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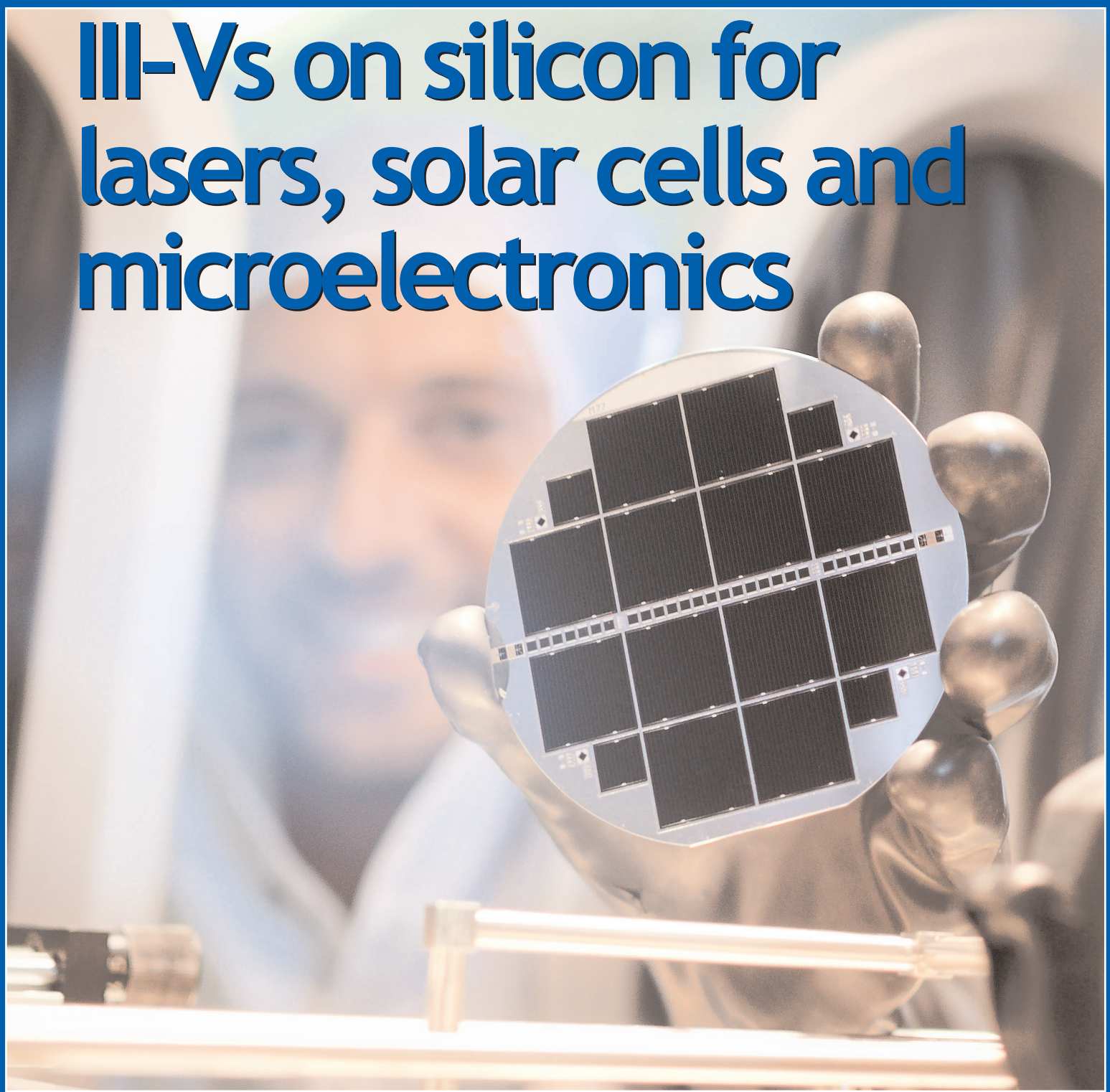
III-Vs on silicon for lasers, solar cells and microelectronics



Cree supplying SiC to ON Semi • BluGlass opens new labs
POET selling DenseLight to Dynax-led concern

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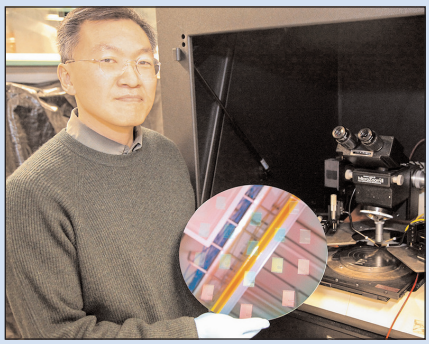
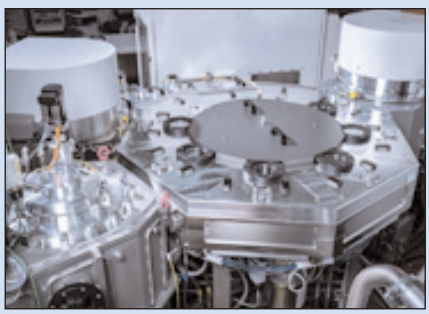
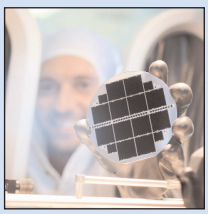


p12 The US NRL has awarded $6.25m to Dr Ji Ung Lee to apply new nanoscale materials at SUNY Poly's 300mm fabrication facility.



p30 Evatec has delivered its latest-generation CLUSTERLINE thin-film deposition tool to SkyWater.

p32 RPCVD firm BluGlass has formally opened its new Paul Dunnigan laboratories in Silverwater, Sydney, Australia.



Cover: Germany's Fraunhofer ISE has raised the energy conversion efficiency record for monolithic triple-junction solar cells made of silicon and III–V semiconductor materials, to 34.1% for wafer-bonded cells and 24.3% for directly deposited cells. **p52**

editorial

Impact of Huawei ban & China tariffs

Second-quarter 2019 financial results have evidenced how many major component makers have been impacted by the US Department of Commerce on 15 May adding smartphone and telecom network infrastructure maker Huawei to its 'Entity List' prohibiting sales to it of products covered by the Export Administration Regulations (EAR) without a license. The ban arose mid-quarter, so the full effect may only be seen in subsequent quarters.

The impact is also difficult to forecast due to uncertainty about when the ban applies and which categories of product are affected.

For example, on 21 May, US-based RF component maker Qorvo cut its guidance by $50m from $780–800m to $730–750m. However, reported Q2 revenue exceeded this, at $775.6m, aided partly by shipment of select products to Huawei in June following a legal review exempting certain products from EAR restrictions (see page 8). In fact, Huawei rose to 22% of Qorvo's total revenue due to a combination of Huawei gaining market share and Qorvo gaining market share at Huawei. However, Qorvo's September-quarter sales to Huawei (and hence China) are expected to be much lower, almost negating growth in Mobile Products from seasonal ramps of flagship smartphone models. For full-year fiscal 2020 (to end-June 2020), Qorvo expects sales to Huawei will fall below 10% of revenue, driving Mobile Products segment revenue down 10% in the second half compared with fiscal first-half 2020. "Although we have filed for a license and are taking other proactive steps to address our ability to sell products to Huawei, the scope, duration and long-term financial impact of the restrictions remain unclear," notes chief financial officer Mark Murphy.

Likewise, rival Skyworks cut its guidance by $60m from $815–835m to $755–775m, but exceeded the mid-point of this by $2m, at $767m (see page 10). Huawei's contribution was reduced from 15% (prior to the ban) to 10% for the quarter, driving the Mobile segment down from 67% of total revenue the prior quarter to 63%. "We ultimately determined that we could lawfully resume shipping certain products, which we did start in early July," says CFO Kris Sennesael. "However, we expect the business with Huawei to remain well below historical level into the current quarter [falling below $10m]… The demand signal that we get from Huawei is actually very low."

Of optical component makers, Lumentum's revenue was down 6.5%, driven by a drop from Huawei of 25% (down $20m - better than the feared $30m+, before resuming non-EAR shipments late in the quarter) — see page 44. Revenue of $404.6m hence exceeded reduced guidance of $375–390m and almost reached the original guidance of $405–425m. However, September-quarter revenue from Huawei should be flat to down.

Huawei fell from 49% to a better-than-feared 36% of NeoPhotonics' sales of $81.7m, down on original guidance of $88–93m but above the revised guidance of $75–80m, aided by re-starting non-EAR product shipments (which comprise most shipments to Huawei) late in the quarter (page 42).

Finally, Emcore's revenue of $17.2m was down on its original guidance of $20–22m, as chip product sales fell from 16% to 11% of revenue (page 48). "An anti-American stance has been taken for many new design-ins in China, threatening to limit future opportunities to only those products that cannot be sourced from China, Taiwan, Korea or Japan," says CEO Jeffrey Rittichier. "Consequently, we are also working to change our supply chain strategy to minimize the impact of additional tariffs," he concludes.

Mark Telford, Editor

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

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

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GaN micro-LED market to grow at 43.5% CAGR to 2029, driven by display applications

Sector to see massive investments in R&D and fabrication technology

The GaN micro-LED market will rise by 33% from $150,000 in 2018 to about $197,000 in 2019, then rise at a compound annual growth rate (CAGR) of 43.5% over 2019–2029 as the technology promises to offer better and brighter displays as well as lighting than existing solutions, forecasts a report 'GaN Micro-LED Market — Embracing the New-Age Display Technology' from Future Market Insights.

GaN micro-LEDs have been in research labs for years, and the launch of Samsung's micro-LED displays (featuring self-emissive technology and modular capabilities) left consumers curious about the emerging technology. However, GaN micro-LEDs will soon be a mass-market proposition, as arrays of millions of microscopic LEDs are set to replace incumbent technologies such as LCDs and OLEDs and penetrate major digital displays markets, reckons the report.

Despite their extremely high price tag and significant complexity in design, GaN micro-LEDs are gradually finding acceptance in a wide range of applications, in view of their greater efficiency, improved brightness and lower power consumption. As the war for supremacy in innovation continues in display markets, GaN micro-LED players are putting greater emphasis on getting production challenges under control and bringing costs down, says the report.

Sensing the application potential of GaN micro-LEDs in newer models of TVs, smartwatches, augmented reality (AR) devices and head-mounted systems such as Google Glass, stakeholders are investing strongly in R&D and deepening their collaborations with technology solution providers.

Mid-power micro-LEDs for lighting applications to capture robust share

The consumption of mid-power GaN micro-LEDs, which accounted for ~75% share in 2018, will become mainstream for lighting applications in the years ahead, forecasts the report. However, a significant proportion of costs goes into packaging, limiting the advantage of reducing overall costs. On the other hand, demand for low-power micro-LEDs is likely to gain significant traction in the future, in view of maintaining full brightness without the loss of noticeable display brightness over the entire illumination time.

Greater demand for GaN micro-LED displays will continue to influence the growth strategies, accounting for about 79% share in 2018. Growth will continue to be driven by demand for visual aspects in modern-day devices, the increasing need for high luminance in small formats for near-to-eye display devices, and demand for high resolution and efficient luminance in battery-powered consumer electronics, the report notes.

Market gains underpinned by innovations in sports & entertainment

In recent years, great potential for GaN micro-LED application has been identified in the sports & entertainment space, due to a spike in the number of video-streaming services, the rapid innovations in television to enhance the viewing experience, and increased penetration of new-generation video-gaming products and accessories, says the report.

The consumption of mid-power GaN micro-LEDs, which accounted for ~75% share in 2018, will become mainstream for lighting applications in the years ahead

While consumer electronics are likely to account for the major share of manufacturers' bottom lines, capitalizing on the ever-expanding sports & entertainment space will remain a key focus of market players.

On the other hand, the consumption of GaN micro-LEDs by the automotive industry will grow by about 39% year-on-year in 2019, backed by the emergence of 'in-car ambience' and 'auto-infotainment' trends leading to innovations in automotive displays units as well as interior automotive lighting.

North America in vanguard; APEJ to outdo European market

Accounting for 26% share in 2018, North America is expected to remain at the forefront of GaN micro-LED market. The European market is likely to lose second position in the foreseeable future to the Asia Pacific (APEJ, excluding Japan), where many players are continuing to demonstrate progress and making the latest breakthroughs in GaN micro-LED technology.

Unprecedented evolution in the number of industry verticals has pushed stakeholders to redefine their growth strategies to retain and attract new categories of customer, states the report. In addition to focusing entirely on new technology while curtailing the launch of conventional solutions, stakeholders are centered on collaborating with research institutes in order to synchronize their advances, the report concludes.

www.futuremarketinsights.com/reports/gan-micro-led-market

Automotive LED revenue still growing at 7% CAGR, with Everlight entering top ten in 2018

The global automotive market has been showing declines since 2018 amid global trade frictions and economic recessions, but the penetration rates of LEDs in various major automotive lighting products has continued to rise, according to the '2019 Global Automotive LED Market Report- Passenger Car and Box Truck' by LEDinside (a division of TrendForce). Furthermore, new energy cars have a greater demand for LEDs than traditional cars while boasting faster growth in shipments. This will cause the volume of and revenue for automotive LED products to maintain modest growth in future years, with automotive LED revenue forecast to reach US$3.17bn in 2019 while rising at a compound annual growth rate (CAGR) of 7% during 2018–2023.

Automotive LED revenue declining for European and American suppliers, with Asian suppliers performing brilliantly

"Looking at the automotive LED revenue rankings for major LED package suppliers worldwide, we see Osram Opto Semiconductors, Nichia and Lumileds still taking the top three in 2018," says TrendForce analyst Terri Wang. "However, we may find that, amid declining car markets in both China and the USA, Osram, Lumileds and other suppliers registered flat growth or small declines in revenue from automotive LED products in 2018. Japan's vehicle market gave a rather brilliant performance in 2018, allowing Japanese LED suppliers to post continual revenue growth. Seoul Semiconductors stood out among Korean suppliers by eagerly meeting the demands of customers for high power and reliability in the automotive exterior LED lighting sector, giving steady revenue growth for automotive products."

TrendForce also notes that Everlight, Cree and other suppliers are actively establishing their place in the OE market and posted significant growth in revenue. Everlight's automotive LED products yielded revenue of about US$48m, placing the firm eighth globally and making it the only Taiwanese supplier in the top ten. Everlight currently offers mass-produced headlight LEDs, which are poised to penetrate the market consisting of top-tier European and American vehicle manufacturers. It also plans to develop matrix LED headlights in collaboration with German manufacturer Hella, to be used in new car models for 2019. Everlight has also released tail-light mini LED concept products, manufactured using its own small-pitch display components and poised to find application in 2020. Furthermore, Everlight plans to extend its business to automotive modules, and is already scheduling the construction of a module production line in its Suzhou plant. We may hence see Everlight grabbing a bigger portion of the automotive lighting market in the future, says the report.

