between the transistor and laser layers and plasma-

enhanced chemical vapor deposition (PECVD) of silicon dioxide passivation completed the transistor part of the fabrication.

Dry and wet etch opened up regions for laser fabrication. Further etching formed the laser structure. Smooth, vertical mirror facets were formed using 250°C plasma etch and PECVD silicon dioxide hard mask. The p-contact metals were titanium/gold. The structure was then planarized with benzocyclobutene (BCB). The top of the laser diode was exposed and annealed gold/germanium/nickel used as the n-contact stack.

Wiring connecting the transistor and laser were created by a metal lift-off process. The device wafer was finally thinned and diced. The fabrication process had a maximum temperature of 400°C. The researchers comment: "The low thermal budget of the overall process helped to maintain the high quality of the QW."

One of the transistors with a 420nm-long channel achieved an on/off current ratio of six orders of magnitude with both 50mV and 500mV drain biases. With 50mV drain the minimum subthreshold swing (S) was 82mV/decade. The threshold was at 50mV gate potential. The drive current was 455μA/μm with the gate 0.95V over threshold and 1V drain bias. The peak transconductance with 0.5V drain was 443μS/μm.

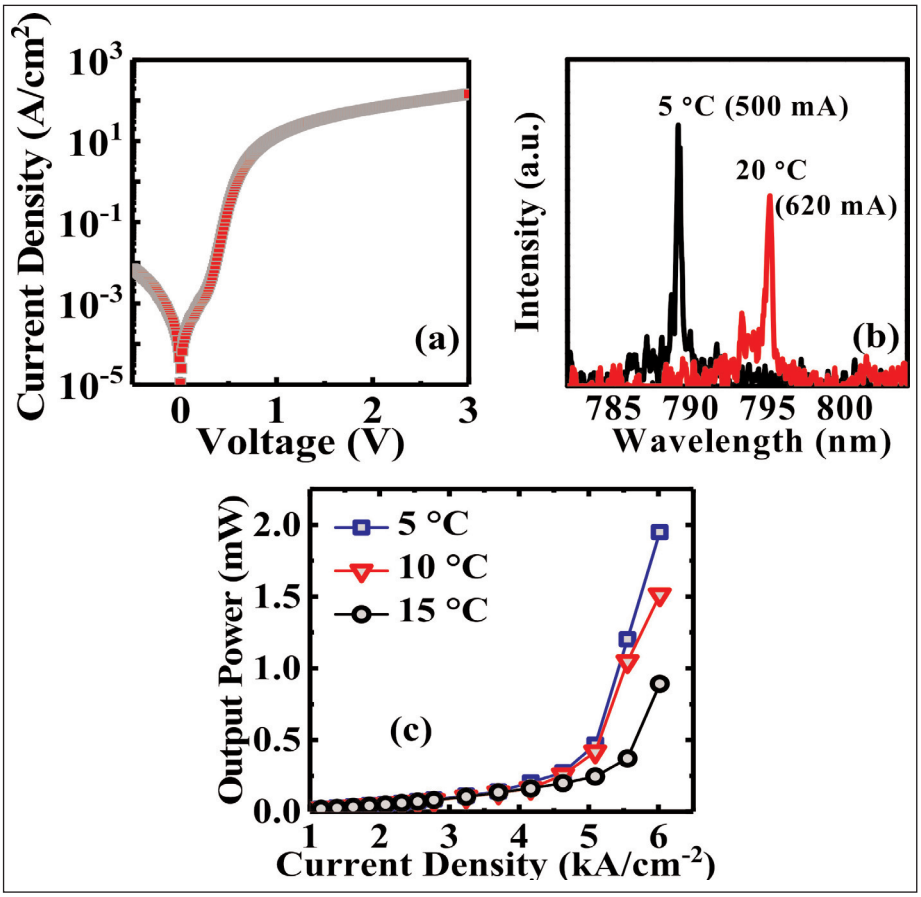

Figure 2. (a) Current density-voltage curve of GaAs/AlGaAs QW laser diode showing on/off current ratio of more than four orders of magnitude. (b) Lasing spectra at 5°C and 20°C at single-mode lasing currents of 500mA and 620mA, respectively. (c) Output power as function of current density for 540μmx20μm-wide laser at various operating temperatures.

Statistical work on a range of transistors showed an improvement in subthreshold after laser diode fabrication, with the mean falling from 107mV/decade to 81mV/decade. The researchers comment: "This improvement in S is attributed to post metal anneal (PMA) during SiO_2 deposition at 350°C which leads to reduction of interface traps at high-k/InGaAs interface".

The laser diode fabrication also improves threshold uniformity and puts it at a positive rather than negative value, due to a reduction in fixed positive charge in the high-k gate oxide stack, according to the researchers.

As for the laser diode performance, under pulsed operation single-mode lasing at 5°C and 20°C had full-widths at half-maximum (FWHMs) of 0.3nm and 0.35nm, respectively. The respective wavelengths were 789nm at 500mA current injection and 795nm at 620mA. The wavelength shift corresponds to the bandgap energy temperature shift of GaAs. The team comments: "Although the FWHM of around 0.3nm is wider as compared to lasers grown on native III–V substrate, it is less or comparable to III–V lasers epitaxially grown on Si substrate."

The threshold current density for a 540μmx20μm laser diode was 4.9kA/cm² at 5°C, higher than the team's previous III–V laser diodes on bulk germanium.

A combined circuit of transistor and laser diode with 2V operating voltage had a through current of the order of 15mA, much less than the 600mA needed for laser output. The researchers suggest that quantum dot devices could lower the laser threshold sufficiently for transistor modulation purposes.

The researchers point out another problem of the proof of concept in that the silicon substrate is not transparent to the produced light. Transparency would require narrower bandgaps for the active region as provided by InGaAs. The team comments: "As compared to the GaAs/AlGaAs system, using the $In_xGa_{1-x}As$/GaAs system with a higher Indium composition involves a higher lattice mismatch with respect to silicon and the challenge of growing such materials with low defectivity for laser fabrication on silicon need to be addressed." ■

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Author: Mike Cooke

Two-dimensional electronics for neuromorphic and other networking

Mike Cooke reports on work presented at December's IEEE International Electron Devices Meeting in San Francisco.

Atomic-scale layers are appearing in many levels of research towards the ubiquitous electronic social universe. Apart from creating smaller devices, the effort is also directed to the vaguely defined 'Internet of Things', where every electronic object has an IP address and even to the link-in of biological/neurological systems.

Many materials have a structure with strong bonds in a plane, but weaker bonds connecting the planes. Such structures offer the possibility of considering properties as being in two dimensions (2D). Examples include graphene (from graphite carbon), black phosphorus, and the transition-metal dichalcogenides based on molybdenum/tungsten atoms combined with two sulfur/selenium/tellurium atoms.

Here, we look at some of the contributions to this work reported at December's IEEE International Electron Devices Meeting (IEDM 2017) in San Francisco.

Electronic synapses

A number of groups put developing electronic synapse-like behavior among the aims of their work. These use hysteresis effects in the performance of the 2D structures to achieve different resistance states. 'Hysteresis' describes systems that 'remember' previous states — such as in the magnetization of ferromagnets. Although hysteresis is not wanted in many electronic applications, electronic memory does need some form of hysteresis. One option that has been widely studied over the years is resistive memory — variously described as 'memristors', resistive random access memory (RRAM), etc.

Northwestern University in the USA presented gate-tunable memristors based on monolayer molybdenum disulfide (MoS_2) [session 5.1]. Chemical vapor deposition (CVD) resulted in polycrystalline MoS_2 films with grain sizes of 3–5μm. The team fabricated memristors in a field-effect geometry with a MoS_2 channel (see Figure 1). Switching ratios for the devices reached up to ~500.

The CVD process was carried out on a silicon dioxide (SiO_2) layer on 300nm-thick silicon. The MoS_2 film was etched and titanium/gold (Ti/Au) source–drain electrodes deposited. Devices where the silicon substrate was used as a back-gate had channels that

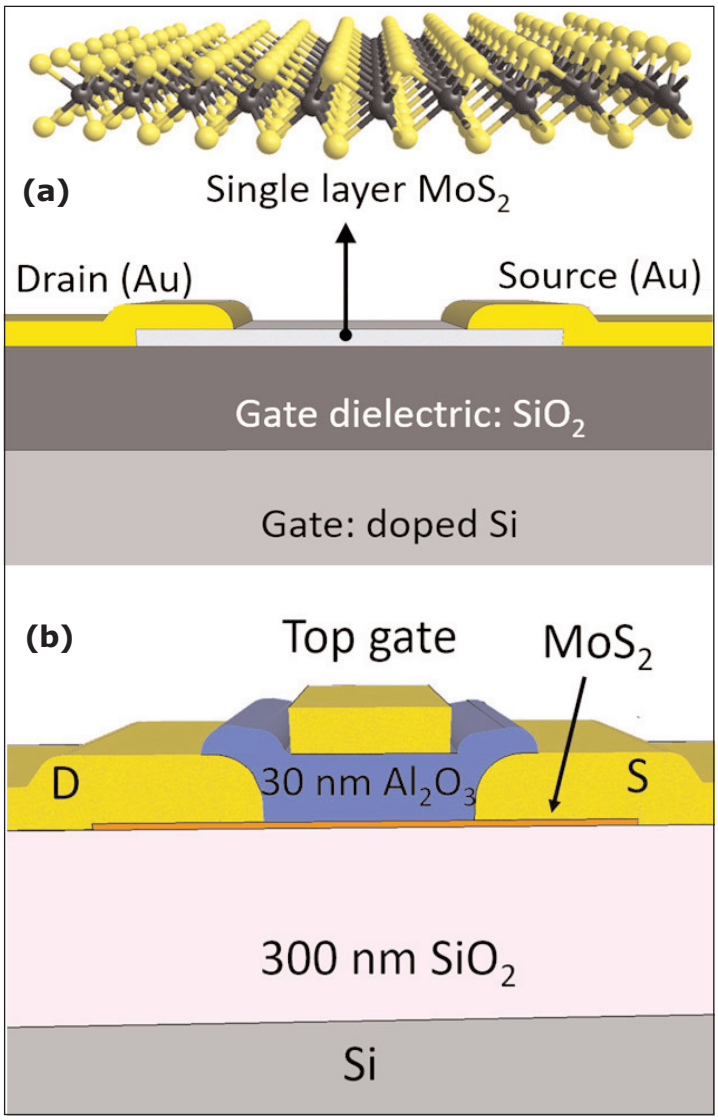

Figure 1. (a) Symbol and schematic of gate-tunable memristor on CVD-grown polycrystalline monolayer MoS_2 on a thermal oxide-coated doped Si substrate that acts as global bottom gate. (b) Top-gated MoS_2 memristor with 30nm-thick top gate Al O_x dielectric grown by ALD.