Global automotive LED revenue rankings (Source: TrendForce, August 2018).

Ranking	Supplier
1	Osram Opto Semiconductors
2	Nichia
3	Lumileds
4	Stanley
5	Seoul Semiconductor
6	Dominant
7	Samsung
8	Everlight
9	Cree
10	Citizen

Amid declining car markets in both China and the USA, Osram, Lumileds and other suppliers registered flat growth or small declines in revenue from automotive LED products in 2018

Headlights growing strongly, with ambient light seeing greater penetration in high-end market

For product development, an increasing variety of LED headlights is seen on the market, with mainstream suppliers releasing mono-chip or double-chip LEDs for use in low-beam applications. As LEDs move towards smaller sizes, headlights are being designed with increasing flexibility as the range of features in demand go beyond lighting to include intelligent systems and even projectors. Revenue and penetration rates for LED headlights are expected to keep growing in the future years to come.

For automotive interiors, some suppliers are releasing LED products with RGB or better specifications for use in ambient lights within cars in an attempt to go along with the current intelligent lighting trend. This allows them to realize effects such as full-color mixing and dynamic ambience. Suppliers of ambient light LEDs mainly comprise Dominant, Osram, Everlight, Lite-On, and Brightek.

Everlight, for example, released its new 0.2W 2525 LED for use in ambient lights and allows customers to decide which chip combination (eg RRYY or RGBB) is most suitable for the interior of their cars. These products have a richer range of colors than that of RGB LEDs.

The emergence of ambient lights may also drive revenue for LEDs used in decorative lights for car interiors. Currently, full-color LED ambient lighting products are being launched into high-end car models in the OE market. As product specifications continue to develop and market demand rises, these will find widespread use in mid-range cars in the future, concludes the report.

www.ledinside.com

Qorvo's quarterly revenue exceeds revised guidance, aided by select allowed product shipments to Huawei

Growth in profit margins and record free cash flow driven by cost control and CapEx discipline

For fiscal first-quarter 2020 (ended 29 June 2019), Qorvo Inc of Greensboro, NC, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has reported revenue of $775.6m, up 13.9% on $680.9m last quarter and 12% on $692.7m a year ago. This is below the original guidance of $780-800m but above 21 May's revised $730–750m guidance, driven by stronger-than-expected mobile demand. About half of the favorable revenue variance (i.e. about $18m) was from the shipment of select products to Huawei in June following an extensive legal review, after US Department of Commerce's Bureau of Industry and Security (BIS) added Huawei to its 'Entity List' prohibiting the sale to Huawei of any products covered by the Export Administration Regulations (EAR) without obtaining an appropriate export license. Sales to Huawei were $172m (22% of total revenue — mostly pre-ban), compared with 14% a year ago and 15% for full-year fiscal 2019. The rise — despite the Huawei ban — is attributed to a combination of Huawei gaining market share and Qorvo gaining market share at Huawei.

"Qorvo delivered June quarter results above revised guidance on strong operating performance and increased overall mobile demand, including select product shipments to Huawei late in the quarter," notes chief financial officer Mark Murphy.

Mobile Products (MP) revenue was $556m, up 25% on $443m last quarter and 14.4% on $486m a year ago, driven by double-digit year-on-year growth with several of Qorvo's top customers.

During the quarter, Qorvo:

- expanded its Wi-Fi 6 portfolio with high-frequency 5GHz BAW filters and secured a design win for a BAW-based iFEM (enabling industry-leading range, throughput and signal integrity);
- secured design wins for coexistence BAW filters and LNAs in support of General Motors, Volkswagen and other automotive OEMs;
- extended power management technologies into new verticals and delivered power management solutions supporting a range of applications (including Skil power tools);
- selected by a leading Korea-based smartphone maker to supply antenna-tuning, high-band and ultra-high-band solutions for 5G marquee device ramping in 2019;
- secured design win at a leading China-based OEM to supply a complete set of low-, high- and ultra-high-band solutions for an upcoming 5G smartphone;
- supplied Samsung with an antenna-tuning, high-band PAD and Wi-Fi iFEM for the mass-market Galaxy A series (significantly expanding product and dollar content in the mid-tier);
- began volume shipments of band 1/3/7 BAW-based hexaplexers (enabling higher orders of carrier aggregation for the export market) to multiple leading China-based smartphone OEMs; and
- received orders for newly released BAW-based antennaplexers and gained the first design win for a programmable 5G antenna tuner capable of performing aperture and impedance tuning.

Despite falling 8% from $238m last quarter, Infrastructure & Defense Products (IDP) revenue of $219m is still up 5.8% on $207m a year ago (despite the issues with Huawei) due mainly to higher demand for infrastructure products (with double-digit revenue growth year-on-year for base stations).

During the quarter, Qorvo:

- expanded gallium nitride (GaN) shipments into S-band (2–4GHz) and C-band (4–8GHz) applications for defense radar programs (complementing its strong presence in high-frequency bands up through millimetre-wave frequencies);
- was selected to supply wideband GaN amplifiers for low Earth orbit (LEO) satellites enabling OneWeb space-based Internet connectivity anywhere in the world.

"Qorvo delivered a strong June quarter, highlighting our technology portfolio and operational excellence," says president & CEO Bob Bruggeworth. "We effectively managed our business and capitalized on underlying growth drivers in our markets despite global trade and economic headwinds."

On a non-GAAP basis, gross margin was 46.2%, down from 48.2% last quarter but up from 44% a year ago, and above the 45–45.5% guidance due to favorable mix and manufacturing productivity gains.

Operating expenses (OpEx) have grown further, from $160.5m a year ago and $160.8m last quarter to $167.9m, but this is below the $173m guidance due to lower personnel costs and effective cost-control measures.

Net income has risen further, from $124m ($0.96 per diluted share) a year ago and $150.9m ($1.22 per diluted share) last quarter to $165.3m ($1.36 per diluted share, above both the $1.30 original guidance and 21 May's $1.15 revised guidance).

Cash flow from operations was $257.1m (up on $187m last quarter). Capital expenditure (CapEx) was $50.3m (up from last quarter's low of $35.3m). Reflecting the "strong operating income generation, working capital effects, and capex discipline", free cash flow was hence a record $206.8m (rising from $152m last quarter and just $31.7m a year ago).

"During the quarter, we completed the purchase of Active-Semi International, adding rapidly growing power management opportunities to our diversified IDP portfolio," says Murphy. "Both the integration and business plans are on track." Also during the quarter, Qorvo repurchased $100m of its stock. Cash and cash equivalents overall hence fell by $81m from $711m to $630m.

"The June quarter was challenging with the abrupt disruption of sales to an important customer and other evolving market conditions," says Murphy. "But Qorvo responded well and delivered a strong quarter of double-digit year-over-year sales growth and record first-quarter earnings and free cash flow."

"Our outlook for the September quarter considers seasonal ramps offset by the continued impact of US Department of Commerce trade restrictions," says Murphy.

For the fiscal second-quarter 2020 (to end-September 2019), Qorvo expects revenue to fall to $745–765m (down by about $130m from the record $884.4m a year previously), despite typical seasonal ramps of flagship products at Qorvo's largest customer driving Mobile Products revenue growth, which will be only slight due to being offset by significantly lower sales to Huawei and, to a lesser extent, China. For full-year fiscal 2020, Qorvo expects sales to Huawei will fall below 10% of total revenue, driving Mobile Products down 10% in the second half compared with the first half due to trade effects and seasonality. "Although we have filed for a license and are taking other proactive steps to address our ability to sell products to Huawei, the scope, duration and long-term financial impact of the restrictions remain unclear and difficult to predict," notes Murphy. Due to these restrictions, IDP sales should fall again in the September quarter. However, they should rebound in the December quarter and recover through the year as the infrastructure market picks up with other customers and Wi-Fi and other markets strengthen, reckons Murphy.

Gross margin should be flat in fiscal Q2/2020, at 46–46.5%, with productivity gains plus some positive mix effects being counteracted by (1) lower volumes (with IDP being down sequentially) enhancing weaker-than-previously forecasted utilization; and (2) the seasonal ramp in mobile being typically dilutive to gross margin. For full-year fiscal 2020, Qorvo originally (before the Huawei ban) expected gross margin of about 48%.

Spending remains weighted towards improving bulk acoustic wave filters and GaN capabilities

"But there is a couple of hundred million dollars of revenue hit that we've taken versus our 7 May guidance [for full-year revenue growth of 4%] that has really reduced the utilization in the factory network," says Murphy. So, Qorvo now expects 46–47% gross margin.

Operating expenditure is projected to fall only slightly in fiscal Q2/2020 to $166m as cost-control benefits are offset by investments in growth programs and the full-quarter addition of the Active-Semi programmable power management business. OpEx is expected to remain below $170m per quarter for the rest of the fiscal year. Diluted earnings per share should be $1.30 for fiscal Q2/2020.

CapEx is projected to be under $200m for full-year fiscal 2020 as Qorvo continues to be highly disciplined on adding capacity. Spending remains weighted towards improving bulk acoustic wave (BAW) filters and GaN capabilities. "We are exhibiting good cost control, good working capital management and good CapEx discipline and expect to see free cash flow growth [through a combination of sustaining decent income despite the sales drop relative to our previous view]," says Murphy.

"Looking forward, Qorvo's products and technologies position us to lead as 5G ramps and IoT proliferates," reckons Bruggeworth.

www.qorvo.com

Skyworks' board gains automotive industry veteran

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

Batey most recently served as executive VP & president of North America for General Motors, as well as the global brand chief for its Chevrolet division. As a member of the senior leadership team, he was responsible for the firm's largest and most profitable region, with over $100bn in revenue and more than 100,000 staff. His career spans more than 39 years with GM, where he held senior management positions in operations, marketing and sales around the world. Batey completed GM's senior executive program at Harvard University and received a certificate in Mechanical Engineering Maintenance Craft Studies from The City and Guilds of London Institute.

"His deep automotive experience and insights will be invaluable, particularly as wireless connectivity becomes increasingly vital for today's connected cars and emerging autonomous vehicles," comments Skyworks' chairman David J. Aldrich.

"I look forward to leveraging my global experience in the automotive industry to help Skyworks diversify across the Internet of Things, capitalize on 5G and achieve its vision of 'Connecting Everything and Everyone, All the Time'," says Batey.

www.skyworksinc.com

Skyworks' quarterly revenue falls 5.4% due to Huawei ban

September quarter to see 8% growth, or 20% in non-Huawei business

For fiscal third-quarter 2019 (ended 28 June), Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) has reported revenue of $767m, down 5.4% on $810.4m last quarter and 14.2% on $894.3m a year ago.

This is below the original guidance of $815–835m, impacted by the US Department of Commerce's Bureau of Industry and Securities (BIS) on 15 May adding smartphone and telecom network infrastructure maker Huawei Technologies Co Ltd and 68 of its affiliates to its 'Entity List' prohibiting the sale to Huawei of products covered by the Export Administration Regulations (EAR) without obtaining an appropriate license. Skyworks subsequently ceased all shipments to Huawei (which had contributed 12% of total revenue in fiscal first-half 2019).

On 4 June Skyworks hence reduced its guidance by $60m to $755–775m. However, fiscal Q3 revenue came in $2m above the midpoint of this. Shipments to Huawei prior to the ban becoming effective still contributed 10% of revenue (although it had been running at 15%, since fiscal Q3 is the stronger seasonal quarter for Huawei).

By market sector, revenue for Mobile (Integrated Mobile Systems and Power Amplifiers) shrank 10% sequentially, falling further from 67% of total revenue last quarter to 63%. Broad Markets revenue was up by low-single digits both sequentially and year-on-year, rising further from 33% of total revenue last quarter to 37%.

During the quarter, Skyworks:

- powered Samsung's Galaxy S10 premium 5G smartphone;
- leveraged SkyOne and SkyLiTE across Oppo, Vivo and Xiaomi flagship phones;
- shipped 5G circulators, LNAs and controllers to leading European infrastructure manufacturers;
- unveiled high-efficiency amplifiers enabling 5G massive MIMO TDD base stations for a tier-one Korean customer;
- bolstered its Sky5 portfolio with MIPI ultra-high-linearity antenna tuners;
- ramped 802.11ax engines for Cisco's enterprise platforms;
- expanded its automotive footprint with CAT 6 LTE modules for embedded in-vehicle displays;
- enabled Facebook's Oculus virtual reality gaming headsets with highly integrated SkyOne connectivity solutions;
- captured content in award-winning wireless earphones designed for Xbox;
- launched analog SoCs and cognitive wireless devices for Vizio sound bars and wireless subwoofers; and
- introduced proprietary low-k materials for thermal barrier coatings in aerospace applications.

On a non-GAAP basis, gross margin has fallen further, from 50.9% a year ago and 50.7% last quarter to 50.4% (below the 50.5–51% guidance).

Operating expense (OpEx) has been cut further, from $135m last quarter to $134m (better than the expected $137m).

Net income has fallen further, from $299.9m ($1.64 per diluted share) a year ago and $256.6m ($1.47 per diluted share) last quarter to $233.6m ($1.35 per diluted share, below the originally forecasted $1.50 but slightly above the revised guidance of $1.34).

"The core fundamentals of our business remain strong despite current market volatility," says president & CEO Liam K. Griffin. "The resiliency of our business model allowed us to maintain strong profitability and cash flow."

Cash flow from operations was $209.3m (down from $258m but up from $192.1m last quarter, contributing to $950m year-to-date). Capital expenditure (CapEx) has been cut further, from $191.5m a year ago and $96.7m last quarter to $87.8m (but still about 12% of revenue).

During the quarter, Skyworks distributed $65.7m in dividends and repurchased 1.2 million shares of common stock for $85.8m (contributing to $710m returned to shareholders via share repurchases and dividends year-to-date, or 112% of the free cash flow generated).

Overall, cash, cash equivalents and marketable securities hence fell from $991m to $970.1m. The firm has no debt.

Inventory was up by $25m (and days of inventory up by 13 days to 139 days). "During our seasonal slowest quarter of the year here, we definitely have been level loading our factories in order to drive efficient usage of our capital equipment," says senior VP & chief financial officer Kris Sennesael. "All of it of course is in support of the new product ramps that we have with our key customers."