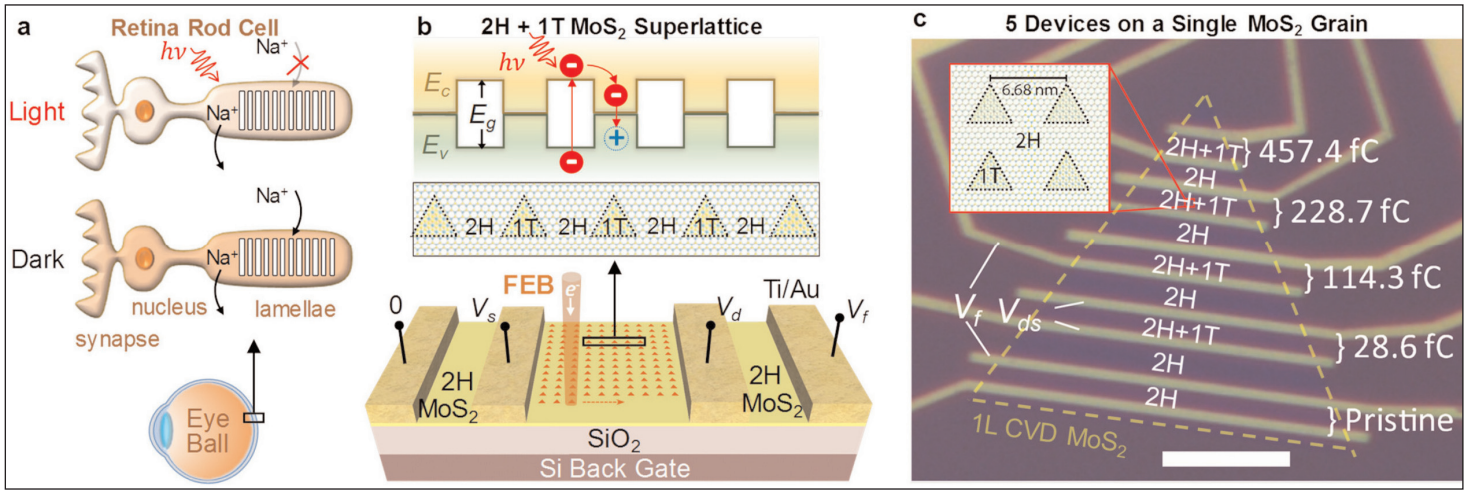

Figure 2. (a) Working principle of retina rod cell that accumulates charges with light stimulation and reduces charges in dark. (b) Schematics of device structure (bottom), 1T regions grown in triangle shape (middle), and band diagram of 2H/1T superlattice (top). (c) Optical image of five back-gated FETs. Scale bar 10μm.

were 5–15μm long and 50–100μm wide. Top-gated memristors were also fabricated with atomic layer deposition (ALD) of 30nm aluminium oxide (AlO_x) and deposition of gate metal.

The high-resistive and low-resistive states were controlled by the gate voltage over a range of three orders of magnitude for bottom-gated MoS_2 memristors and four orders for top-gated MoS_2 memristors. When the drain was positively biased, the source was a reverse-biased Schottky contact. Switching of the resistance occurs due to variation of the Schottky barrier height, which the researchers attribute tentatively to "vacancy migration and/or charge trapping".

The top-gated devices were able to tune the threshold voltage reversibly. The researchers admit that their devices are not ideal for high-performance RRAM. However, they comment: "The key innovation is in the continuous tunability of the resistive switching by the gate electrode that mimics realistic neural functions."

University of California Santa Barbara (UCSB) and Rice University in the USA claimed the first room-temperature light-sensitive memristive transistor, using quantum dot superlattice structures on monolayer MoS_2 [session 5.3]. The dots are used as charge traps that create memristive effects controllable by gate-induced electric fields and light stimulation.

The researchers see potential for artificial retina devices with artificial intelligence, and memristive receivers for optical-electrical neuromorphic interfaces (Figure 2). The short-term plasticity of the devices is seen as mimicking the properties of synaptic connections in neurological systems. Previous quantum dot memristive transistors have been produced before, but the operation was cryogenic.

The MoS_2 was produced by CVD on 285nm SiO_2 on Si. The quantum dots were produced by converting the semiconducting 2H (trigonal prismatic D_{3h}) phase of the deposited MoS_2 into metallic 1T (octahedral O_h) phase using a focused electron beam. A silicon substrate back-gate was used. The contact electrodes were Ti/Au.

Another approach to electronic synapses, using 2D hexagonal boron nitride (h-BN) was presented by Soochow University in China, Stanford University in the USA, Singapore University and Università di Modena e Reggio Emilia in Italy [session 5.4]. This was the first use of h-BN for synaptic resistive switching, according to the researchers. Stacks of h-BN layers were grown by CVD on copper. In the fabricated devices the copper served as the bottom electrode, while the top electrode was Ti/Au.

Unlike devices based on transition-metal oxides, the h-BN electronic synapse demonstrated both volatile and non-volatile resistive switching. Simple short-term and long-term plasticity rules can be applied through different electrical stresses varying the current-voltage magnitudes and limits along with pulse durations and periods. Conductive filaments form through boron vacancies in stacks of h-BN layers, altering the resistance. Differences in performance with the polarity of the signals was attributed to the different diffusion properties of the electrode metals into the h-BN stack.

Stanford University in the USA also says it has demonstrated "the first 1-transistor-1-resistor (1T1R) memory cell using the monolayer MoS_2 field-effect transistor (FET) and resistive random access memory (RRAM)" [session 19.5].

The team believes that the development could lead to "tight integration of memory with logic in a monolithic 3D integrated chip". The RRAMs were based on oxygen vacancy formation in ALD hafnium dioxide (HfO_2). The addition of transistors is designed to suppress sneak path leakage currents.

The monolayer MoS_2 was grown by CVD on a 300nm SiO_2/Si substrate. The fabrication process temperature did not exceed 200ºC.

The RRAM component had median set and reset voltages of 1.18V and −0.9V, respectively. The median high over low resistance ratio was 148. The retention time was ~10^4s at 125ºC. The transistor had an on/off current ratio of ~10^6 with the top gate biased at +2V and −2V. The drive current reached 190μA/μm with 2.5V drain bias.

In the 1T1R configuration, the high over low resistance ratio was more than 10^4. The configuration also enabled multi-level resistance states that could be used for electronic synapses and neuromorphic computing or for in-memory computing — storage of data in fast RAM rather than in complex databases on relatively slow disk drives.

On the basis of simulations, the researchers believe that, with suitable device scaling, multi-layer 3D-integration structures could be achieved.

Photodetectors

Infrared

National University of Singapore presented a black phosphorus carbide (b-PC) phototransistor designed for infrared spectroscopy [session 8.4]. The researchers believe that the b-PC could detect wavelengths over the range 2000–8000nm, allowing molecular vibration fingerprinting. Only a few 2D materials have the narrow bandgap needed to cover this range – others being graphene and black arsenic phosphorus. The b-PC material was achieved using a carbon doping technique.

The team reports that the b-PC phototransistor

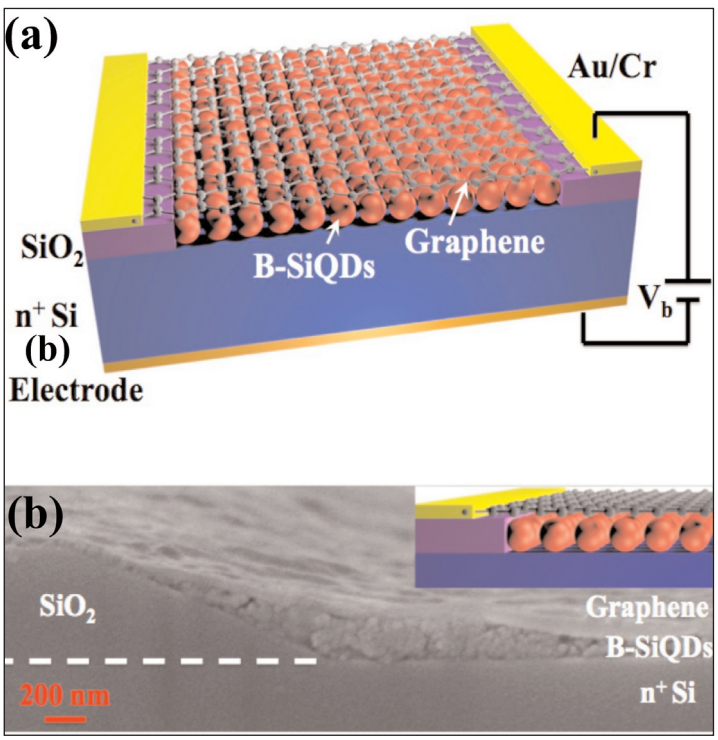

Figure 3. Schematic of Gr/B-SiQDs/Si device structure, and (b) corresponding cross-sectional scanning electron microscope image.

achieved a responsivity of 2163A/W and a short response time of 5.6ps. The device was operated at room temperature.

The researchers comment: "Under the same excitation power, its responsivity and detectivity performance in ambient and room-temperature conditions are currently ahead of all recent top-performing photodetectors based on 2D materials, showing promise for future Internet-of-Things (IoT) applications."

Zhejiang University in China has used graphene (Gr) on boron-doped silicon quantum dots (B-SiQDs, Figure 3) to give a Schottky-PN cascade heterojunction that can detect short-wavelength infrared (SWIR) [session 8.7]. The operating range was 800–1870nm with a response up to 0.6A/W at 900nm wavelength. The researchers see potential for spectroscopy, environmental monitoring, industrial inspection, medical diagnostics and bio-imaging.

The 6nm spherical p-type dots were formed from boron hyper-doping through a non-thermal plasma method. The silicon substrate was n-type. The researchers comment: "The built-in potential of Schottky junction, induced by the graphene (Gr) and n-type Si wafer, extracts the photo-electrons into Gr, leaving holes trapped in B-SiQDs. Then electron injections increase the Fermi energy of Gr, thus lowering the Schottky barrier height and leading to an exponential amplification of SWIR photocurrent."

Solar-blind UV

King Abdullah University of Science and Technology (KAUST) in Saudi Arabia and University of Maryland in the USA reported on flexible solar-blind deep-ultraviolet sensors fabricated from boron nitride nanopaper [session 8.5] The BN sheets combined with 1D nanofibrillated cellulose into a nanopaper structure had a thermal conductivity of 146W/mK, compared with 0.03W/mK for conventional paper and ~0.2W/mK for plastic. The cellulose fibers were also thought to enhance the strength of the structure by linking the nanosheets together.

The device used 300nm-thick platinum electrodes. Dark current was of the order of pico-Amps, compared with micro-Amps for devices constructed from BN nanosheets. The devices were stable up to 200ºC, and performance degradation compared with 25ºC was superior to photodetectors based on β-phase gallium oxide, silicon carbide, gallium nitride or silicon.

The researchers suggest applications of the device include military sensing, automation, short-range communications, security, and environmental detection.

A graphene/ultra-thin silicon metal–semiconductor–metal ultraviolet (UV) photodetector was described by a team from China's Zhejiang University, Chinese Academy of Sciences, Tsinghua University, and State University of New York (SUNY) in the USA [session 8.6]. The UV/visible rejection ratio was about 100, compara-

ble to the state-of-the-art Schottky photodetectors. The team also replaced a CCD array from a digital camera with the graphene/Si sensor to create an imaging platform.