"Our capital investments have enabled us to build highly specialized vertically integrated supply chains capable of meeting the complex demands of the world's most innovative customers," says Griffin. "We continue to advance our filter capabilities, creating leadership positions in surface acoustic wave (SAW) and temperature-compensated surface acoustic wave (TC-SAW) filters, and in Q3 we commenced volume production of bulk acoustic wave (BAW)-enabled Sky5 devices [shipping in fiscal Q4]. Incorporating BAW expands our TAM [total addressable market] in mobile and positions us to support a wider array of customers, markets and applications," he adds.

"Four or five years ago, we were making none of the filters in-house. We were purchasing them all from third parties, and maybe two years ago we got to roughly 50% of the filters in-house. Now, we are getting close to 95% of the filters in-house," says Sennesael. "That is

obviously driving some higher levels of inventory. But again inventory is fully in line with what we expected [fluctuating between 110 days to 140 days — slightly higher than historical levels], and days of inventory will come down in the September and December quarters [as Skyworks consumes some inventory]."

"After an in-depth review of the Export Administration Regulations and the scope of the Entity List restrictions, we ultimately determined that we could lawfully resume shipping certain products, which we did start in early July," notes Sennesael. "However, we expect the business with Huawei to remain well below historical level into the current quarter," he adds.

"Skyworks is on track to deliver sequential revenue and earnings growth in the September quarter as we execute on strategic product ramps," says Sennesael.

For fiscal fourth-quarter 2019 (to end-September), Skyworks expects revenue to grow 8% sequentially to $815–835m, despite revenue from Huawei probably falling below $10m. "We can legally ship certain products, but the demand signal that we get from Huawei is actually very low," says Sennesael. "The revenue outlook assumes Huawei revenue remains at nominal levels, given the uncertainty associated with ongoing trade related issues," he adds. "Excluding Huawei in the June and September quarters, we expect our revenue to increase 20% sequentially, reflecting strong seasonal ramps at our large customers as we demonstrate our expanding reach and ability to deliver complex and highly integrated solutions."

Gross margin should be flat to only slightly down at 50–50.5% in fiscal Q4, despite the lower factory utilization from the reduced demand from Huawei. OpEx is targeted to remain low, at $135m. Diluted earnings per share should be $1.50. CapEx may trend to below 12% of revenue, believes Sennesael.

"If we net out the effects of Huawei, in the fiscal Q1/2020 December quarter, we see sequential growth coming again," notes Griffin.

After an in-depth review of the Export Administration Regulations and the scope of the Entity List restrictions, we ultimately determined that we could lawfully resume shipping certain products, which we did start in early July. However, we expect the business with Huawei to remain well below historical level into the current quarter

"Our design-win pipeline is expanding, as we capitalize on the ramp of 5G and wireless infrastructure, smartphones and across IoT," says Griffin. "For example, in wireless infrastructure Skyworks is now supporting a number of global 5G deployments. Our solutions address both 5G macro base stations and small-cell radios. And we are ramping today with leading European and Japanese infrastructure OEMs. In addition, Skyworks is enabling 5G massive MIMO base stations for a leading Korean customer," he adds. "Across the IoT space, we are gaining share in new emerging categories, with recent wins at Facebook for their Oculus VR headset and with Vizio for their sound bars, leveraging our analog SOCs and cognitive wireless radios. We also secured low-power LTE CAT M design wins with the leading module providers, including Telit, Gemalto, U-Blox and Sierra Wireless. And we are expanding our reach in the wearables market, where we are populating devices that combine our cellular and Wi-Fi technology."

"We've also extended our Wi-Fi leadership with several signature design wins in the last quarter, including Cisco with their Wi-Fi 6 solutions, DirectTV for over-the-top (OTT) streaming devices, as well as design wins with industry leaders such as Amazon, Nest and Netgear," Griffin says.

"In mobile, for the coming wave of 5G phones, we've deepened our engagements with key customers, leveraging our unique suite of solutions to support launches at Samsung, LG, Oppo, Vivo and others."

"As these opportunities demonstrate, the demand for advanced connectivity and the expansive nature of 5G are creating real-time opportunities for architectures that facilitate high-speed data, near-zero latency and exceptional reliability," says Griffin. "We are leveraging our Sky5 platform and systems expertise to enable billions of connections across a vast set of diverse end markets, providing the foundation for an entirely new ecosystem. With 5G now launched on four continents, operators are seeing the compelling economics that 5G services can bring. We expect momentum to continue building into 2020 and beyond."

"In addition to 5G, our capabilities in Broad Markets have grown as we now serve an expanded set of global customers, including companies like Ford, Continental and LG, along with factory automation leaders such as Bosch, Honeywell, Siemens and GE," continues Griffin. "Today we generate nearly $1.1bn in annual revenues from our Broad Market portfolio. That's a compound annual growth rate (CAGR) of 16% since 2013."

"Given our confidence in Skyworks' strategic outlook and strong cash flow generation, we are announcing a substantial raise to our quarterly dividend." Skyworks' board of directors has declared a cash dividend of $0.44 per share of common stock (payable on 17 September, to stockholders of record at the close of business on 27 August), representing a 16% increase from the prior quarterly dividend of $0.38 per share.

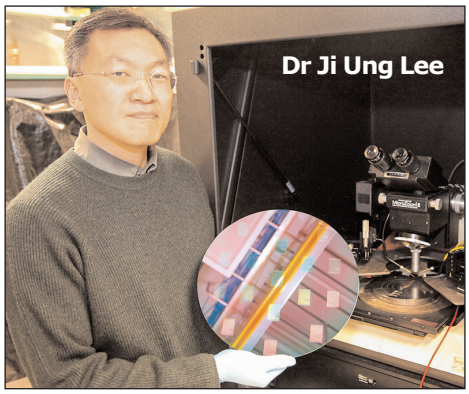
www.skyworksinc.com

NRL awards SUNY Poly $6.25m, five-year grant to use new nanoscale materials to develop electronic devices

The US Naval Research Laboratory (NRL) has awarded $6.25m in federal funding (over five years) to Dr Ji Ung Lee (professor of Nanoscale Engineering) to leverage the 300mm fabrication facility at the State University of New York (SUNY) Polytechnic Institute's Albany campus and use new nanoscale materials to fabricate advanced electronic devices in order to impart more functionalities to future computer chips. Lee's team will also develop artificial intelligence (AI)-specific hardware, which could lead to greater efficiency for AI applications, such as pattern and voice recognition. The grant represents SUNY Poly's largest single investigator-faculty award to-date.

The research "could lead to exciting advancements for a variety of both military and public applications that depend on efficient and highly capable electronic hardware," says SUNY Poly's interim president Dr Grace Wang.

As part of the award, a number of SUNY Poly graduate students and post-doctoral researchers will be able to take part in the characterization



of the materials and devices to be fabricated inside the 300mm cleanrooms. Also, the researchers plan to work closely with an on-site engineering team to be able to fabricate the devices, which will incorporate reconfigurable logic capabilities and 3D monolithic integration technologies to help continue to advance Moore's Law. Lee will also develop special electronics for the Navy.

The work is a "culmination of ten years of impactful, collaborative research," says Lee. "With our world-class fabrication capabilities, and together with our experienced SUNY Poly team including dedicated engineers and students, we are fortunate to be leading the way in the development of cutting-edge devices to address NRL and Department of Defense needs," he adds. "I am also thrilled to provide students with a truly unique experience where they will be able to learn first-hand the skills required to advance technologies in this growing and important field."

The research 'SOI Wafer Development and Post CMOS Devices for NRL/DOD requirements' will include examination of the fundamental properties of materials, leading to the development of novel nanoscale electronic devices to achieve the team's engineering objectives. Along with the partnering engineering team, Lee's group plans to fabricate advanced AI-specific hardware to achieve more efficient chips for pattern and image recognition, allowing these applications to be run on handheld devices, in addition to carrying out advanced nanoscale electronic device development in Lee's laboratory to support the fabrication efforts.

www.sunypoly.edu

Arralis launches integrated low-profile K/Ka-band SmallSat transceiver

Arralis Technologies of Limerick, Ireland — which has a design center in Belfast and manufactures RF, microwave and millimeter-wave devices, modules and antennas up to and beyond 110GHz (the W-band) for aerospace/satellite and security markets — has launched its LE-KaTR-102 K/Ka-band transceiver, designed to fit within a 1U cubesat profile (100mm x 100mm x 100mm) for satellite applications , covering 27–30.5GHz in the uplink band and 17–21.2GHz in the downlink band.

The system utilizes Arralis' Leonis monolithic microwave integrated circuit (MMIC) portfolio and a fully integrated voltage-controlled oscillator (VCO) and phase-locked loop (PLL) with IQ mixers, for high-speed datacom links between satellites and ground-based stations. The Leonis chipset was developed to meet the growing demand for low-cost K/Ka-band satellite equipment that is simple to interface with existing digital internet hardware.

"Our experienced integrated MMIC design team, and company-wide capability from antenna design right through to full system integration, has enabled us to meet the challenges of developing this low-profile, integrated system," says transceiver principal design engineer Michael Major. "We see the LE-KaTR-102 transceiver as an important component in the future delivery of LEO [low Earth orbit] mega constellations and the realization of worldwide high-speed data communications."

Arralis showcased the new system at the 31st Annual AIAA/USU Conference on Small Satellites (SmallSat 2019) in Logan, Utah (5–8 August). The firm aims to work with interested customers who wish to evaluate the system.

Arralis also announced its expansion into the US market with the official opening of its Florida office in Daytona on 12 August.

www.arralis.com

US Army awards Lockheed Martin contracts for additional GaN-based Q-53 radars and capabilities

The US Army recently awarded Lockheed Martin of Bethesda, MD, USA three contracts to produce additional Q-53 systems and outfit the radar with enhanced capabilities, including extended range and counter unmanned aerial system (CUAS) surveillance. The flexible architecture of the Army's most modern radar allows for these upgrades, which support adaptable growth of the system to address aircraft, drone and other threats in the future.

In use around the world since 2010, the primary mission of the Q-53 is to protect troops in combat by detecting, classifying, tracking and identifying the location of enemy indirect fire in either 90 or 360-degree modes.

"The warfighter needs new and improved capabilities. The Q-53 represents a fast path to respond to current and emerging threats," says Rick Herodes, director of the Q-53 program at Lockheed Martin. "The flexibility of the architecture continues to allow the Q-53 to provide capabilities far beyond the original mission and allows for additional upgrades in the future," he adds.

- Full-rate production — The Army awarded Lockheed Martin a contract for a third lot of 15 full-rate production systems. Once this contract is delivered, the Army will own 189 Q-53 systems. The Lot 3 systems will continue to be produced using gallium nitride (GaN) transmit-receive modules, providing the radar with additional power, reliability and the possibility for enhanced capabilities including extended range, counterfire target acquisition (CTA) and multi-mission, which delivers simultaneous CTA and air surveillance.
- Surveillance — Lockheed Martin was also awarded a contract to enhance the Q-53's CUAS capability. This true multi-mission capability delivers simultaneous counterfire, CUAS and air surveillance.
- Extended range — Lockheed Martin was also awarded a contract by the Army that will extend the operating range of the Q-53 system by utilizing recent next-generation technology insertions already available in the radar.

Lockheed Martin uses an open GaN foundry model, leveraging relationships with commercial suppliers that utilize the power of the expansive telecoms market to provide military-grade GaN modules while taking advantage of commercial cost efficiencies.

www.lockheedmartin.com/gbas

GTAT and GlobalWafers sign multi-year deal to develop source of SiC wafer supply

Silicon wafer maker GWC to add 150mm silicon carbide, manufactured from GTAT's bulk SiC crystal

GTAT Corp of Hudson, NH, USA (which produces crystal growth equipment for the solar, power electronics and optoelectronics industries as well as sapphire material for precision optics and other specialty industries) and GlobalWafers Co Ltd (GWC) of Hsinchu, Taiwan have entered into a long-term agreement whereby the expertise of both companies will combine to forge a new source of supply of silicon carbide (SiC) wafers.

Already one of the world's three largest silicon wafer manufacturers — having been founded in 1981 as the semiconductor business unit of SAS (Sino-American Silicon Product Inc.) before being spun off in 2011 — GWC will now add 150mm silicon carbide to its offering, made from bulk SiC crystal produced by GTAT. As the electric vehicle (EV) and power electronics industries shift away from silicon to SiC, GTAT and GWC aim to pool their respective capabilities to increase supply while lowering costs for the high-demand substrate material.

"The fundamental advantages of silicon carbide are well known and demand for it is high, but it's a difficult material to make," says GTAT's president & CEO Greg Knight. "Because of our crystal-growth knowhow and ability to master this complex process, we can positively shape and influence the SiC wafer industry by diversifying the supply chain, enabling higher wafer volumes and lowering costs significantly for this high-value material," he reckons.

For GTAT, the agreement marks the completion of an 18-month transition from selling equipment to providing advanced materials. By utilizing this incoming supply of SiC material from GTAT, GWC can now apply years of wafer process development to become a SiC wafer supplier

For GTAT, the agreement marks the completion of an 18-month transition from selling equipment to providing advanced materials. By utilizing this incoming supply of silicon carbide material from GTAT, GWC can now apply years of wafer process development to become a SiC wafer supplier, complementing its other substrate offerings. "The power electronics industry needs supply agreements such as the one we've entered into with GWC," says Knight.

"Bringing our companies' respective technical strengths together will benefit high-growth industries such as EV because we will increase the global supply of silicon carbide wafers," says GWC's chairperson & CEO Doris Hsu. "Pairing our expertise in wafers with GTAT's premiere-quality silicon carbide crystal will enable important, high-growth industries like EV to reach key adoption milestones sooner and at lower cost," she adds.

www.gtat.com
www.sas-globalwafers.com

GTAT introduces 150mm bulk SiC crystal material for rapidly expanding markets

GT Advanced Technologies Inc (the parent company of GTAT Corp of Hudson, NH, USA) is introducing its CrystX silicon carbide (SiC) material for power electronics applications such as electric vehicles.

With decades of experience in crystal growth, GT Advanced Technologies is producing CrystX SiC in increasing volume for expanding markets that demand the technical advantages that the material enables. "Our heritage in crystal growth gives us a tremendous platform from which to produce CrystX silicon carbide with an aggressive cost-down focus going forward," says president & CEO Greg Knight. "We are at-scale now for volume production and can add capacity more rapidly than anyone in the industry," he claims. SiC will allow electric vehicles to have markedly better range because the material enables much smaller and lighter modules and circuits, the firm notes. This holds true for other industrial applications where high-power and high-temperature demands preclude the use of more common silicon material.

CrystX silicon carbide is available in bulk-crystal form and ready for wafering. Presently, the available form factor is 150mm in diameter, with a target usable height of 25mm or greater.

"The rapidly growing power electronics and EV markets can now take advantage of our ability to produce exceptionally high-quality CrystX silicon carbide at volumes and cost structures that global markets will demand," concludes Knight.

Cree wins $85m multi-year deal to supply silicon carbide wafers to ON Semiconductor

Agreement to boost commercial expansion of SiC in automotive and industrial applications

A multi-year agreement worth more than $85m has been executed whereby Cree Inc of Durham, NC, USA will produce and supply its Wolfspeed 150mm silicon carbide (SiC) bare and epitaxial wafers to ON Semiconductor Corp of Phoenix, AZ, USA – which supplies power management, analog, sensors, logic, timing, connectivity, discrete, system-on-chip (SoC) and custom devices – for use in high-growth markets, such as electric vehicle and industrial applications.

"ON Semiconductor continues to be a leader in driving the development of energy-efficient innovations and devices," says ON Semiconductor VP & chief procurement officer Jeffrey Wincel. "Partnering with Cree is essential in maintaining a world-class supply base. This agreement supports our commitment to growing automotive and industrial applications and ensuring the availability of industry-leading silicon carbide that helps engineers solve their unique design challenges," he adds.

"We are committed to leading the global semiconductor market's transition from silicon to silicon carbide solutions and are pleased to support ON Semiconductor as we work to accelerate this market," says Cree's CEO Gregg Lowe. "This is the fourth major long-term agreement for silicon carbide materials that we have announced in the past year and a half," he notes. "We will continue to drive silicon carbide adoption and availability through ongoing wafer supply agreements, such as this, and our recently announced major capacity expansion."

www.onsemi.com
www.cree.com

UnitedSiC adds 650V FET packages to UF3C FAST Series

Power semiconductor maker United Silicon Carbide Inc (USCi) of Monmouth Junction, NJ, USA has added two new TO220-3L package options to its growing range of hard-switching UF3C FAST series of 650V SiC field-effect transistors (FETs).

The new products have on-resistance ($R_{DS(on)}$) of 30mΩ (UF3C065030T3S) and 80mΩ (UF3C065080T3S). The three-leaded, industry-standard TO220-3L package features enhanced thermal characteristics made possible by a sintered-silver packaging technology developed by UnitedSiC.

The new devices are targeted at designers seeking more powerful performance in a 3-lead TO220 package option for applications such as electric vehicle (EV) charging, solar photovoltaic (PV) inverters, switch mode power supplies (SMPS), power factor correction (PFC) modules, motor drives and induction heating.

Both new SiC FET products are based on a unique UnitedSiC cascode circuit configuration, in which a normally-on SiC JFET is co-packaged with a silicon MOSFET to produce a normally-off SiC FET device. The device's standard gate-drive characteristics allows a true 'drop-in replacement' to silicon IGBTs (insulated-gate bipolar transistors), silicon FETs, SiC MOSFETs or silicon superjunction devices on existing designs in which designers can expect a performance increase with lower conduction and switching losses, enhanced thermal properties and integrated gate ESD protection.

UnitedSiC says that, in the case of new designs, its FETs deliver increased switching frequencies to gain substantial system benefits in both efficiency and reduction in size, and cost of passive components, such as magnetics and capacitors. The FAST Series devices are said to offer not only ultra-low gate charge but also the best reverse recovery characteristics of any device of similar ratings. The devices are suitable for switching inductive loads when used with recommended RC-snubbers, and any application requiring standard gate drive.

The UF3C FAST SiC series (which now totals 14 devices) is available in a range of TO247-3L, TO247-4L, TO220-3L and D2PAK7-3L packages, with four 1200V and ten 650V options.

Prices are $5.18 for the UF3C065080T3S and $13.79 for the UF3C065030T3S, each in 1000-unit quantities. Stock is available from global distribution partners Mouser and Richardson Electronics, as well as other local distributors.

www.unitedsic.com

PowerAmerica awards $24m to 24 new projects to advance wide-bandgap technology in USA

More than $100m now awarded to over 100 projects since 2015

The PowerAmerica Institute at North Carolina State University (NCSU) in Raleigh, NC – a member of Manufacturing USA – has awarded $24m in funding to 24 new member projects that aim to enhance wide-bandgap technologies in the USA.

"These projects are instrumental in fulfilling PowerAmerica's mission of accelerating commercialization of wide-bandgap power electronics," says PowerAmerica executive director & chief technology officer Victor Veliadis. "They also aim to expeditiously produce a highly skilled workforce, which is key in creating the large wide-bandgap demand that spurs mass manufacturing with its cost-lowering benefits," he adds. "To date, projects funded by the institute have contributed to the development of more efficient power electronics that benefit a range of applications – from electric vehicles to renewable energy and data centers."

The latest round of projects encompasses a number of applications – from heavy-duty vehicles to medium-voltage motor drives to high-efficiency power conversion for transportation refrigeration unit to energy storage. Recipients include companies such as John Deere, Toshiba and General Electric Aviation Systems as well as leading universities, and the projects involve many examples of collaborative partnerships.

The projects were selected based on applications received through the 2018 Call for Projects and are funded by the Department of Energy (DOE) and funding recipients through a cost-share agreement. A detailed list of all projects with descriptions is available online at:

https://poweramericainstitute.org/member-projects

US DOE's Early Career Research Program awards NREL to synthesize theoretically predicted new nitrides

The US Department of Energy's Office of Science — through the Early Career Research Program — has awarded $2.5m in funding (over five years) for Andriy Zakutayev and his colleagues at the US National Renewable Energy Laboratory (NREL) to determine the accuracy of their theoretical predictions. He and other researchers published a paper earlier this year predicting the existence of hundreds of new nitride materials, and made a few of these nitrides that were predicted to be stable.

"The results of this recently funded research can lead to discovery of new nitride materials for energy applications, such as new semiconductors for more efficient lighting or better superconducting qubits for quantum computing," says Zakutayev.

His research project 'Kinetic Synthesis of Metastable Nitrides' aims to understand how to synthesize new metastable nitrides via chemical methods, instead of a more energy-intensive process that uses high pressure and high temperatures. Metastable materials will change over time (taking millions of years in some cases like diamond), but focusing solely on stable nitride materials leaves a vast research area unexplored. The paper predicted the existence of about 200 new stable ternary metal nitrides, bringing the total number to just over 400. By comparison, the number of predicted metastable nitrides alone was 417.

NREL's Andriy Zakutayev.

Zakutayev proposes a couple of unique methods to synthesize metastable nitrides. One involves arranging atoms into a desired crystalline structure, first combining unwanted elements and then swapping those for the elements he does want. "To use an analogy from mountaineering, it's like climbing a difficult mountain by first summiting another one that may be taller but easier than the desired one, and then taking a downhill trail from there," he says.

The other method involves mixing elements on the atomic scale and then crystalizing them into the desired structure.

The Early Career Research Program is open to scientists who earned a doctorate within the last 10 years. Zakutayev received Ph.D. in physics from Oregon State University in 2010, then joined NREL that year as a postdoctoral researcher and became a staff scientist in 2012.

www.nrel.gov

Cambridge GaN Devices co-founder & CEO named RAEng Engineers Trust Young Engineer of the Year

Dr Giorgia Longobardi, co-founder & CEO of UK-based Cambridge GaN Devices Ltd (CGD), has been selected by the Royal Academy of Engineering (RAEng) as one of five young female engineers who have been outstandingly successful in their respective fields at an early stage of their careers. As an RAEng Engineers Trust Young Engineer of the Year, she has received a £3000 prize.

Longobardi completed her PhD (focused on the physics of power devices) in 2014, in collaboration with NXP Semiconductors.

She then spent a year in Japan sponsored on a JSPS Postdoctoral Fellowship. Funding of £75,000 from the UK Engineering and Physical Sciences Research Council (EPSRC) Impact Acceleration Account (IAA) Follow-on-Fund has enabled Longobardi to work on prototyping a new generation of power devices, to file two patents, and in 2016 (together with group leader Professor Florin Udrea) to set up Cambridge GaN Devices (spun out of the Electrical Power and Energy Conversion Group of the University of Cambridge's Department of Engineering), which shared first prize in the annual Postdoc Business Plan Competition run jointly by the Entrepreneurial Postdocs of Cambridge (EPoC) and Cambridge Enterprise.

CGD develops highly efficient power electronics targeting energy savings in applications ranging from power supplies for consumer electronics to LED drives, data centers and wireless chargers. The firm now employs 10 people and was recently selected as one of the best deep-tech startups to watch by the School of Entrepreneurship & Innovation in Turin.

Dr Giorgia Longobardi.

Longobardi also has a research fellow in Electronic Engineering at the University of Cambridge's Gonville & Caius College, focusing on gallium nitride technologies including sensors and system solutions for efficient power management.

"I'm very grateful to all the people that have contributed to this prize by supporting my work at both the Department of Engineering and Gonville & Caius College," says Longobardi. "A special thank you goes to my team in Cambridge GaN Devices for their work and commitment towards this amazing venture."

As an STEM ambassador engaging with school students in countries around the world (including Italy, the UK and Japan), Longobardi aims to promote STEM subjects to the next generation, especially women.

www.cai.cam.ac.uk/people/giorgia-longobardi
www.enterprise.cam.ac.uk/tag/cambridge-gan-devices

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process systems

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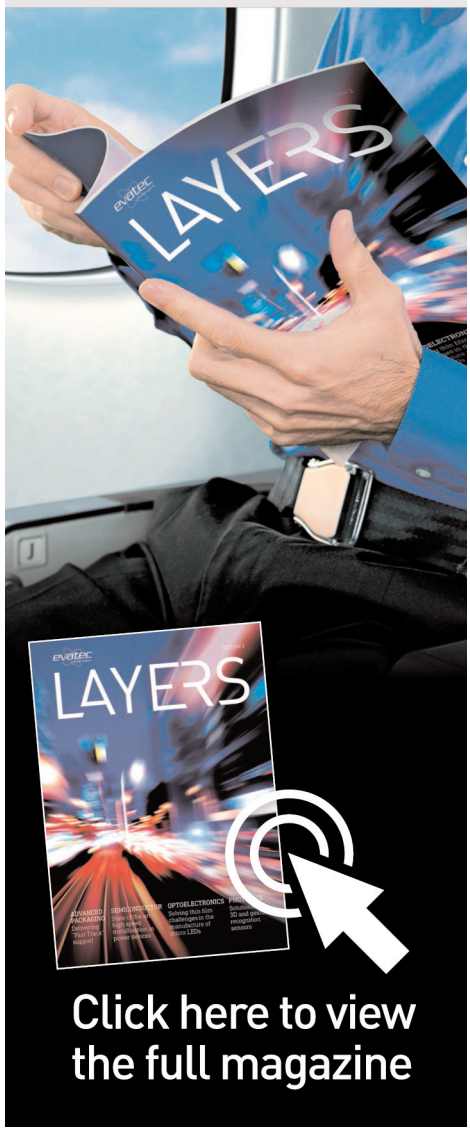

StratEdge expands packaging and assembly services for high-frequency and high-power devices

New ISO 9001:2015-certified facility equipped with latest eutectic die attach systems

StratEdge of Santee, near San Diego, CA, USA (which designs and manufactures packages and provides chip assembly & test services for microwave, millimeter-wave and high-speed digital devices) has expanded its Assembly Services Division and its facilities and capabilities for packaging RF and microwave devices ranging from DC to 63+GHz. Assembly services cover the gamut of packaging, from manual to fully automatic and first article prototypes to hundreds of thousands of modules for fully automated production.

StratEdge's new ISO 9001:2015 facility has a Class 1000 cleanroom and Class 100 work area with workstations for performing sensitive operations. It is fully furnished with the assembly equipment for high-speed fine wire wedge and ribbon bonding. The bonder is specially equipped for eutectic gold-tin (AuSn) attachment of devices, achieving bond line thickness less than 6µm. The firm says that its

proprietary eutectic die attach technology has been honed to get the best possible power output for gallium nitride (GaN) devices and results in lower junction temperatures and increased device reliability.

StratEdge's Assembly Services specialize in:

- RF and microwave devices, including GaN and gallium arsenide (GaAs);
- high-frequency passive and active components;
- multiple component multi-chip modules; and
- power amplifiers, low-noise amplifiers, and mixed-signal devices.

Capabilities include:

- epoxy and eutectic die attach;
- automated gold-tin die attach developed for GaN and GaAs devices;
- automatic and manual wedge wire bonding;
- ribbon bonding;
- low-profile wire bonds;
- 50Ω lines for reducing wire lengths;
- conductive and non-conductive epoxies; and
- full packaging as well as chip-on-tab where StratEdge provides the heat-spreading tabs.

"Flexible equipment, skilled operators and experienced applications engineers enable StratEdge to accommodate the numerous needs of our customers," says VP global sales Casey Krawiec. "Our new die attach system is the fastest and most reliable multiple die-type bonder on the market and the automated eutectic die attach vastly increases throughput," he claims.

www.stratedge.com

StratEdge president & CEO selected as finalist for CEO of Year Award by San Diego Business Journal

StratEdge of Santee, near San Diego, CA, USA (which designs and manufactures packages and provides chip assembly & test services for microwave, millimeter-wave and high-speed digital devices) says that president & CEO Tim Going has been selected as a finalist for the 2019 CEO of the Year Award in the Privately Held Company category. Sponsored by the San Diego Business Journal, the award recognizes San Diego's local industry leaders' achievements within their companies and in the community. Specifically, finalists are recognized for demonstrating "determination and insight that

Tim Going.

has yielded huge successes for their organizations and who have taken the lead in driving their businesses and the local economy".