CVD graphene was used as a thin active electrode that forms a Schottky junction with the underlying ultra-thin silicon. The silicon bar structures were patterned on p-type silicon-on-insulator substrates that were subsequently transferred to polyimide material. The CVD graphene sheet was then transferred onto the silicon bars and etched into interdigitated patterns. Chromium (Cr) and gold (Au) were evaporated as contacts.

The device uses the short penetration depth of UV in silicon and the ultra-shallow junction provided by the graphene to separate electron-hole pairs without significant recombination to give high response. Some hot carriers are also produced in the graphene with up to 10% photon absorption. The maximum response was 0.47A/W with 3V bias and 365nm-wavelength illumination. The short UV penetration depth and the 20nm ultra-thinness of the silicon bars made the devices relatively visible-blind.

Subthermionic subthreshold swing

University of Minnesota in the USA presented black phosphorus tunneling FETs (TFETs) that demonstrated subtheshold swings (SSs) near the thermionic limit of 22mV/decade at 110K [session 15.7]. Subthreshold swing represents the sharpness of the transition from off current to on current below the threshold gate potential — with low values usually being desired for a steep turn-on. It is possible for TFETs to have subthermionic SS, since the limit really only applies to non-tunneling devices. At room temperature (~300K) the limit increases proportionately to around 60mV/decade.

The TFETs used transport directions for the 9nm channels that were aligned to the armchair and zigzag crystal orientation. The performance was anisotropic with the maximum 0.9μA/μm on-current being achieved with armchair orientation. The bandgap of black phosphorus varies from 0.3eV in bulk material, up to 2.0eV for monolayers.

Purdue University in the USA and National Nano Device Laboratories in Taiwan presented subthermionic (<60mV/decade) SS negative-capacitance FETs (NCFETs) based on a few-layer MoS_2 channel and ferroelectric hafnium zirconium oxide (HZO) underlayer [session 23.5]. The device also used an internal metal gate (Figure 4). The forward-gate sweep SS was 37.6mV/decade, while the reverse SS was 42.2mV/decade. In high-speed switching, the reverse SS was as low as 8.3mV/decade, although with larger hysteresis that reduced the transistor's performance.

The polycrystalline HZO was deposited by 250ºC ALD. Amorphous ALD AlO_x was used for capacitance matching. The MoS_2 channel was derived by mechanical exfoliation on scotch tape.

The hysteresis problem was attributed to parasitic capacitance. The researchers comment: "High parasitic capacitance prevents the NC-FETs to work at high speed so that the optimization of parasitic capacitance to balance between SS and working speed in NC-FETs is required."

China's Nanjing University, Fudan University and Hong Kong Polytechnic University also developed MoS_2 NCFETs with subthermionic performance [session 23.6]. The structure was essentially the same as for the Purdue University and National Nano Device Laboratories NCFET without the internal metal gate. The fabrication process was also similar with ALD 4nm AlO_x and 20nm HZO or, for lower SS, 2nm AlO_x and 20nm HZO. The channel length was 1.7μm or 2.6μm, respectively.

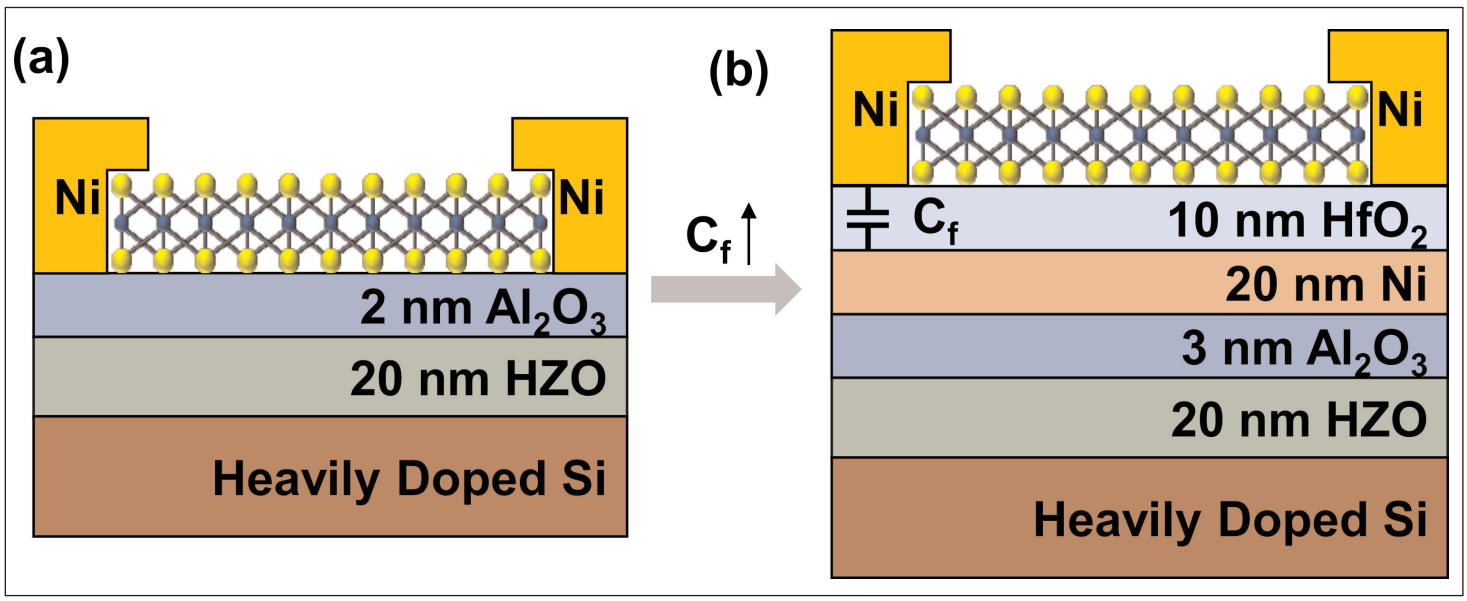

Figure 4. Schematic of MoS_2 NCFETs (a) without and (b) with internal metal gate.

The SS in the Nanjing et al case was as low as 23mV/decade and the drain current spanned a range of six orders of magnitude. The on/off current ratio was more than 10^9 with a maximum drain current of 250μA/μm (180μA/μm for 2nm AlO_x). The performance was "nearly hysteresis-free" (less than 24mV for 4nm AlO_x, 77mV for 2nm) up to 1V drain bias, the team reports.

The researchers see their devices as potential components for future ultra-low-power applications with sub-0.5V operation.

Combining carbon nanotubes and graphene

Peking University in China has scaled the gate lengths of carbon nanotube (CNT) transistors down to 5nm by using graphene contacts [session 5.5]. The researchers comment: "Scaling trend study reveals that sub-10nm CNT CMOS FETs significantly outperform Si CMOS FETs with the same gate length but at much lower supply voltage V_{ds} (0.4V versus 0.7V), with an excellent subthreshold slope swing (SS) of about 73mV/decade even with the gate length being scaled down to 5nm."

Single-walled tubes were grown on SiO_2/Si. Semiconducting tubes were identified by field-effect measurements where the silicon substrate was used as a back-gate. Graphene source/drain (S/D) contacts were created by transferring CVD-grown material and patterning with electron-beam lithography (Figure 5). The gate stack consisted of 4nm yttrium oxide (Y_2O_3) and palladium (Pd) electrode.

The graphene-contacted CNT FETs enabled SS values less than 80mV/decade even down to 5nm gate length, unlike metal-based contacts on CNT or even silicon FETs. The researchers comment: "This improvement is due largely to the much thinned S/D, i.e. graphene S/D, and the better gate control due to the use of Y_2O_3 as the gate dielectric."

The team further claims that the performance of the device in terms of intrinsic gate delay and energy-delay product are close to the theoretical limits based on Shannon–von Neumann–Landauer thermodynamic and Heisenberg quantum-uncertainty analyses. They report: "In particular, the gate delay of the 5nm CNT FET is scaled down to 43fs, which should be compared with the theoretical limit of 40fs... [O]n average, there exist only 1.35 electrons in the 5nm CNT channel in its on state, suggesting that typically a single electron is involved during the transition of the CNT FET."

Peking University also reported solution-processed CNT transistors with current density reaching 1.7mA/μm and peak transconductance (g_m) 0.8mS/μm with 120nm gate length (L_g) [session 5.6]. The researchers increased the CNT density to 160/μm, and adopted stacked contacts and double gates (SCDGs) to claim record performance (Figure 6). "In contrast to Si FETs with similar L_g, our SCDG CNT FETs exhibited not only higher I_{on} and but also higher g_m, which are achieved by CNT-based FETs for the first time," the team says.

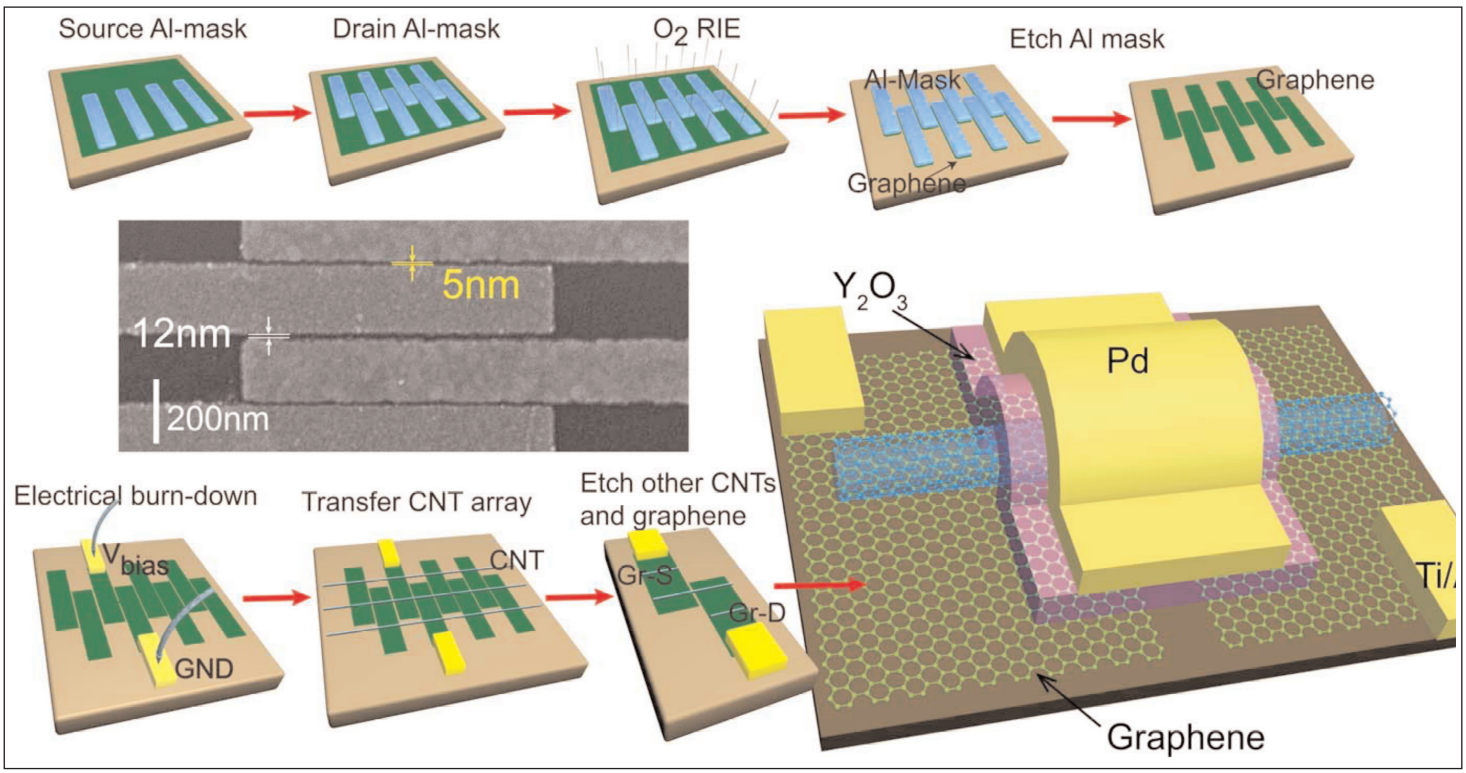

Figure 5. Process flow of GC CNT FET. (1) Transferring CVD graphene to SiO_2/Si substrate. (2) Forming source mask. (3) Forming drain mask. (4) Forming gaps on graphene. (5) Forming connecting wires and pads, and performing electrical burn-down process. (6) Transferring CNTs to graphene source and drain arrays. (7) Forming Y_2O_3 gate insulator. (8) Forming gate electrodes and finishing GC-CNT FETs.