Going has 40 years of experience in the semiconductor and microelectronics industries, including being with StratEdge for 24 years, taking on the role of CEO in 2004 and leading the firm through several challenging business cycles, predicting technology trends within the compound semiconductor community and helping to develop solutions required for advanced technologies. Almost half of the employees have been with the firm for over 15 years. Customers include companies involved with aerospace, telecommunications, test & measurement, military, and clean energy. StratEdge high-frequency packages are used in the communications systems of the Mars rovers, including the upcoming Mars 2020 vehicle.

www.stratedge.com

IGaN launches MPW shuttle program for GaN-on-Si transistors

Singapore-based IGSS GaN Pte Ltd (IGaN) – which provides proprietary gallium nitride on silicon (GaN-on-Si) epitaxial wafer fabrication services for both power and radio frequency (RF) devices – has announced its cost-effective and quick prototyping multi-project wafer (MPW) shuttle program, as it seeks to advance volume production in 200mm-diameter silicon substrates.

Enabling customers to tape-out their designs for rapid prototyping, the MPW offers cost reduction through the expense sharing of masks and wafers with other MPW shuttle program partners. The service leverages the shift in demand towards GaN devices capable of improving power efficiency conversion up to 50%.

"The industry is ripe for a transition to GaN devices, with various infrastructure coming together making it conducive to new technologies," believes president George Wong. "Today, challenges around reliability have been primarily addressed, paving way for a wider adoption of GaN that is spurred by the increasingly cost-friendly manufacturing capabilities," he adds. "This is where IGaN completes the supply chain."

www.igssgan.com

Teradyne launches test system for 5G mmWave semiconductors

Automated test solutions provider Teradyne Inc of North Reading, MA, USA has launched UltraWaveMX44, an UltraFLEX test solution for the new 5G-NR millimeter-wave (mmWave) market, enabling faster time to market and higher product yields for devices used in emerging 5G mmWave applications.

The UltraWaveMX44 supports characterization and production device testing for probe, package, over-the-air and module applications. Its patented active thermal control and NIST-traceable integrated calibration circuitry delivers what is claimed to be superior instrument performance and tester-to-tester repeatability for frequencies between 6GHz and 44GHz.

The UltraWaveMX44 maintains complete DIB (device interface board) and test cell compatibility with currently released wireless applications, such as LTE and WLAN, making it an upgrade solution for installed UltraFLEX systems while maximizing return on investment for new system purchases.

"Over the past two years, we have worked with our customer base to develop and validate the most effective mmWave production test solution," says Stephen Pruitt, product marketing manager for wireless semiconductors. "UltraWaveMX44 is a true high-volume mmWave ATE [automated test equipment] instrument with innovative technology integration providing complete test coverage for complex 5G wireless devices," he adds. "With this UltraFLEX solution, our customers can achieve the highest test quality without sacrificing compatibility or performance, all while realizing lower cost of test."

This addition to the UltraFLEX platform leverages the test system's native features of dedicated background DSP computers, IGXL software environment, fully integrated debug tools and instrument pattern support to deliver high test cell throughput and fast time to market.

www.teradyne.com/products/test-solutions/semiconductor-test/ultrawavemx44

evatec
process systems

AlN piezoelectric films – The road to even better stress uniformity

AXT's revenue grows a more-than-expected 22.8% in Q2

Record InP sales driven by 5G build-out, aiding return to net profit

For second-quarter 2019, 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 $24.8m, down 8.5% on $27.1m a year ago but up 22.8% on $20.2m last quarter (and above the expected $23.5–24.5m).

In particular, revenue from raw material joint ventures was $4.2m, down 23.6% on $5.5m a year ago but up 23.5% on $3.4m last quarter. Substrate sales were $20.6m, down 4.6% on $21.6m a year ago but up 22.6% on $16.8m last quarter.

Of total revenue, 75% came from Asia-Pacific (rebounding from a low of 65% last quarter), 19% from Europe (down from 22%) and just 6% from North America (down from 13%). There were again two 10%-or-more customers. The top five customers generated about 48% of total revenue (up from 35% last quarter).

"Amidst a backdrop of turbulent geopolitical and global economic conditions, AXT posted a solid quarter," says CEO Morris Young. "Revenue came in just ahead of our expectations and our InP sales achieved an all-time high, having surpassed GaAs as the single largest revenue contributor again this quarter," he adds.

Over the past four years, AXT's revenue from InP has grown from $1–2m per quarter to more than $10m. "Four years ago, PON [passive optical networks] was the only meaningful driver for our indium phosphide revenue. Three years ago, we reported that the data center will begin adding to the demand for indium phosphide. Earlier this year, we saw telecom beginning to contribute," says Young. "During the second quarter we completed the shipment of the large order relating to 5G infrastructure… evidence that a major infrastructure upgrade cycle for 5G is on the horizon."

In contrast, GaAs revenues for both wireless and LED applications have seen setbacks in recent quarters. "Overall, 2018 has seen a softer year for gallium arsenide market. We have used this opportunity to execute a methodical and careful relocation of our gallium arsenide manufacturing [from Beijing to Dingxing, China]," notes Young. Up to 20% of AXT's GaAs revenue came from the new Dinxing facility in Q2/2019, he adds. "We are delivering qualification samples… utilization is only 20%."

"With continued focus on manufacturing efficiency, inventory reduction and cash management, we improved our gross margins and achieved positive cash flow," says Young.

"With the changes we made last quarter to our portfolio raw material companies, we are able to show improvement in the overall contribution to our results in Q2. In particular, those we account for with the equity method had a cumulative gain in this quarter," says Young. "This comes at a time when the pricing environment for raw material is stabilizing and we are doing a better job and leveraging the benefit of our portfolio in improving our substrate cost structure."

Although down on 40.6% a year ago, gross margin of 34.3% is up from 33.1% last quarter due primarily to product mix.

Operating expenses were $6.2m, up from $6.1m last quarter but cut from $6.5m a year ago. Income from operations was $2.3m, up from $0.63m last quarter but almost halving from $4.5m a year ago.

Although down on $3.9m ($0.10 per diluted share) a year ago, net income was $1.5m ($0.04 per diluted share, at the upper end of the $0.02–0.04 guidance range), an improvement from a net loss of $1.1m ($0.03 per share) last quarter.

Depreciation and amortization was steady at $1.4m. Capital expenditure (CapEx) was $5.5m (up from $4.2m last quarter).

Overall, during the quarter, cash, cash equivalents and investments rose from $34.1m to $37.5m. "In a difficult demand environment, we achieved solid financial results, including profitability expansion and cash generation," notes Young.

Net inventory fell from $53m to $50.3m (48% in raw materials, 47% in work in progress, and only 5% in finished goods). "Reduction in inventory is the focus for us in 2019," says chief financial officer Gary Fischer.

"We are continuing to execute on the relocation of our facility," says Young. AXT still estimates that it will use about $21m of cash for the relocation in 2019. "We are increasingly now focused on assisting our customers through the process of a qualification shipment and shipment grant from the new facility. Those efforts will likely continue through the balance of the year and into Q1/2020," he adds. AXT now reckons on spending about $9m in first-half 2019 and $12m in second-half 2019. "We are laying a solid foundation for the significant technology trends that are likely to drive growth in our business over time," believes Young.

"We are operating cash-flow positive for the first half of 2019 for approximately $5m, which helps offset the outflow," notes Fischer. "We do have a $10m line of credit with Wells Fargo Bank, which we have not utilized, and we are setting up a bank loan in Chinese renminbi in China as another source of cash," he adds. "Further, we think the second half of 2019 will also be positive operating cash flow. We are continuing to monitor cash and remain confident that we have sufficient resources. The current facility in Beijing has considerable value that we will be able to monetize in the future."

"We had a strong increase in our revenue in Q2 in part driven by a sizable order for indium phosphide and that will not repeat in Q3,"

notes Fischer. AXT is not expecting incremental growth from PON applications in Q3. "However, we are pleased to see indications of an improving demand environment for indium phosphide in the data center and for gallium arsenide in LEDs," he adds.

For third-quarter 2019, AXT therefore expects revenue of $24.5–26m, and earnings per share of $0.01–0.03. "Gross margin will not be as good in Q3 and it's primarily because of product mix, as indium phosphide revenue will be down sequentially," says Fischer. Revenue from LEDs should grow. "While weakness is persisting in wireless applications, we are now pleased to see the beginning of a potential improvement in the LED market for higher-end applications as we enter into Q3," says Young. "Discussions with certain customers are taking a more positive turn than in the previous quarters and we are seeing incremental stronger demand," he adds.

"Indium phosphide could fuel other major applications based on the development work being done right now. These include health monitoring, advanced 5G wireless devices and LiDAR for the automotive industry," Young concludes.

www.axt.com

AKHAN issued Korean patent

AKHAN Semiconductor Inc of Gurnee, IL, USA – which was founded in 2013 and specializes in the fabrication and application of lab-grown, electronics-grade diamond as functional semiconductors – has been issued a patent by the Korean Intellectual Property Office covering a method for the fabrication of diamond semiconductor materials. The technology is core to next-generation applications in automotive, aerospace, consumer electronics, military, defense and telecoms systems, among others.

Originally filed in 2014, the Korea-issued patent 10-2007051 is the fourth foreign counterpart of other issued and pending patents owned by AKHAN (including US Patent Application #61/513,569) related to its Miraj Diamond Platform products. With other patents awarded in 2017 and 2018 in Japan and Taiwan, this is the first patent for the Korean market and will cover Korean-based semiconductor electronics.

According to AKHAN, the patent protects use beyond existing applications, including microprocessors. Covering the base materials common to nearly all semiconductor components, the intellectual property can be utilized in everything from diodes, transistors and power inverters, to fully functioning diamond chips in integrated circuitry.

"The award of this key Korean patent and the country's recognition of our intellectual property is a significant development for our business, underscoring our leadership in the diamond semiconductor space," says founder & CEO Adam Khan. "Korea represents the world's fourth-largest economy and is home to major OEMs such as LG, Samsung and others."

Diamond-based technology is capable of increasing power density and creating faster, lighter and simpler devices for consumer use. Cheaper and thinner than its silicon counterparts, diamond-based materials could become the industry standard for energy-efficient electronics, reckons AKHAN.

"We are delighted to add this latest patent to the AKHAN portfolio of intellectual property safeguards in the diamond semiconductor field, including the ability to fabricate transparent electronics and the ability to form reliable metal contacts to diamond semiconductor systems," says president & chief operating officer Carl Shurboff. "The award also represents another significant milestone in our ongoing efforts with major defense, aerospace and space system development partners."

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ASSET project gains £1.3m in funding from Welsh Government's SMARTExpertise program

South Wales-based collaboration to develop Application Specific Semiconductor Etching Technology

The Welsh Government has announced a new £1.3m project to develop semiconductor processing technologies for a range of applications, including autonomous vehicles, novel devices for clean energy, future mobility, artificial intelligence (AI), advanced packaging, and biosensors and wearable sensors.

Part-funded by the European Regional Development Fund (ERDF), the project ASSET (Application Specific Semiconductor Etching Technology) is funded under the Welsh Government's SMARTExpertise program and is an industrially driven, collaborative project with partners across South Wales, including: SPTS Technologies, IQE, The Compound Semiconductor Centre (CSC), Biovici, BioMEMS, Swansea and Cardiff Universities, and Integrated Compound Semiconductors Ltd (Manchester).

The industrial partners provide technologies that go into almost all the world's leading smartphones. By developing a host of new semiconductor process technologies, ASSET aims to develop these technologies for compound semiconductors and next-generation semiconductor materials to service new emerging applications in automotive sensing, 5G, photonics and healthcare.

The ASSET project follows the recent announcement of the new £90m Centre for Integrative Semiconductor Materials (CISM) facility at Swansea University, which is expected to be completed in first-half 2021.

"The ASSET project is another example of south Wales' semiconductor cluster working together to deliver world-class technology and drive economic growth for Wales," comments professor Owen Guy, head of chemistry at Swansea University and lead of the ASSET project.

"The ASSET project gives the consortium the ability to work with the extensive fabrication supply chain in the region to further expand our capabilities and capitalize on new and exciting market opportunities," says SPTS Technologies' president Kevin Crofton.

"The south Wales semiconductor industry employs over 1400 highly skilled people in the region and is set to expand rapidly over the next five years with the development of 5G, AI and other mega-trend markets," says Wyn Meredith of the Compound Semiconductor Centre. "ASSET will support these developments by developing a range of advanced semiconductor processes and expertise to overcome technical and industry challenges."

www.swansea.ac.uk/campus-development/developing-bay/key-projects-bay/cism

Riber's first-half revenue falls 17% year-on-year

Growth in System and Services & Accessories revenues partially offsets 90% drop in Evaporator revenue

Riber S.A. of Bezons, France — which manufactures molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells — has reported revenues of €13.9m for first-half 2019, down 17% from first-half 2018's €16.7m.

Evaporator revenue has plummeted by 90% from €10.4m to €1m due to the freeze in investments in organic light-emitting diode (OLED) screen production equipment (following the major investments made in previous years).

System revenue has more than doubled, rising by 132% from €3.7m to €8.6m, reflecting this activity's robust development. Four production systems were delivered, compared with just one production system and three research systems in first-half 2018.

Services & Accessories revenue rose by 65% from €2.6m to €4.3m, in line with the development strategy for this strong contributive business.

Corresponding to the strong cyclical decline in evaporator sales, the proportion of total revenue from Asia has fallen from 74% to 22%, while Europe has risen from 20% to 56% and the USA from just 6% to 22%.

The order book at end-June has fallen year-on-year by 17% from €34.3m to €28.4m. However, this is largely due to Evaporator orders falling from €3.8m to zero. Services & Accessories orders fell by 17% from €8.3m to €6.9m, while Systems orders were down by just 3% from €22.2m to €21.5m. The latter comprised 13 systems including six production units.

Riber says that, considering the still healthy level of the order book (including a large number of systems to be delivered in 2019), it is forecasting year-on-year growth in revenue for full-year 2019.

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Veeco's Q2 revenue still suppressed by soft LED market while MOCVD platform developed for As/P-based photonics

Losses cut and cash flow improved through decreases in accounts receivable and inventory

For second-quarter 2019, epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA has reported revenue of $97.8m, down 1.6% on $99.4m last quarter and 38% on $157.8m a year ago. This is also slightly below the midpoint of the $90–110m guidance, due to the recent trading restrictions with Huawei (which impacted revenue by about $2m). "The semiconductor capital equipment industry is experiencing headwinds from multiple end markets," notes CEO William J. Miller Ph.D.

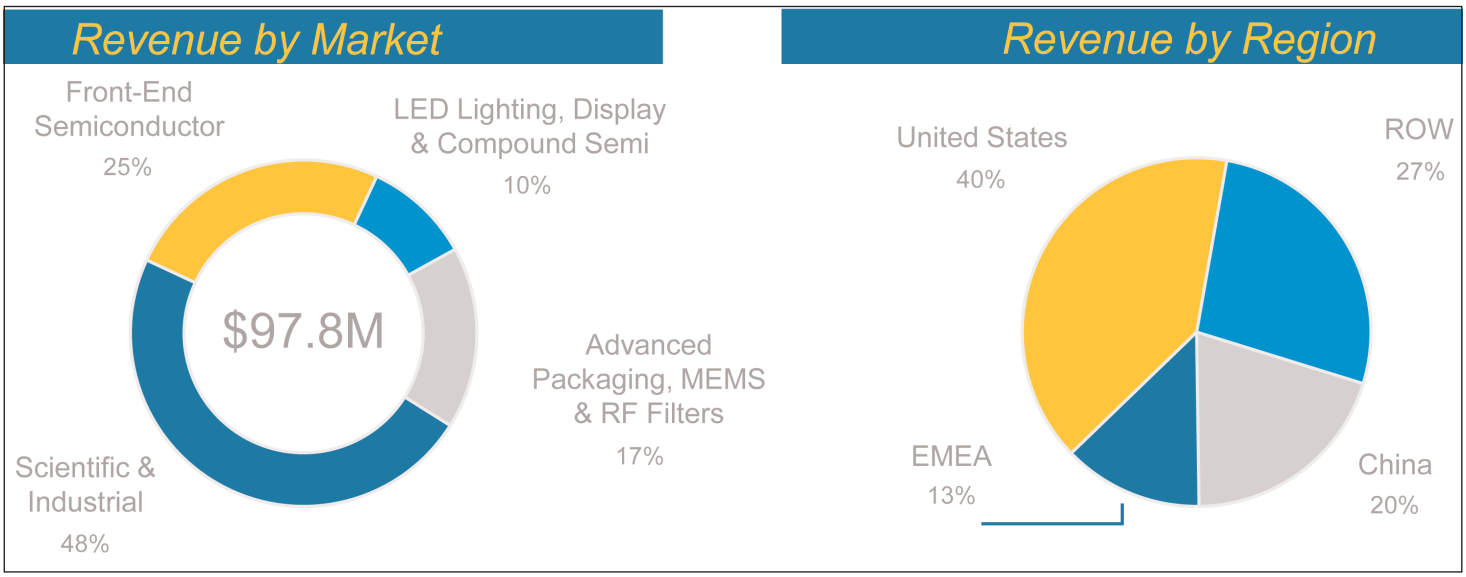
The LED Lighting, Display and Compound Semiconductor segment — including metal-organic chemical vapor deposition (MOCVD) systems — comprised just 10% of total revenue (down from 14% last quarter and 55% a year ago). This reflects softness in the global LED market and Veeco being in the early stages of penetrating the photonics market.

The Front-End Semiconductor segment (formerly part of the Scientific & Industrial segment, before the May 2017 acquisition of lithography, laser-processing and inspection system maker Ultratech Inc of San Jose, CA, USA) reached its highest revenue level in several years, comprising 25% of total revenue (up from 23% last quarter and just 12% a year ago). Growth was driven by shipments of Veeco's first extreme ultraviolet (EUV) mask blank system for volume production as well as sales of multiple laser spike anneal (LSA) systems.

The Advanced Packaging, MEMS & RF Filter segment — including lithography and Precision Surface Processing (PSP) systems sold to integrated device manufacturers (IDMs) and outsourced assembly & test firms (OSATs) for Advanced Packaging in automotive, memory and other areas — comprised 17% of total revenue (falling back from 23% last quarter, but up from 16% a year ago). Revenue growth was driven by multiple advanced packaging (AP) lithography systems for high-bandwidth memory and CPU application. "Automotive sales growth has slowed, the memory market is in a cyclical downturn with high inventory levels and the smartphones supply chain is in a state of overcapacity as smartphone unit volume growth has slowed," says Miller. "As a result of these headwinds, wafer fab equipment spending is expected to be down in 2019, and estimates vary regarding the timing of recovery."

The Scientific & Industrial segment comprised 48% of total revenue (rebounding from 40% last quarter, and up on just 17% a year ago), driven by ion beam system shipments to data storage and optical customers. "As demand for cloud storage increases, we continue to see strength in our data storage products," says Miller.

By region, the USA contributed 40% of revenue (up from 33% last quarter), driven by the data storage market. The rest of the world (including Japan, Taiwan and Korea) contributed 27%, driven by EUV mask blank systems sales. China contributed 20% of revenue (up from just 10%), driven by services revenue and LSA product shipment. Europe, the Middle-East & Africa (EMEA) contributed 13% of revenue.



Due to the improved product mix as well as cost-reduction efforts, gross margin has rebounded from 35.5% last quarter to 37.8%, up from 35.8% a year ago.

Operating expenses (OpEx) have been cut further, from $45.7m a year ago and $40m last quarter to $38.5m (below the expected $40m) due to reduced R&D spending.

Compared with net income of $7.2m ($0.15 per diluted share) a year ago, net loss was $3m ($0.06 per diluted share), but this was cut from $6.4m ($0.14 per diluted share) last quarter.

Cash flow from operations was +$14m (compared with outflow of –$22m last quarter), driven by decreases in accounts receivable (from $75m to $59m) and inventory (from $148m to $140m) as well as an increase in customer deposit, offset by a reduction in accounts payable (from $36m to $22m). "We made good progress reducing inventory by converting evaluation tools in this quarter, however inventory is still high because we are experiencing slow-moving inventory in the LED business due to the ongoing softness there," says executive VP, chief operating officer & chief financial officer Sam Maheshwari.

So, despite capital expenditure (CapEx) almost doubling from $2.2m last quarter to $4.3m, cash and short-term investments hence rose during the quarter by $10m from $237m to $247m (of which $43m is held offshore). Long-term debt was $294m (up slightly from $290m last quarter), representing the carrying value of $345m in convertible notes.

"We have been enhancing our TurboDisc MOCVD platform for the photonics [arsenide/phosphide] market," says Miller. "We shipped our first beta MOCVD system optimized for photonics applications… Initial feedback suggests our new product has advantages over our competition in key customer requirements, such as particle defectivity, growth rates, uniformity and run-to-run consistency. This is an important step in our penetration into the arsenide/phosphide MOCVD market with customers focused on VCSELs [vertical-cavity surface-emitting lasers], edge-emitting lasers and ROY [red, orange, yellow] specialty LEDs," he adds. "We continue to work with other customers to place additional systems… Future growth drivers for this market will be machine vision and industrial applications, world-facing sensors and automotive LIDAR. We are working with customers to help them build capacity when the market returns." Another beta tool should be shipped in second-half 2019.

"We continue to see strength in our technology-driven purchases but capacity-related orders were soft," says Miller. Order bookings hence fell from $107.2m to $78.2m. "This was expected given the soft macro-environment," he adds. Order backlog correspondingly declined from $295m to $274m.

We shipped our first beta MOCVD system optimized for photonics applications… This is an important step in our penetration into the As/P MOCVD market with customers focused on VCSELs, edge-emitting lasers and red, orange, yellow(ROY) specialty LEDs. We continue to work with other customers to place additional systems… Future growth drivers for this market will be machine vision and industrial applications, world-facing sensors and automotive LIDAR

For third-quarter 2019, Veeco expects revenue of $95–115m. Gross margin should be 37–39%, aided by cost reduction. OpEx is expected to be about $39m. "We expect OpEx to remain at these levels for the remainder of this year and expect to reduce it in 2020," says Maheshwari. Operating income should range between a loss of $3m and a profit of $6m. Net income should range between a loss of $5m (–$0.10 per diluted share) and a profit of $4m (+$0.10 per diluted share).

"Based on our current visibility, we are reiterating second-half top-line growth of roughly 10% over the first half," says Maheshwari. "We continue to target gross margin of 40% by the end of this year due to the favorable product mix and cost reductions. And we expect positive EPS in Q4," he adds.

"We've seen good bookings in July already. So some of the business that we were planning to close in June, it just got pushed over to the first two weeks in July," says Maheshwari. "We are looking at improving our bookings in Q3 over Q2," he adds.

"Veeco is impacted by the industry slowdown. But we benefit from technology inflection spending," says Miller. "While we see softness in the short term, long-term trends driving this semi industry are intact," he adds. "We are making progress with exciting new products and remained focused on winning our customers business," he says, citing growth initiatives supporting EUV adoption, front-end semiconductor manufacturing with laser annealing, MOCVD for the photonics market, and advanced packaging. "We have completed most of the development activity on our MOCVD system designed for photonics applications, our next-generation advanced packaging lithography system, and our laser annealing system for the sub-7nm market."

"We remain optimistic about our long-term growth prospects," says Miller. "We are still working toward our goal of returning to profitability, and we'll be reducing infrastructure in the coming quarters to further improve the cost structure of the company."

www.veeco.com

Aixtron returns to positive free cash flow in Q2/2019 after 19.5% year-on-year equipment revenue growth

Order growth expected in H2/19 with recovery in demand from Asia

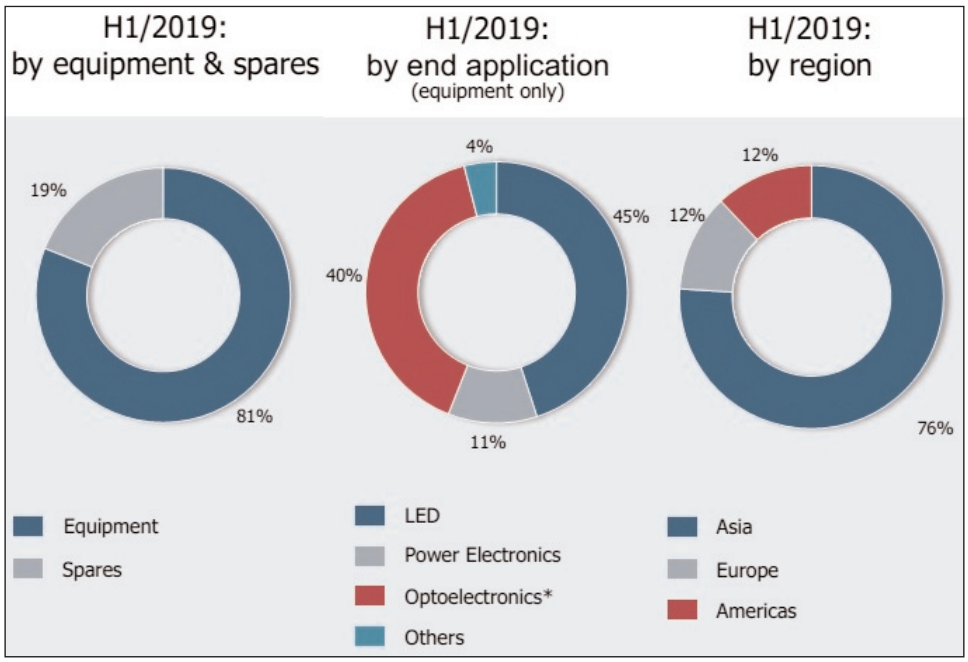
For second-quarter 2019, deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany has reported revenue of €63.3m, down 8% on last quarter's €68.7m but up 1.4% on €62.4m a year ago. Equipment revenue in particular was €50.3m (79% of total revenue), down 10.3% on €56.1m (82% of total revenue) last quarter but up 19.5% on €42.1m (76% of total revenue) a year ago.

This contributed to first-half revenue rising by 12% from €117.6m in 2018 to €132m in 2019. In particular, equipment revenue grew by 15% from €92.9m to €106.5m (rising from 79% to 81% of total revenue), while sales of spare parts & services rose by just 4% from €24.6m to €25.5m (falling from 21% to 18% of total revenue).

On a regional basis, 76% of total revenue came from Asia (rebounding from just 50% in first-half 2018), while Europe fell back from 30% to 12% and the USA from 20% to 12%.

This corresponds to metal-organic chemical vapor deposition (MOCVD) systems for 'LEDs' comprising the largest share of equipment revenue, at 45% (up from 17% in first-half 2018). Systems for 'Power Electronics' rose from 7% to 11% of revenue. MOCVD systems for 'Optoelectronics' (consumer optoelectronics, telecom/datacom and solar) fell to 40% of revenue (from 69% in first-half 2018), including just 32% for optoelectronics alone. This reflects "the expected customer reluctance to invest in new production capacity, which was further exacerbated in the short term by the US sanctions against Huawei," notes president Dr Bernd Schulte.

Cost of sales rose from €66.9m (57% of revenue) in first-half 2018 to €79.4m (60% of revenue) in first-half 2019, also reflecting the higher share of LED systems (which are relatively low margin) in the revenue.



Due to the increased share of low-margin LED systems in the product mix, gross margin hence fell from 43% to 40%, although the advantageous $/€ exchange rate and lower product costs helped to offset margin effects (achieving the upper end of the 35–40% forecast). Most recently, quarterly gross margin rose from 39% in Q1 to 41% in Q2/2019.

Due mainly to the lower project-related expenses, first-half operating expenses have been cut by 13% from €38.7m in 2018 to €33.5m in 2019 (with quarterly OpEx cut from €17m in Q1 to €16.6m in Q2).

Due mainly to business and cost development, first-half operating profit (EBIT) has risen from €12m (EBIT margin of 10% of revenue) in 2018 to €19.1m (14% EBIT margin) in 2019. Despite quarterly EBIT falling slightly from €9.7m in Q1 to €9.3m in Q2, this still grew as a proportion of revenue from 14% to 15% EBIT margin (and is more than double the €4.1m a year ago).

Revenues, gross profit and EBIT rose significantly year-om-year, while operating expenses continued to fall. Gross and EBIT margins reached the upper end of the ranges forecasted at the beginning of the year.

First-half net profit was €15.8m (12% of revenue) in 2019, roughly level with €16m (14% of revenue) in 2018 (remaining €0.14 per share), despite quarterly net profit falling from €8.5m (€0.08 per share) in Q1 to €7.3m in Q2 (€0.06 per share), remaining 12% of revenue (and double the €3.7m a year ago).

Capital expenditure (CapEx) was €6.7m in first-half 2019 (up from €4.5m in first-half 2018). First half free cash flow has hence improved from –€12.7m in 2018 to –€4.9m in 2019. Also, this was due mainly to –€17.5m in Q1 (resulting from supplier payments and additional inventories acquired in Q1), before returning to positive free cash flow of +€12.6m in Q2, reflecting the profitable course of business.