The bottom gate and contacts were Ti/Au/Pd and the top contacts were Pd/Au while the top gate was Pd. The gate dielectrics were ALD HfO_2.

University of California Santa Barbara claimed the first all-carbon interconnect scheme integrating graphene wires and carbon nanotube vias [session 14.3]. The team found through simulation analysis that the hybrid interconnects surpassed the performance, energy efficiency and reliability of copper for 5nm-node VLSI technology.

Nickel was used to make the contact between the multi-layer graphene and carbon nanotubes. This metal has high carbon solubility when annealed at temperatures above 400ºC. Via-chain structures were constructed using 10nm-thick CVD multi-layer graphene (MLG) transferred onto thermal SiO_2. It is hoped in future to use low-temperature 435ºC synthesis of graphene directly on a dielectric substrate.

The MLG was patterned and etched. Further SiO_2 insulation was created using plasma-enhanced CVD. The 0.7μm-high 40nm-diameter vertical CNT vias were fabricated by etching holes and depositing 5nm nickel at the bottom as catalyst for CNT plasma-enhanced CVD. The CNT was capped with nickel for the contact to the upper-level MLG.

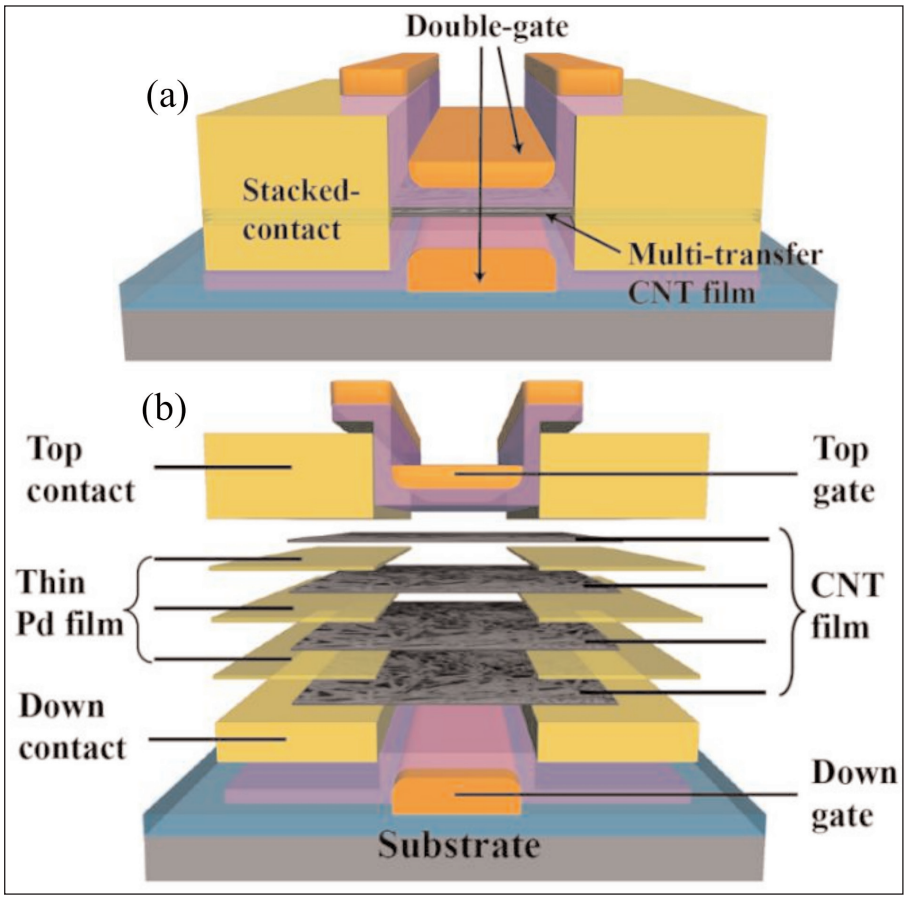

Figure 6. (a) Schematic of SCDG CNT FET, and (b) decomposed layer structures.

The nickel contacts were annealed by a series of steps passing current through the structure for 100 seconds to create self-heating above 400ºC. Before annealing, the via-chain resistance was 9.56kΩ — this reduced to 7.5kΩ after annealing. The experimental structures were 2μm wide.

Extremely scaled interconnects are expected to suffer from self-heating effects that impact performance. The researchers comment: "By using all-carbon interconnects, both current crowding and local self-heating effects are alleviated for both with and without via misalignment, because (1) barrier layers are eliminated thus creating larger contact area, and (2) MLG wires and CNT vias exhibit relatively high horizontal and vertical thermal conductivity, respectively."

Vanadium dioxide

École polytechnique fédérale de Lausanne (EPFL) in Switzerland combined MoS_2 with vanadium dioxide (VO_2) to create n–n van der Waals (vdW) heterojunction devices such as tunable rectifiers, photodiodes and FETs [session 36.1].

Tunable diode characteristics with rectification ratios of more than 10^3 were derived from a favorable band alignment and a sharp, clean atomic-level vdW interface (Figure 7). The VO_2 could also be forced to transition from an insulating to a metallic phase under high voltage or high temperature (>68ºC) stress, giving Schottky behavior. Photosensitivity was found in the 500–650nm wavelength range.

The team also reports "the first ever field-effect transistor based on gated MoS_2/VO_2 heterojunctions, which is a true low-power FET exploiting a phase-change material where the electrostatic doping effect of the gate on the junction results in a subthreshold slope (SS) of 130mV/dec at room temperature, $I_{ON}/I_{OFF} > 10^3$ and $I_{OFF} < 5pA/\mu m$ at $V_D=1.5V$."

The 75nm VO_2 was sputtered onto a 2μm wet oxide layer on a silicon substrate. The MoS_2 came from mechanical exfoliation. For three-terminal devices an AlO_x/HfO_2 gate stack was fabricated by sputtering and oxidizing a 2nm Al layer and ALD, respectively. The gate metal was 1nm tantalum and 140nm gold.

Paper substrate

University of Texas in the USA claims the first demonstration of record GigaHertz graphene and MoS_2 transistors on paper substrates [session 5.2]. The researchers used commercially available glossy paper as a substrate for a range of wet and thermal growth processes such as ALD. The substrate was first coated with polyimide to improve surface smoothness.

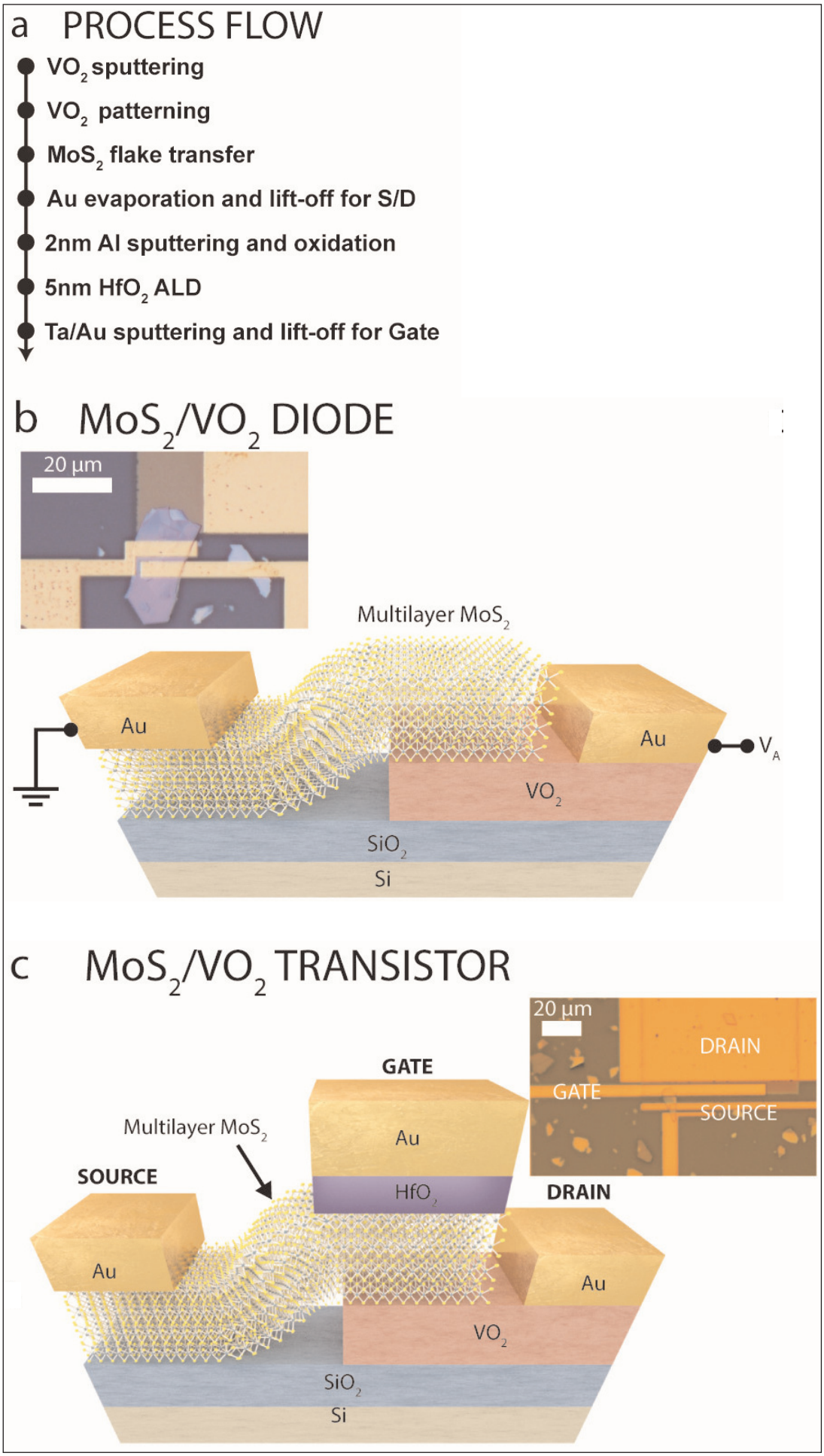

Figure 7. (a) Fabrication of MoS_2/VO_2 heterojunction devices. (b) 3D schematic view of two-terminal device and optical image (inset). (c) Three-terminal device schematic and optical image.