Although down by €4.8m on €263.7m at the end of 2018, cash including other financial assets (bank deposits with a maturity of at least three months) recovered during Q2/2019 from €247.9m to €258.9m.

First-half order intake (including spare parts and service) was €98.3m in 2019, down 36% (especially in the optoelectronics segment, as expected) from €154.3m in 2018. "Against the backdrop of the ongo-

ing trade dispute between the USA and China, our customers were reluctant to invest in the expansion of their production capacities," says Aixtron. "Despite this, the key figures for the first half of the year are fully in line with the annual guidance." Most recently, the decline in quarterly order intake has slowed, with Q2's €44.7m down 17% on Q1's €53.6m.

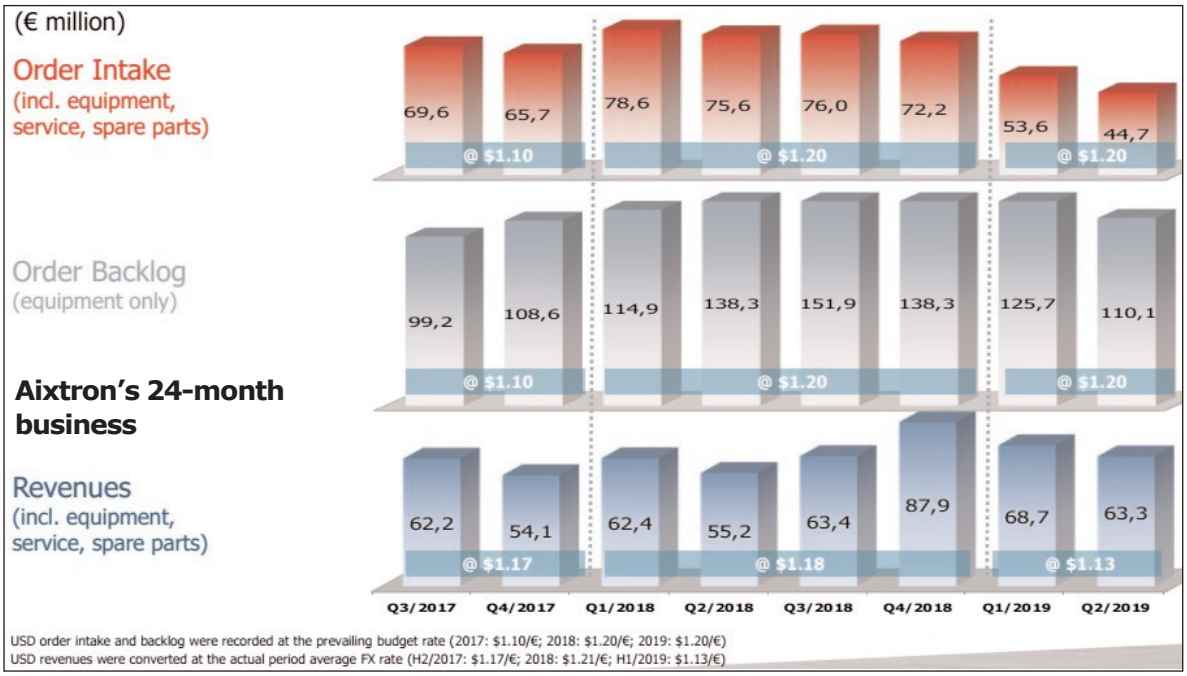
Equipment order backlog has fallen further to €110.1m at the end of first-half 2019 (most scheduled for shipment in 2019), down by 12% on €125.7m at the end of Q1/2019 and by 20% on €138.3m at the end of first-half 2018.

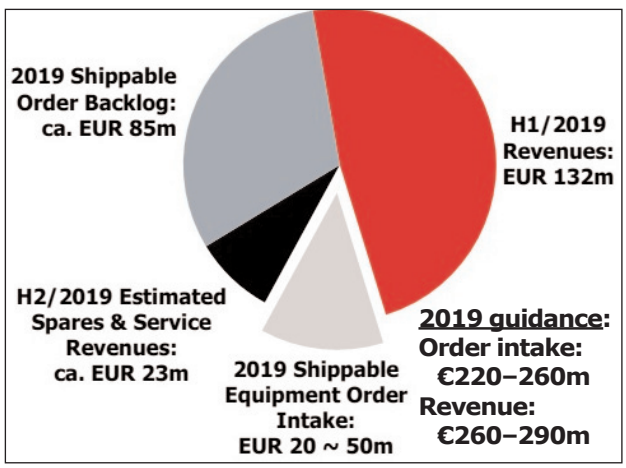
However, the market developments of increasing use of lasers for 3D sensor technology and optical data transmission, a progressive expansion of the 5G network, and increasing use of energy-efficient power electronics remain positive and are only affected for a short time by the current geopolitical tensions, reckons Aixtron.

"We are optimistic that order intake will improve in the second half of the year, in particular due to an expected recovery in demand from Asia," says Schulte. "In combination with our strong order backlog, we plan to meet our forecast for the year," he adds.

Based on the good first-half 2019 results and an assessment of demand development taking into account the current market environment and the budget exchange rate of 1.20$/€, Aixtron has confirmed its full-year 2019 guidance for sales and orders.

Aixtron now expects stable to growing revenue of €260–290m (compared with €268.8m in 2018). Also, margins and profit should be at the upper end of the previously forecast ranges, with gross margin of about 40% (previously 35–40%) and EBIT of about 13% of revenues (previously 8–13%). Free cash flow should be €15–25m (up from just €4.4m in 2018). Expectations for 2019 fully include the results of Aixtron's organic light-emitting diode (OLED) subsidiary APEVA (including all necessary investments to continue the development of OLED activities).





Full-year 2019 orders should be €220–260m, including an order from its OLED customer for the next test tool as part of the ongoing qualification process for organic vapor phase deposition (OVPD) technology for OLED displays.

The Gen2 OLED system was installed in a pilot-production line at the customer's facility and is operated jointly by engineers from the customer and APEVA. "The tool is currently undergoing an extensive evaluation program," says president Dr Felix Grawert. In the coming months, the system is expected to confirm the efficiency of the OVPD technology, as part of another scheduled step towards qualification of the OVPD technology for this customer.

"In power electronics, we see a steadily rising demand for systems for gallium nitride (GaN)-based applications, driven among other things by the expansion of 5G mobile communication networks," says Grawert. "In addition, we are making great progress in marketing our new silicon carbide (SiC) production system, for which we have already received initial orders in addition to positive customer feedback," he adds.

"Especially in the areas of lasers, power electronics and special LEDs, we continue to see three strong growth drivers that are important building blocks for global megatrends such as the next generation of 5G wireless networks, 3D sensors for mobile phones and power electronics for electro-mobility and renewable energies, as well as next-generation micro-LED displays," concludes Schulte.

www.aixtron.com

Edwards Vacuum opens North American semiconductor HQ in Hillsboro

Innovation and manufacturing center to employ 250+ workers, including 100 new jobs

UK-based semiconductor vacuum and abatement equipment maker Edwards Vacuum has completed and opened its new innovation and manufacturing center in Hillsboro, OR, USA, which will serve as its North American semiconductor headquarters, creating 100 new jobs.

Edwards is consolidating its Hillsboro staff in the 75,000ft^2 facility. Previously, the firm had more than 150 employees in multiple Hillsboro locations. The new 8-acre site is located on NE Century Boulevard, and will house more than 250 staff. Edwards plans to hire many more workers at the site in the coming years.

"Northwest Oregon is a growing hub for innovative businesses in the semiconductor industry and other fields," says Congresswoman Suzanne Bonamici. The Greater Portland region is a global hub for

chipmakers, with Intel, Qorvo and Jireh Semiconductor employing tens of thousands of workers conducting research, development and production in Hillsboro.

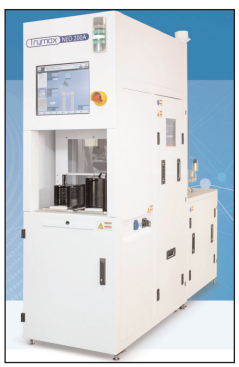
The location in 'Silicon Forest' allows Edwards Vacuum to work closely with key Pacific Northwest accounts. "Edwards is fully committed to the Northwest Region, creating jobs and participating in the local growth, as environmentally conscious corporate stewards in the neighbourhood," says Scott Balaguer, general manager for Edwards Vacuum's Semiconductor Division North America. "We anticipate continued expansion on site as we plan to design and manufacture our integrated vacuum and abatement production solutions, as well as other world-class products in our portfolio," he adds.

www.edwardsvacuum.com

NanoLab@TU/e orders Trymax plasma system for resist stripping, descum and surface cleaning on InP

Trymax Semiconductor Equipment BV of Nijmegen, The Netherlands (which provides plasma-based solutions for photoresist removal, surface cleaning, isotropic etch and UV curing/charge erase) says that Eindhoven University of Technology's NanoLab@TU/e has ordered a NEO 200A system with microwave downstream plasma technology (for installation in third-quarter 2019) for resist stripping, descum and surface cleaning on indium phosphide (InP) wafers. Trymax claims that the order illustrates the competitiveness of its single chamber and fully automated solution for the photonics market.

"European research organizations and equipment companies are at the forefront of the global photonics



industry," comments Carlos Lee, director general of the European Photonics Industry Consortium (EPIC). "Having a company such as Trymax collaborating with Eindhoven University of Technology goes in the right direction to build an efficient manufacturing infrastructure."

Eindhoven University of Technology selected Trymax after running technical demonstrations on InP substrate and other compound semiconductor substrates. The results achieved on the NEO 200A platform in terms of ash rate, non-uniformity and handling of critical substrate materials of different sizes are said to have outperformed competing solutions.

"Beyond silicon, Trymax has a long experience and unique capabilities in handling various substrates materials such as SiC, GaN, GaAs, LiNbO3, LiTaO3, glass and eWLB," says CEO Leo Meijer.

"Eindhoven University of Technology has chosen the Trymax NEO 200A because of the robustness of the tool, the expertise of the Trymax team and the short distance to the lab, all of which is superior to what we found elsewhere on the market," comments NanoLab@TU/e's managing director Huub Ambrosius.

www.trymax-semiconductor.com

MRSI-H/HVM die bonder accuracy improved from 3μm to 1.5μm

Mycronic Group's MRSI Systems of North Billerica, MA, USA (which makes fully automated, high-precision eutectic and epoxy die bonding systems) has announced the latest advance in its MRSI-H/HVM-series product line. Testing placement accuracy using industry-standard glass die reference samples shows enhancement from ±3μm (at 3σ) to ±1.5μm (at 3σ). Beginning with shipments from 1 October, the product names will be MRSI-H and MRSI-HVM (formerly known as MRSI-H3 and MRSI-HVM3).

MRSI says that its trademark of high-speed and high flexibility remains uncompromised with the improved accuracy. Users now have options to design products for higher-density and higher-speed parts in miniature packages. This is critical for advanced products such as 400G+ photonics devices for data centers and backbone networks, as well as complex DFB/WDM/EML TO-can TOSA/ROSA devices for 5G wireless applications.

"With proven success in the field and a large worldwide installation base, these MRSI-H/HVM-series products have demonstrated their ability to deliver ultra-precision, high-speed and high-flexibility concurrently," says Dr Yi Qian, VP of marketing. "This is critical for our customers' high-mix high-volume photonics manufacturing," he adds.

MRSI is attending the China International Optoelectronic Exposition (CIOE 2019) in Shenzhen (4–7 September).

www.cioe.cn/en

www.mrsisystems.com

MRSI appoints China country sales director

MRSI has appointed Hendry He as its new China country sales director, based in Shanghai and working alongside the existing sales team and representatives in the region. The firm reckons that his substantial technical experience selling semiconductor equipment along with his network in the Chinese market will further enhance its responsiveness to customers' needs.

Hendry spent the past 18 years working in the microelectronics/optoelectronics industry including advanced photonics, holding senior positions in sales management, technical service and process engineering at First Technology (a subsidiary of Sojitz Group), Plasmatreat Trading Shanghai Co Ltd, ASM Pacific (Shanghai), and Vishay Passive Components Shanghai Co Ltd.

"He has a deep understanding of automation and broad exposure to multiple market applications," comments Daniel Crowley, VP of sales.

With the support of its Swedish parent company Mycronic, MRSI is expanding globally in the die bonding market. Hendry is joining the team at a busy time as MRSI's growth continues. "Joining a market leader that continues to adapt to the changing needs of its customers through significant new product launches is a great opportunity," he comments.

www.mrsisystems.com

Web: laytec.de

LayTec's EpiTT FaceT for GaAs laser facet coating is an in-situ spectroscopic metrology tool especially designed for accurate temperature measurement during MBE passivation of GaAs laser facets in conjunction with real-time passivation layer thickness sensing.

EpiTT FaceT

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- Integrated metrology tool communicating with the MBE control software

For more information:
laytec.de/epitt

LayTec AG | Web: laytec.de | sales@laytec.de

LAYTEC
Knowledge is key

Evatec's next-generation CLUSTERLINE supporting SkyWater's 3DSoC and carbon nanotube custom foundry

Evatec AG of Trübbach, Switzerland (which makes thin-film production equipment for advanced packaging, power device, MEMS, optoelectronics, wireless communication and photonics applications) has delivered the latest generation of its CLUSTERLINE thin-film deposition tool (including evaporation capability) to SkyWater of Bloomington, MN, USA – a US-owned DMEA-accredited technology foundry that manufactures integrated circuits for markets including aerospace & defense, automotive, cloud & computing, consumer, industrial, the Internet of Things (IoT) and medical.

The tool is said to bring new levels of thin-film performance, key to the production of carbon nanotubes and other emerging technologies. CLUSTERLINE is an industry-proven, high-volume single-wafer processing production solution enabling integration of PVD (physical vapor deposition), highly ionized PVD, soft etch and PECVD (plasma-enhanced chemical vapor deposition) process technologies, along with extensive pre- and post-treatment steps. The open system architecture allows easy tool configuration.

The latest tool from Evatec provides SkyWater new capabilities in processing of metals and dielectrics, and is important in its 3DSoC (system-on-chip) work, providing unconventional processing capabilities for a CMOS-based foundry. This new tooling supports SkyWater's business model as a technology foundry by giving innovators additional processing options to establish manufacturable process flows for emerging technologies. This capability supports on-going process development at SkyWater not only for carbon nanotubes but also for photonics and MEMS device types as well as where conventional PVD processes do not provide flexibility or the precision that these applications require.