Graphene transistors were fabricated from CVD graphene grown on copper foil transferred onto an embedded gate stack consisting of Cr/Au metal and ALD AlO_x insulator. The source–drain electrodes were nickel/gold. The devices were estimated to have hole and electron mobilities of 3600cm^2/V-s and 2380cm^2/V-s, respectively. The channel length was 250nm and the width was 10µm. The current density achieved is claimed to be a record for paper-based 2D atomic materials. The intrinsic cut-off frequency was ~25GHz.

The MoS_2 devices were fabricated similarly to the graphene devices using material grown by CVD on SiO_2/Si. The extrinsic power gain cut-off of the device reached a record 7.2GHz.

The researchers hope flexible paper-substrate electronics could open up roll-to-roll processing with opportunities for high-performance nanoelectronics on low-cost paper substrates deployed in 'Internet of Things' and disposable sensor technology. ■

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III–N resonant tunneling diodes at room temperature and below

Findings represent a significant step in resonant tunneling, intersubband-based physics, and III-nitride quantum devices, according to team.

Researchers in the USA have been studying III–nitride resonant tunneling diodes (RTDs) at room temperature and below [Jimy Encomendero et al, 'New Tunneling Features in Polar III-Nitride Resonant Tunneling Diodes', Phys. Rev. X, vol7, p041017, 2017].

The team from Cornell University, University of Notre Dame, and University of Utah, reports: "Resonant tunneling transport via the ground state and first excited state over a wide temperature window is demonstrated for the first time in III–nitride RTDs. These findings represent a significant step forward in resonant tunneling, intersubband-based physics, and III–nitride quantum devices."

According to Huli Grace Xing, one of the authors from Cornell, room-temperature GaN RTDs have been sought after by the community for the past 20 years.

Theoretical work by the group suggests a sensitive dependence of performance on the built-in polarization fields due to charge density differences in the partial ionic bonding of aluminium nitride (AlN) and gallium nitride (GaN) layers used in the devices.

Resonant transport has been used in highly efficient injectors of electrons into the upper lasing level of terahertz (THz) quantum cascade lasers (QCLs), but applications have been hampered by the low temperatures needed to maintain quantum coherence in narrow-bandgap semiconductors such as the III–arsenide family.

Out of resonance conditions in RTDs since they result in decreasing currents with increasing bias — negative differential conductance — can be used to create high-frequency oscillators.

GaN structures with double 2nm AlN barriers inserted (Figure 1) were grown on commercial c-plane n-GaN bulk substrates by molecular beam epitaxy (MBE). The dislocation density of the substrates was ~$5x10^4/cm^2$. The growth used metal-rich conditions at 700°C temperature with 200W-power nitrogen plasma. Such growth has been found to result in smooth surfaces. In particular, Ga was used as a surfactant during the AlN growth — Al is incorporated into the growth front in preference to Ga. The presence of Ga reduces the surface energy without getting incorporated. The Ga-rich conditions were used in a step-flow growth mode.

Scanning transmission electron microscopy (STEM) studies suggested that the barriers were 8 monolayers of AlN, and the GaN well was 11 monolayers. The fluctuation in barrier width was around 1 monolayer.

"Maintaining these conditions has proven to be critical for achieving atomically smooth interfaces and minimizing the formation of defects, which is crucial for resonant tunneling transport," the team comments.

The smooth surface was aided by the fact that the thickness of the AlN barrier was below the critical thickness of 5–7nm for pseudomorphic films on GaN.

RTD fabrication used titanium/aluminium/gold/nickel for collector and titanium/aluminium/gold for emitter contacts.

The devices exhibited a resonant peak in current and a region of negative differential conductance after the

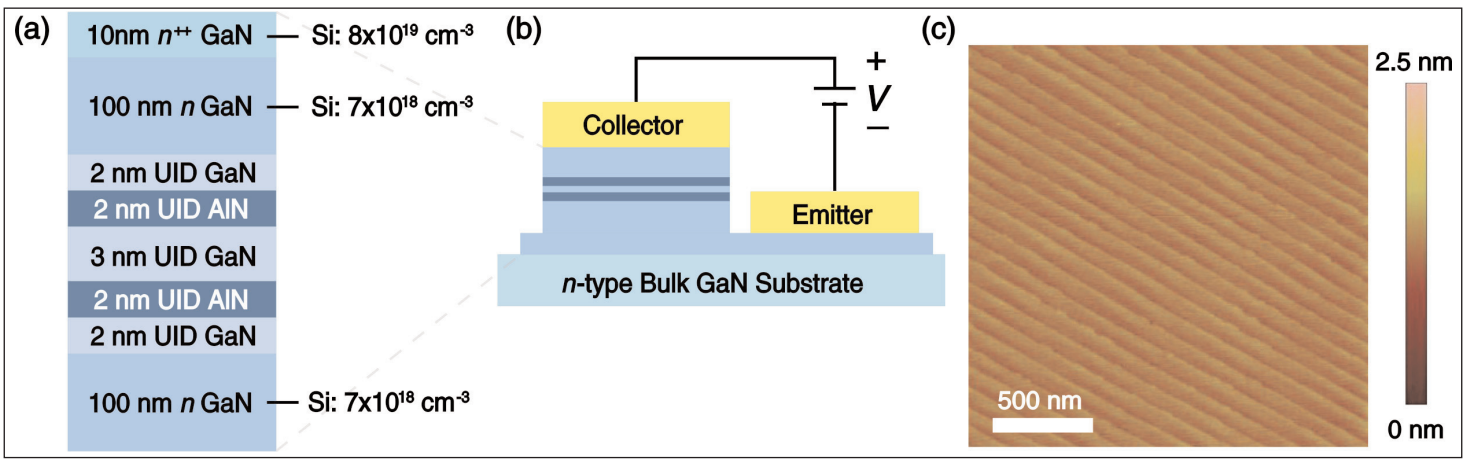

Figure 1. (a) Schematic of device structure and doping concentrations of GaN/AlN double-barrier heterostructure. (b) Cross-sectional schematic of fabricated resonant tunneling diode with collector and emitter metal contacts under forward bias. (c) Surface morphology of as-grown RTD heterostructure with root-mean-square roughness of ~0.146nm over a 2μmx2μm area.

peak voltage. The peak is attributed to resonance of the energy of electron waves trapped between the barriers and the Fermi level of the biased region.

Sweeping back through the resonance results in the peak occurring at higher voltage due, it is thought, to some form of charge trapping. Different mesa areas give current scaling that suggests that sidewall leakage is not significant.

Further scans result in peaks at a higher voltage. The subsequent valley increases in current, giving a lower peak-to-valley current ratio (PVCR). The behavior stabilizes after a number of scans.

The team comments: "This behavior suggests the presence of defects in the AlN barriers in this sample that act as current leakage paths and degrade the energy filtering mechanism of the double-barrier heterostructure. It should be noted, however, that these leakage paths exhibit limited effects and do not prevent resonant tunneling transport of carriers across the active region at room temperature."

Bias in the reverse polarity does not have a peak in the current–voltage (I–V) domain — there is a low-injection-current region before a threshold voltage for higher current than in the forward direction. The team says: "This asymmetric I–V is a direct consequence of the polarization electric fields present in the heterostructure, due to broken inversion symmetry of the uniaxial crystal."

Decreasing the temperature to 4.2K, the first resonance peak shifts to lower voltage and a second emerges, attributable to the resonant tunneling transport from the first excited state in the well between the barriers (Figure 2).

The researchers explain the asymmetric current–voltage behavior as resulting from the built-in polarization fields. The team has further analyzed the reverse-bias threshold behavior: "if we consider a set of polar RTDs with different barrier thicknesses, the polarization discontinuity will be given by half the slope of the threshold voltage versus barrier thickness, assuming symmetric double-barrier heterostructures."

The polarization field was found to be 11.0MV/cm for AlN pseudomorphically strained on GaN, compatible with theoretical and experimental values. For example, a value of 10.9MV/cm has been extracted from experiments on AlN/GaN high-electron-mobility transistors.

Further analysis suggests that thinning the AlN barrier to 1nm could increase the resonant tunneling current by two orders of magnitude. "This trend is experimentally verified since RTDs featuring AlN barriers of 1.5nm and 2.4nm drive resonant currents of ~2.5×10^2A/cm^2 and ~2.6×10^4A/cm^2, respectively," the team reports.

Devices with larger PVCR are expected from lowered MBE growth rates to enhance adatom mobility, reducing defect formation and creating atomically smooth interfaces for decreased carrier scattering. The built-in polarization fields can be avoided or reduced with non-polar or semi-polar substrates. ■

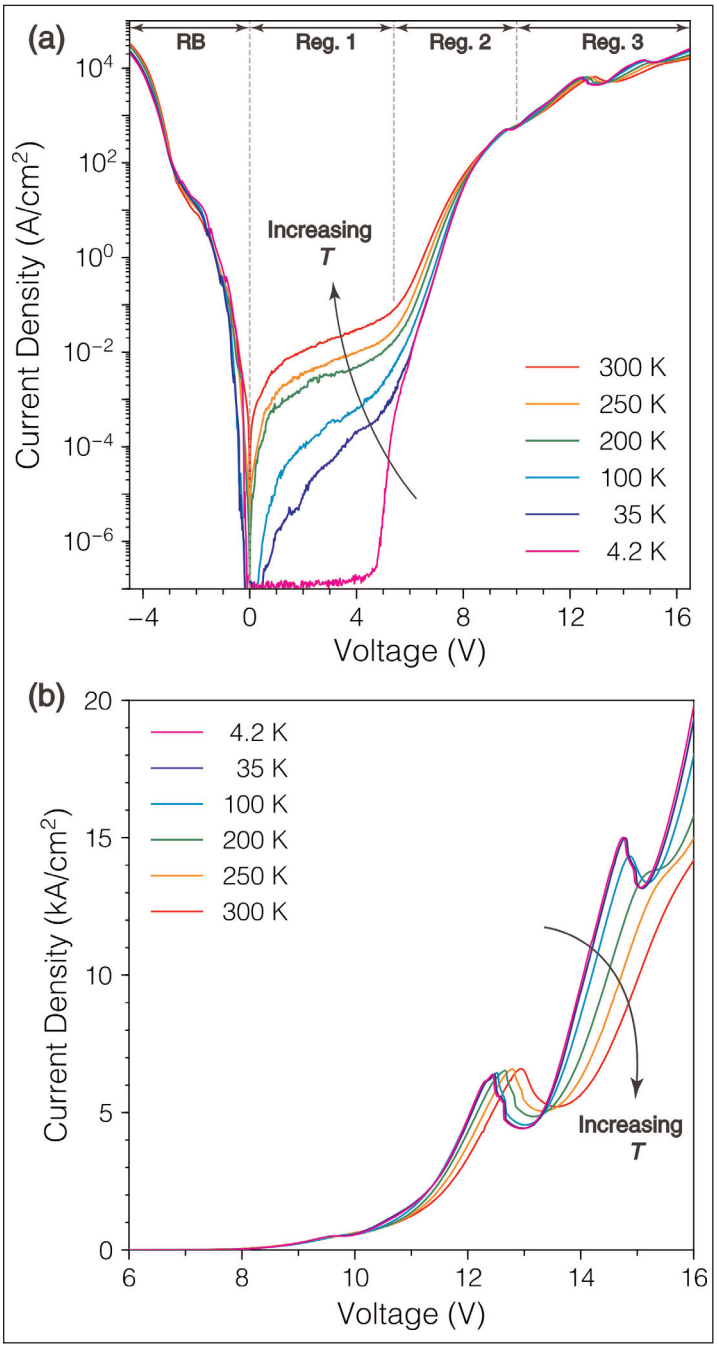

Figure 2. (a) Semilogarithmic I-V plot showing regions with different transport regimes as a function of temperature: under a reverse bias (RB), the current exhibits weak temperature dependence. By contrast, forward-bias region 1 shows strong temperature dependence attributed mainly to thermionic electrons. Region 2 presents a weak dependence on temperature due to enhancement of tunneling current component. Transport within region 3 is mainly due to resonant tunneling of carriers. (b) Forward I–V curves at different temperatures showing repeatable room-temperature resonant peak and higher-order resonance for temperatures below 200K.

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Author: Mike Cooke

IEMN demonstrates over 1400V breakdown on ALLOS' new GaN-on-Si epi

With potential to compete with silicon carbide at lower cost, epi firm ALLOS seeks industrial partner on 1200V devices.

A team around Dr Farid Medjdoub at Institut d'Electronique, de Micro-électronique et de Nanotechnologie (IEMN-CNRS) research institute in Villeneuve-d'Ascq, France has made devices and conducted measurements on two different gallium nitride on silicon (GaN-on-Si) epitaxial wafer products supplied by IP licensing & technology engineering firm ALLOS Semiconductors GmbH of Dresden, Germany.

One is a prototype of ALLOS' upcoming product designed specifically for 1200V device applications. With this epiwafer IEMN achieved over 1400V for vertical and 1600V for lateral (grounded) breakdown. The other epiwafer is ALLOS' established product for 600V applications, which equally showed very high breakdown voltages of 1200V and more for both lateral and vertical measurements.

The new epiwafer for 1200V device applications is from an ongoing internal development program at ALLOS. Its performance results from a structure combining ALLOS' unique strain-engineering and high-crystal-quality approach with additional measures to suppress leakage and enhance breakdown voltage further. This was achieved without compromising on other essential parameters such as crystal quality or wafer bow and without introducing carbon doping. Epi growth was conducted on a standard Aixtron G5 metal-organic chemical vapor deposition (MOCVD) reactor.

Already at November's International Forum on Wide Bandgap Semiconductors (IFWS) in Beijing, China, ALLOS presented device results from an industry partner using ALLOS' 600V epiwafer. With a mature device design and measurement setup for up to 1000V, leakage values of 0.003μA/mm^2 at 600V and of 0.033μA/mm^2 at 1000V were achieved. The partner's feedback was "another confirmation for the capability of our technology for 600V applications," says ALLOS' chief technology officer Dr Atsushi Nishikawa. "Now the big question was at which voltage above 1000V the physical breakdown occurs and whether we are on track with our development in the 1200V domain too."

The results demonstrated by IEMN used a simplified device design and processes allowing much faster feedback than from an industrial process. On a prototype of ALLOS' new epiwafer for 1200V devices, IEMN achieved more than 1400V for vertical and 1600V for lateral (grounded) breakdown voltage (Figure 1(a) and 2(b) respectively). Supplementing characterization with a floating measurement setup resulted in a lateral breakdown of over 2000V with 12μm contact distance (Figure 1(c)). Saturation of lateral floating breakdown occurred at 12μm contact distance for the 7μm thick epi-stack with breakdown already more than 1100V for 4μm contact distance (Figure 1(d)).

We are already at 1.7MV/cm laterally and 2MV/cm vertically — and we have a program to realize further improvements on the epiwafer level

"With over 1400V for vertical and 1600V for lateral breakdown with substrate grounded, ALLOS' epiwafer favorably compares to all the samples we have measured so far from various industry and research partners," comments IEMN's GaN team leader Dr Farid Medjdoub. "Furthermore, the results we have seen indicate that the device performance is very uniform over the wafer, which is a very important characteristic to qualify for actual device production."

On ALLOS' 600V epiwafer, IEMN achieved 1200V for vertical and 1500V for lateral (grounded) breakdown voltage. Both epiwafer products are not doped with carbon, which is often used by GaN-on-Si makers to enhance isolation but has negative impacts on crystal quality and dynamic switching behavior. Both are available with 675μm thickness for 150mm wafer diameter and 725μm thickness for 200mm. Bow for all ALLOS epiwafer products is tightly controlled to below 30μm.

"The results now available show that we are already at 1.7MV/cm laterally and 2MV/cm vertically — and we have a program to realize further improvements on the epiwafer level," says ALLOS' CEO Burkhard Slischka. "Now is the time to establish a strong partnership with an industrial partner also in the 1200V product range," he adds. "As we are a pure epiwafer technology provider without own device making we are seeking a close cooperation with an experienced power electronics

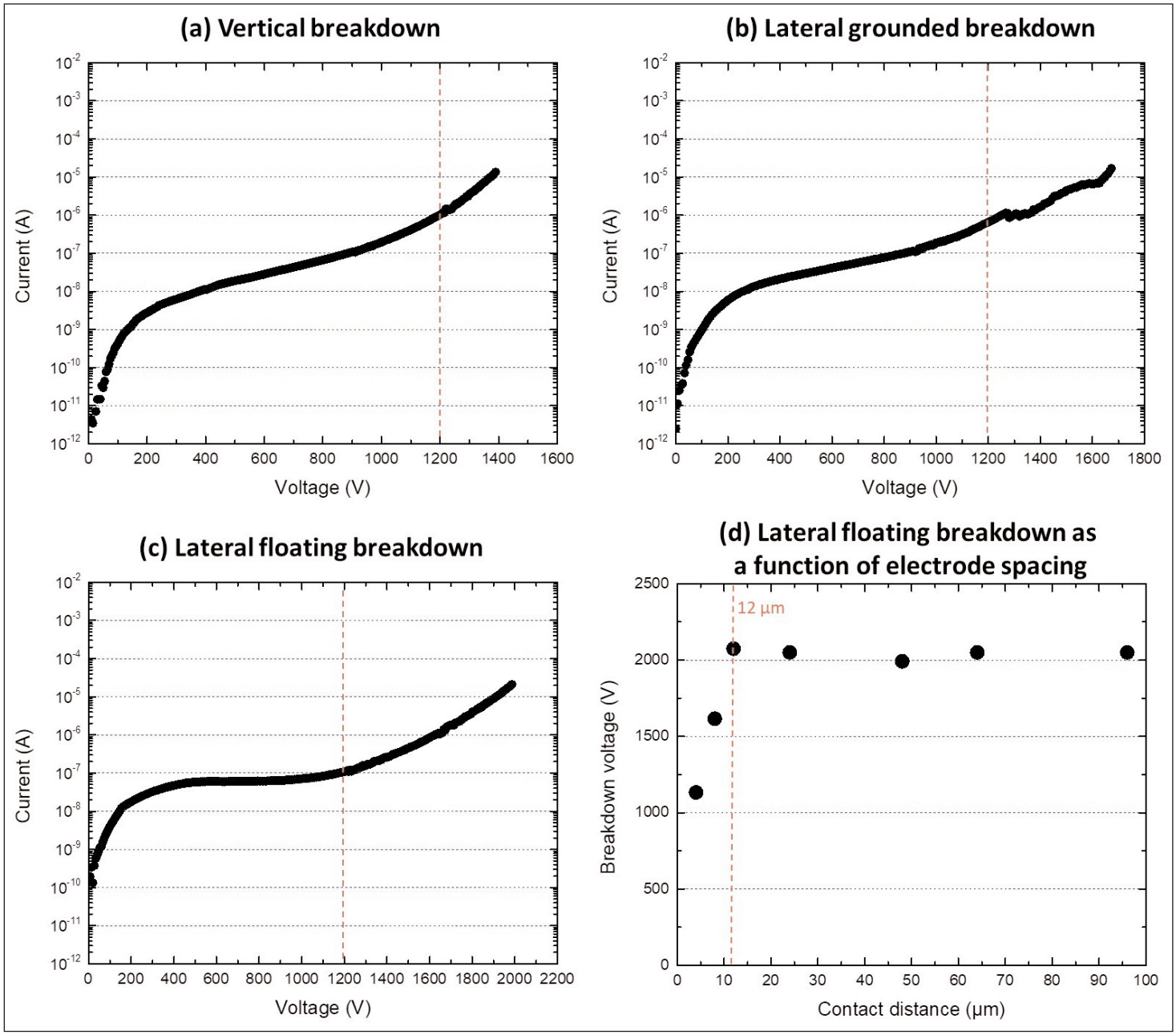

Figure 1(a) to (d): Results from IEMN on ALLOS' epiwafer technology for 1200V application.

player to exploit the opportunities for their 1200V GaN-on-Si based applications. With our technology, GaN-on-Si has the potential to effectively compete with SiC performance at a fraction of the wafer cost."

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'First' quasi-vertical gallium nitride trench MOSFET on 6-inch silicon

Researchers report 645V off-state breakdown capability for low-cost power electronics.

École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland claims the first gallium nitride (GaN) quasi-vertical trench gate metal-oxide-semiconductor field-effect transistors (MOSFETs) on 6-inch silicon (Si) substrates with 645V off-state breakdown [Chao Liu et al, IEEE Electron Device Letters, vol39, p71, 2018].

The researchers hope that combining compact vertical-structure GaN MOSFETs with silicon substrates will reduce costs for the emerging power electronics technology. Up to now, vertical GaN power devices have usually been produced on ultra-expensive bulk or free-standing GaN substrates, since reducing threading dislocations is imperative for low current leakage and for avoiding breakdown in the off-state. Threading dislocations arise from the large lattice and thermal expansion mismatch between silicon and GaN.

The researchers grew an n-p-n heterostructure on six-inch (111) silicon by metal-organic chemical vapor deposition (MOCVD). The structure consisted of a 1.1µm AlN buffer, 1µm of n^+-GaN, a 4µm n^--GaN drift layer, 350nm of p-GaN, a 200nm n-GaN layer, and 20nm of n^+-GaN. The buffer used an optimized process, with particular focus on nucleation on silicon, to achieve a low-threading-dislocation-density, high-quality aluminium nitride layer. The subsequent GaN layers were grown without relaxation of compressive stress to compensate the tensile stress that arose during cooling after deposition.

Lateral mobility measurements on the drift layer gave a value of 720cm^2/V-s. The team comments: "To the best of our knowledge, this is the highest electron mobility in vertical GaN on Si".

Transistor fabrication (Figure 1) involved dry etching 1.6µm-deep trenches, tetra methyl ammonium hydroxide (TMAH) wet etch to repair sidewall damage, rapid thermal annealing (RTA) to activate the p-type magnesium

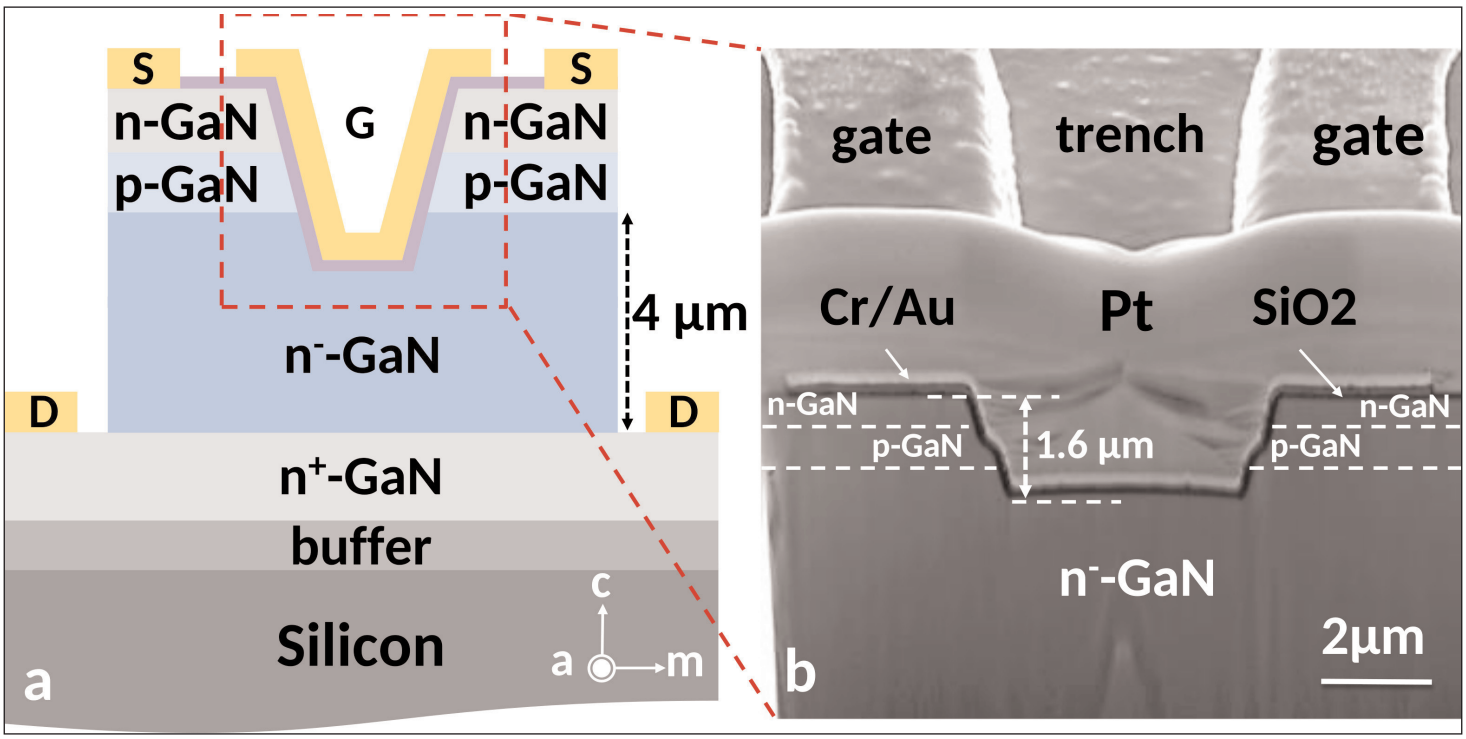

Figure 1. Cross-sectional (a) schematic, and (b) SEM image of fabricated quasi-vertical trench gate MOSFETs on silicon substrate.

doping, atomic layer deposition (ALD) of 100nm silicon dioxide gate dielectric, contact hole etch, chromium/gold source-gate deposition, 5μm mesa etch, and chromium/gold drain deposition.

The on/off current ratio of the device was more than 10^8, while off-state leakage was less than 10^{-8}kA/cm^2. Gate leakage was 1.2x10^{-9}kA/cm^2 at 0V gate potential, rising to 2.5x10^{-6} at 15V. The team believes this can be reduced by trench and gate dielectric optimization.

The measured threshold of +6.3V confirmed normally-off operation. The researchers say that the high threshold "is preferable for high-power applications to guarantee a safe operation and better noise immunity." The peak transconductance was 269S/cm^2.

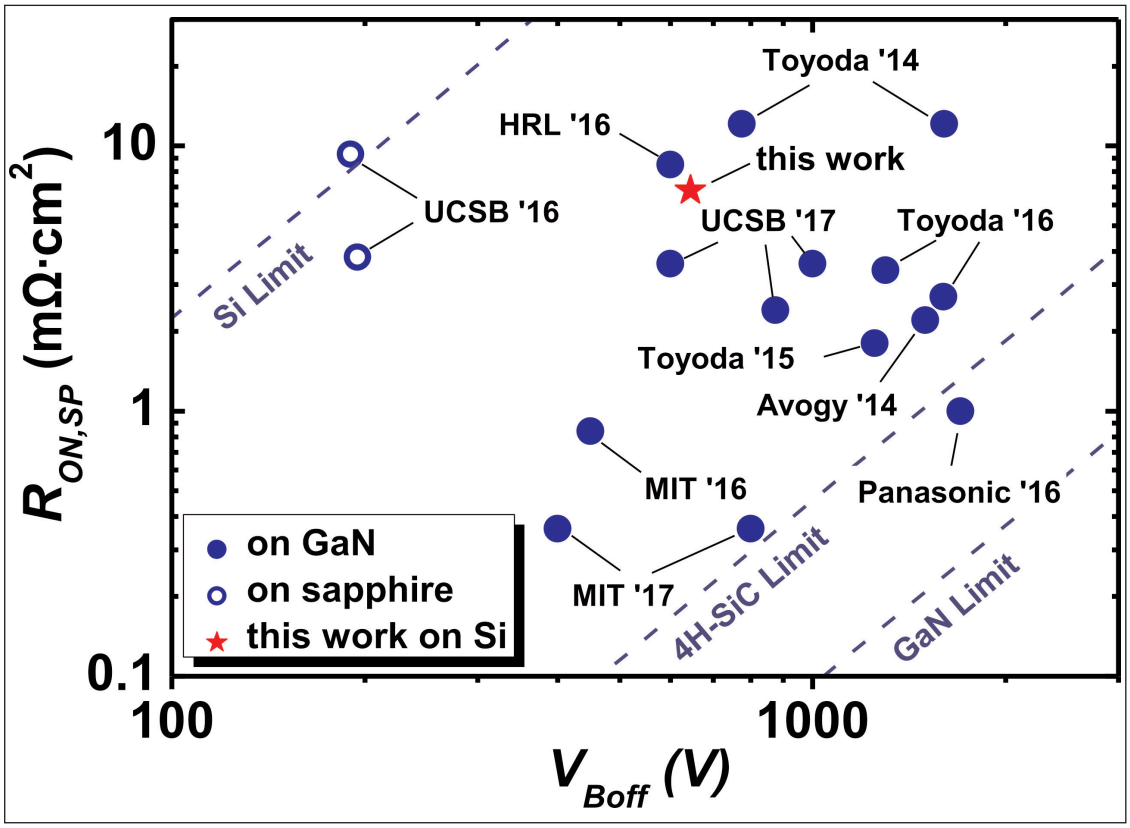

Figure 2. $R_{ON,SP}$ versus V_{Boff} benchmarks of vertical trench gate MOSFETs on silicon substrates with state-of-the-art enhancement-mode (normally-off) vertical transistors on sapphire and GaN substrates.

With the gate and drain at 12V and 11V, respectively, the on-state current was 1.3kA/cm^2 with a specific on-resistance of 6.8mΩ-cm^2.

Hard breakdown of the 0V gate off-state occurred at 645V. The gate current was below 10^{-5}kA/cm^2 at breakdown. The team comments: "The observed breakdown was destructive and mainly happened at the mesa edges. By introducing field-plates and edge-termination technologies to these devices, the electric field at the junction edge could be reduced, which would further enhance their breakdown voltage. However, the performance observed even without edge termination is quite remarkable, which reveals the enormous potential for GaN-on-Si vertical transistors."

Two-terminal circular n–p–n test structures had a similar breakdown at 679V. The similarity of the leakage current magnitude through different diameter structures indicate that the leakage flows mainly through the heterostructure rather than the etched sidewalls, according to the researchers.

Combining the breakdown voltage (V_{Boff}) with the specific on-resistance ($R_{ON,SP}$) gives a Baliga figure of merit ($V_{Boff}^2/R_{ON,SP}$) of 61MW/cm^2. This improves on what has been achieved on sapphire (Figure 2).

The team believes that better results could be forthcoming from enhancing the TMAH wet etch of the sidewalls, adding field plates and edge-termination, and removing the silicon substrate to give fully vertical devices. ■

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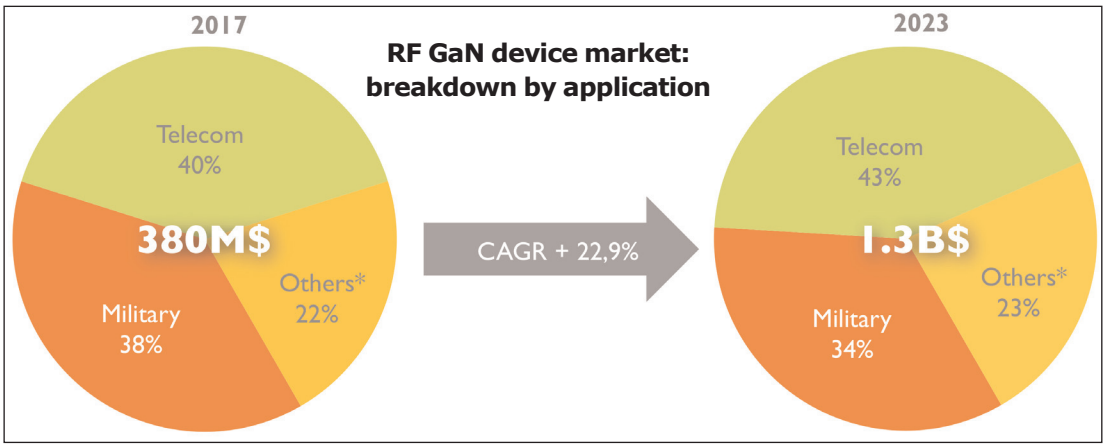
Author: Mike Cooke

RF GaN market to grow at 22.9% CAGR over 2017–2023, boosted by 5G implementation

Threefold increase over next five years to be driven by telecoms and defense.



In the last couple of years, the radio-frequency gallium nitride (RF GaN) market has been reshaping the RF power industry landscape after seeing impressive growth to nearly $380m by the end of 2017 (which was was undoubtedly a good year), says Yole Développement in a new report 'RF GaN Market: Applications, Players, Technology, and Substrates 2018–2023'. The penetration rate in various markets had a breakout period in the last two years, particularly in telecom and defense applications, which saw a compound annual growth rate (CAGR) of more than 20%.

But Yole expects that, led by the implementation of 5G networks, another a strong surge will occur around 2019–2020, so that the total RF GaN market will be 3.4 times larger by the end of 2023, posting a CAGR of 22.9% over 2017–2023.

The report covers GaN's presence and development in markets including wireless infrastructure, defense and aerospace, satellite communication, wired broadband - both in coaxial cables used in cable TV (CATV) and fiber-to-the-home — and other industrial, scientific & medical (ISM) radio band applications.

Recognized by industry players, RF GaN technology is becoming the current mainstream within the RF industry, which is mostly dominated by the integrated device manufacturers (IDMs) Sumitomo, Qorvo and Cree (which has reintegrated its Wolfspeed business after the latter's acquisition by Infineon was thwarted). However, the industry is at a critical stage, as the future should be different due to the penetration of foundries. In addition, Ampleon has announced an acquisition offer by Chinese LED maker Aurora Sapphire (a competitor of San'an Optoelectronics). With the GaN industry expected to grow in the coming years, existing market leaders will no doubt increase their revenue, but they will likely not increase their market share, predicts Yole.

Telecom and defense driving market

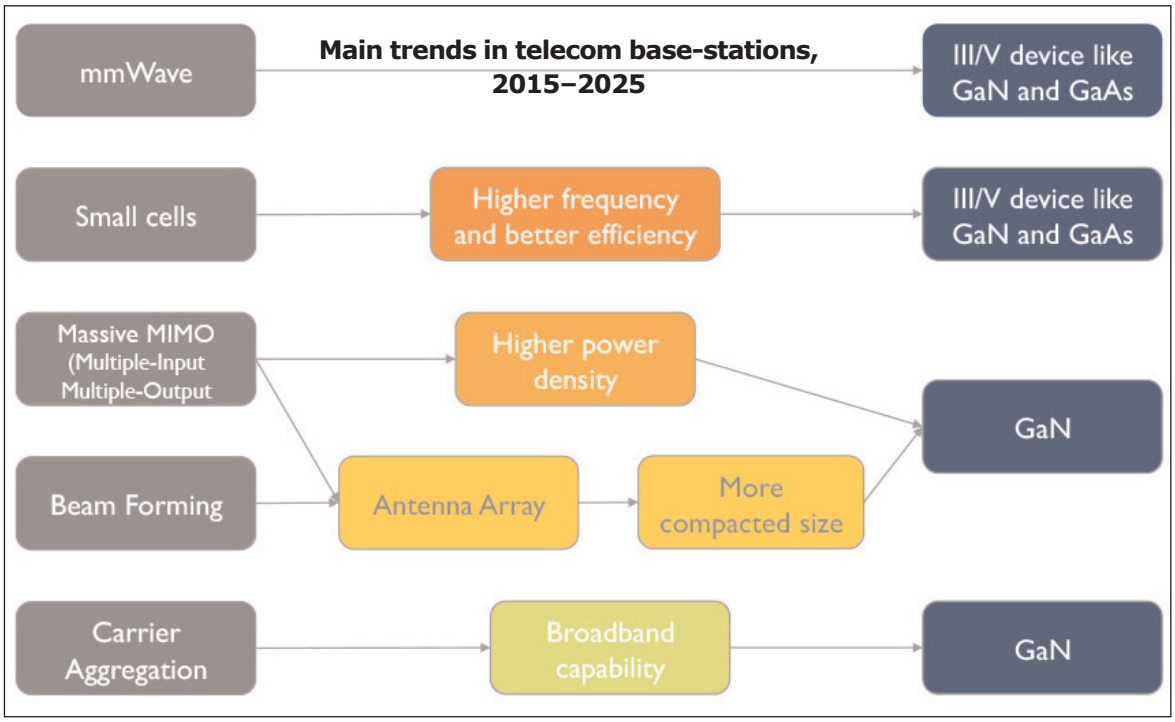
In the future, Yole sees telecom and defense markets as the mainstay of the industry.

Due to the increasing pace of development of 5G networks, the telecom market will bring a huge opportunity for GaN devices, beginning in 2018, reckons Yole. Compared with existing silicon LDMOS and gallium arsenide (GaAs) solutions, GaN devices can deliver the power/efficiency required for next-generation high-frequency telecom networks. Also, GaN's broadband capability is a key factor for enabling important new technologies, such as multi-band carrier aggregation.

GaN high-electron-mobility transistors (HEMTs) have been the candidate technology for future macro base-station power amplifiers. Yole estimates that most sub-6GHz macro network cell implementations will use GaN devices because LDMOS can no longer hold up at such high frequencies and GaAs is not optimum for high-power applications. However, because small cells do not need such high power, existing technology such as GaAs still has advantages. At the same time, market volumes will increase faster because higher frequencies reduce the coverage of each base station, hence more transistors will be implemented.

The defense market has been the major driving force for GaN development in the past decades. Originating in the US Department of Defense, GaN devices have been implemented in new-generation aerial and ground radars. GaN's high-power capability improves detection range and resolution, and designers are becoming increasingly familiar with the new technology.

Nevertheless, this military-related technology is very sensitive. Also, as GaN devices are becoming popular in defense applications, development in the non-military segment could be affected. This is especially true in terms of mergers and acquisitions. Governments could block deals if businesses target military applications, as in the thwarted acquisitions of Aixtron by China-based FGC Investment Fund and of Wolfspeed by Germany's Infineon Technologies.



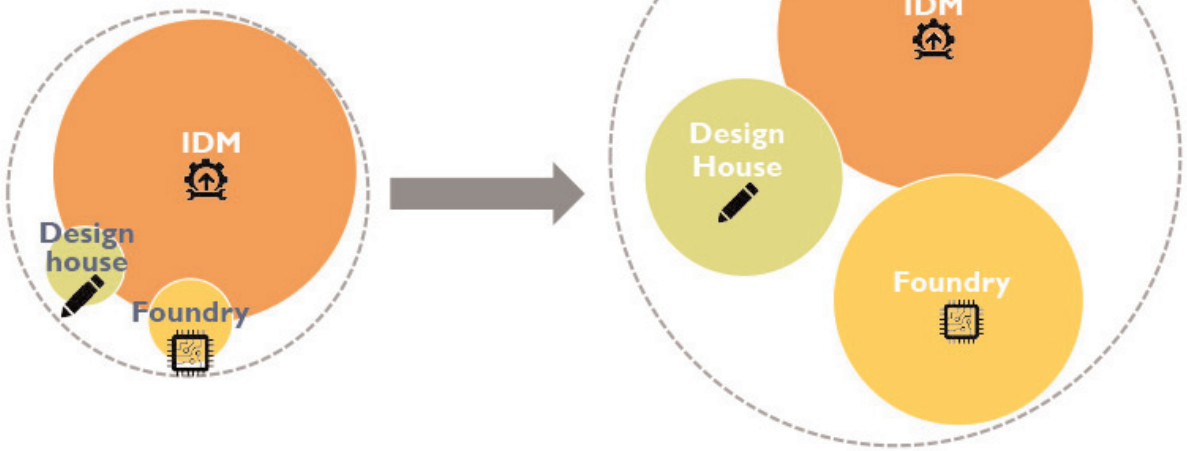
"GaN RF has been recognized by the industry and has become mainstream," notes Zhen Zong, technology & market analyst at Yole. "Indeed, leading players are increasing revenue very rapidly and this trend will remain for the next several years," he adds.

The price of GaN transistors is still relatively high today. According to Yole's analysts, in the near future more and more players should penetrate the market, ensuring that volumes increase and prices decrease. In parallel, Yole highlights significant issues related to packaging. An effort in packaging could also strongly reduce prices to an attractive level. More players are now choosing plastic packages: the industry is showing some movement on new types of packaging material and new die attach methods. Companies such as MACOM and Sumitomo have begun using silver sintering as the die attach material, which aids thermal control and improves device quality. Also, it has been established that the next step will be to use pure copper as the flange material for packages.

Driven by significant R&D investments, new technologies in the package material and die attach will be used more frequently in higher-frequency and higher-power applications, reckons Yole. "Indeed, we believe it will help reduce the price and ameliorate the performance," says Zhen Zong.

www.i-micronews.com/category-listing/product/rf-gan-market-applications-players-technology-and-substrates-2018-2023.html

Comparison of business models: integrated device manufacturer versus foundry



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Index

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www.MCP-group.com

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2 Bulk crystal growth equipment

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3 Substrates

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www.waferworld.com

4 Epiwafer foundry

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5 Deposition materials

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AkzoNobel Functional Chemicals,
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USA
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Tel: +1 312 544 7000
Fax: +1 312 544 7188
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Fax: +1 978 557 1701
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Newark, CA 94560,
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Mining & Chemical Products Ltd
(see section 1 for full contact details)

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Fax: +1 845 398 8304
www.praxair.com/electronics

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www.safchitech.com

Materion Advanced Materials Group
2978 Main Street,
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USA
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www.williams-adv.com

6 Deposition equipment

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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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Fax: +41 81 403 8001
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MA 02464, USA
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Fax: +1 617 965 5818
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Praxair Electronics
(see section 5 for full contact details)

8 Wafer processing equipment

EV Group
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www.logitech.uk.com

Oxford Instruments Plasma Technology
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Plasma-Therm LLC
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Newport NP18 2TA,
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85748 Garching,
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Tel: +49 89 32007 0
Fax: +49 89 32007 162
www.suss.com

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9 Materials & metals

Goodfellow Cambridge Ltd
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www.cambridge-fluid.com

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11 Process monitoring and control

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www.wepcontrol.com

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www.jawoollam.com

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18 Chip foundry

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Fax: +33 169 33 02 92
www.ums-gaas.com

19 Facility equipment

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20 Facility consumables

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event calendar

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Europe's SEMI Industry Strategy Symposium (ISS Europe 2018)
Clontarf Castle Hotel, Dublin, Ireland
E-mail: aniedballa@semi.org
www.semi.org/eu/iss-europe-2018

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

11–15 March 2018
Optical Fiber Communication Conference & Exposition (OFC 2018)
San Diego Convention Center, San Diego, CA, USA
E-mail: OFC@compusystems.com
www.ofcconference.org

14–16 March 2018
SEMICON China 2018
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E-mail: semichina@semi.org
www.semiconchina.org

14–16 March 2018
LASER World of PHOTONICS CHINA 2018
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E-mail: info@world-of-photonics-china.com
www.world-of-photonics-china.com

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University of Nottingham, UK
E-mail: i.farrer@sheffield.ac.uk
https://ukmbe.wordpress.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

16–18 April 2018
14th International Conference on Concentrator Photovoltaics (CPV-14)
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