The latest generation of CLUSTERLINE extends the range of thin-film deposition technologies available on traditional cluster tools. In addition to techniques like sputter, PECVD or ALD (atomic layer deposition), it is now possible to integrate evaporation capability. Evatec says that its long know-how in building both cluster systems and box coaters for evaporation has addressed the challenge of integrating evaporation technology into a compact module suitable for up to 300mm cluster tools with long-life evaporation sources and simple access for maintenance.

"Evaporation continues to be the process of choice for many custom applications and offers the chance to process material compositions which wouldn't be possible otherwise," says Silvan Wuethrich, head of Evatec's Semiconductor business unit. "We are very pleased to be working with SkyWater, which is focused on making possible the most advanced emerging technologies," he adds.

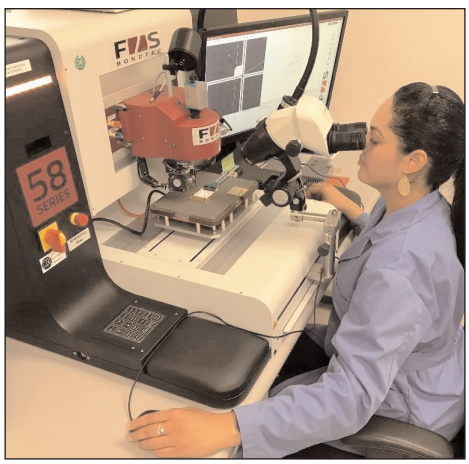
"Evatec's tooling allows customers to try new materials or processes quickly in a quality fab environment and opens up a whole new range of custom foundry possibilities for us," comments Gregg Damminga, SkyWater's VP of technology development. "We appreciate Evatec's professional support and industry-proven expertise and look forward to the value they add to our development and manufacturing operations."

www.skywatertechnology.com
www.evatecnet.com/products/clusterline-platforms/clusterline300-ii

Innovations in Optics buys F&S BONDTEC automatic die bonder

Innovations in Optics Inc of Woburn, MA, USA has purchased a new Model 5830 automatic wire bonder from F&S BONDTEC of Braunau am Inn, Austria to produce chip-on-board die arrays used in its high-power UV LED light sources.

The new addition will not only expand capacity but also enhance capabilities, increasing efficiency and overall throughput times as well as bringing value-added throughout the entire manufacturing process.



The BONDTEC 5830 can handle bond wire diameters to 3 mils (75μm), a critical feature for the high-current-density operation applicable to all LED arrays within products made by Innovations in Optics. Key features of exchangeable bond heads and the ability to store an unlimited number of complex bond programs support the firm's variety and intricacy of die arrays.

www.fsbondtec.at
www.innovationsinoptics.com

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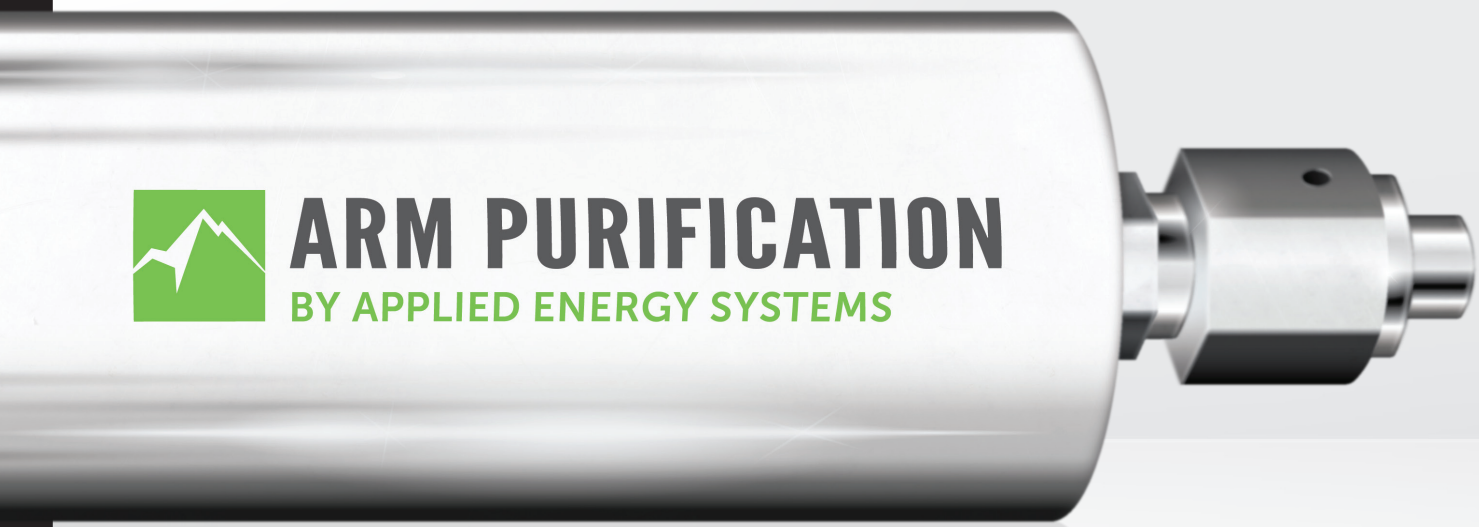

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BluGlass opens new manufacturing and demo labs

Two additional deposition systems to triple wafer capacity for RPCVD development and commercialization

At its facility in Silverwater, Sydney, Australia, BluGlass Ltd — which was spun off from the III-nitride department of Macquarie University in 2005 — has formally opened its Paul Dunnigan laboratories — named after its late engineer Paul Dunnigan (who contributed to developing both the firm's RPCVD hardware and facility) — in the presence of members of his family and the City of Parramatta Lord Mayor councillor Andrew Wilson.

BluGlass is developing and commercializing its proprietary low-temperature remote-plasma chemical vapor deposition (RPCVD) technology for manufacturing group III nitrides, offering better-performing, lower-cost devices and more environmentally sustainable processes for producing LEDs for automotive and overhead LED lighting, micro-LEDs for wearables and virtual reality (VR) displays, and power electronics for efficient power conversion.

Representing an investment of over $6m in additional equipment and associated infrastructure, the new labs incorporate two new cleanrooms housing two additional RPCVD systems, significantly expanding the firm's operational and manufacturing capacity.

The first of these new systems, the BLG-300II, is now commissioned and has started wafer growth runs using BluGlass' patented RPCVD process and has already expanded the firm's operational capacity. BluGlass aims to commission the second — its largest RPCVD system — by retrofitting a commercial-scale AIX 2800 G4, in collaboration with equipment maker Aixtron SE of Germany, for operation by the end of 2019. Together, the lab, with the two new systems (BLG-300II and RPCVD G4), will more than triple BluGlass' RPCVD wafer capacity and customer output in process and equipment development while also demonstrating RPCVD's benefits in cost, scale and flexibility to the global opto industry.

BluGlass officially opens the Paul Dunnigan Labs: (L–R) BluGlass NED James Walker; Lynda Voltz MP; BluGlass MD Giles Bourne; Councillor Patricia Prociv; City of Parramatta Lord Mayor Andrew Wilson; BluGlass' head of Hardware and Facilities, Denis Timoney; Susan Dunnigan; Senator Hollie Hughes; BluGlass' CTO Dr Ian Mann; Julie Owens MP; and BluGlass' investor relations Stefanie Winwood.

Output from the new facilities will be used in commercial contracts, on collaborations with commercial partners, and as part of BluGlass' continuing development of RPCVD for the manufacture of LEDs, micro-LEDs, laser diodes, power electronics and other optoelectronic devices.

"These new systems and infrastructure allow us to expand our revenue-generating epitaxy foundry services, accelerate our RPCVD development for commercial applications, and will provide the foundation for our continued negotiations with leading specialist opto-electronics manufacturers around the world," says BluGlass' CEO & managing director Giles Bourne.

www.bluglass.com.au

Plessey's micro-LED advisory board gains Apple's former VP of Macintosh Hardware Systems Engineering

UK-based Plessey, which develops embedded micro-LED technology for augmented-reality and mixed-reality (AR/MR) display applications, has appointed Dr Edward H. Frank to its micro-LED advisory board, as part of the rapid development of the firm's micro-LED technology (which promises thinner, brighter, lighter and low-power displays). Combining the best features of liquid-crystal displays (LCDs) and organic light-emitting diodes (OLEDs), micro-LEDs represent the fourth-generation flat-panel display technology after plasma, LCD and OLED.

"Ed's strong and proven history of developing and bringing revolutionary solutions to market makes him an excellent addition to our advisory board," reckons Plessey's co-CEO and CTO Dr Keith Strickland. "His expertise in delivering innovative silicon and systems, at companies both large and small, will be invaluable as we continue to provide cutting-edge micro-LED display solutions to AR applications," he adds.

"Micro-LED display has many advantages such as high brightness, ultra-low power consumption, fast response time, very high contrast rate, wide colour gamut, long lifetime, environmental stability, high resolution, the option of flexible backplanes and integration of sensors in the display," comments Frank. "Its main challenges are manufacturing complexity and yield issues, all of which Plessey is addressing."

Previously, Frank was CEO & co-founder of voice-of-the-customer start-up Cloud Parity. Earlier, he served as VP of Macintosh Hardware Systems Engineering at Apple, as corporate VP of Research and Development at Broadcom (a broad-based manufacturer of wireless chips used in many Apple devices) and as a Distinguished Engineer at Sun Microsystems. He is currently on the boards of directors of Analog Devices and Marvell.

Frank earned a BSEE and MSEE from Stanford University, and a Ph.D. in Computer Science from Carnegie Mellon University, where he is presently vice-chair of its Board of Trustees. He is a member of the US National Academy of Engineering and is a named inventor on over 50 patents.

www.plesseysemiconductors.com/products/microleds

K&S and Rohinni receive initial orders for PIXALUX mini- and micro-LED placement solution

Singapore-based chip assembly & packaging equipment and materials supplier Kulicke and Soffa Industries Inc (K&S) and Rohinni LLC of Coeur d'Alene, ID, USA (which has developed a proprietary method for transferring semiconductor devices) have received initial orders for PIXALUX - K&S's micro- and mini-LED high-speed die placement solution that was jointly developed with Rohinni. K&S expects to ship several additional systems during its current fiscal quarter and anticipates higher-volume market adoption as early as calendar year 2020.

Looking ahead, both K&S and Rohinni anticipate meaningful growth as PIXALUX is increasingly positioned to enable high-volume and cost-competitive production of LED technology — through a combination of throughput and accuracy for small-die applications — enabling new forms of backlighting and direct-view LED displays.

Also, at the annual trade show and conference of the Japan Electronics Packaging and Circuits Association (JPCA) in Tokyo, the PIXALUX placement system was honored with an Equipment of the Year Award.

"The industry recognition from JPCA, our initial system shipments and ongoing customer interest highlight the unique value PIXALUX is capable of delivering to the broad display market," says Chan Pin Chong, senior VP at K&S. "We remain focused on accelerating customer adoption as we prepare to ramp production to high volume," he adds.

Customer evaluations of PIXALUX began last fall with systems installed at several manufacturing locations. With nearly 250 million square meters of flat-panel displays produced annually, the growth potential of emerging mini- and micro-LED placement technologies is extremely promising, it is reckoned.

www.kns.com
www.rohinni.com

Lumileds launches LUXEON MultiColor Module 2.5W in 5050-footprint PLCC package with no crosstalk between RGB and white LEDs

Lumileds LLC of San Jose, CA, USA has launched the LUXEON MultiColor Module 2.5W, a compact RGBW module that produces what is claimed to be leading flux and achieves exact color points in architectural and general outdoor lighting applications.

The 4-in-1 module simplifies system design by combining red, green, blue and white emitters in a compact 5050-footprint PLCC package. "We designed a barrier between the color and white emitter to eliminate the problem of crosstalk [when a direct LED excites the phosphor in a neighboring white LED, altering the emitted color], allowing designers to consistently achieve the exact color point they are targeting," says product line director Jennifer Holland.

Typical flux of the LUXEON MultiColor Module 2.5W is 18lm (red), 38lm (green), 15lm (blue) and 53lm (white) at an injection current of 120mA. The emitter may be driven at up to 240mA to achieve what is claimed to be breakthrough lumen output. The single-emitter approach enables seamless color mixing without the shadowing associated with combining emitters of differing heights. The module especially shines in space-constrained applications, including linear architectural designs where four emitters require double the footprint of a single emitter.

LUXEON MultiColor Module 2.5W

Benchmark sulfur testing against the leading competitor revealed nearly twice the flux loss relative to the LUXEON MultiColor Module 2.5W, Lumileds claims. A far simpler solder pad layout also ensures precise contact and streamlines the assembly process.

The colors in the LUXEON MultiColor Module 2.5W can be individually or separately controlled for maximum flexibility in lighting design. An additional convenience of the module's 5050 footprint is compatibility with industry optics to achieve different beam angles and intensities.

Applications include outdoor facade lighting, architectural lighting, signage and any indoor applications with aggressive environments, from industrial plants to swimming pools.

www.lumileds.com/products/luxeon-multicolor-module-2-5w

Lumileds launches LUXEON CSP HL1 LEDs in directional chip-scale packages for small, bright spotlights

Lumileds has launched the LUXEON CSP HL1 LED, supplied in compact, directional chip-scale packages that provide high lumen density in directed, narrow beams or in ultra-high-density arrays for indoor area lighting. The package size is 1.4mm x 1.4mm x 0.3mm, with two pads that attach directly to the PCB for ease of SMD assembly and reduced cost. The line is designed to set new records for shrinking the footprint of spotlights, wall grazing, wall washing and linear fixtures for architectural, high-impact retail, home and office lighting venues.

The LUXEON CSP HL1 consists of side-coated CSPs that emit 100% of their light from the surface and none from the sides, enabling very tight packing of packages together with no crosstalk and complete beam control (beam steering) using LEDs. The result is a very clear beam and what is claimed to be excellent color over angle, leading to outstanding punch (CBCP, center-beam candle power) and use of the industry's smallest secondary optics. To achieve smart color tuning for human-centric lighting, fixture makers can combine CSPs of cool and warm color temperatures and use a simple control scheme.

The LUXEON CSP HL1 LED.

"The combination of tiny source size, high lumen density and uniform color translates to spotlights with outstanding punch and color quality," says product manager Alvin Yeoh.

The LUXEON CSP HL1 is available in correlated color temperatures (CCTs) from 2700K to 6500K with a color rendering index (CRI) of 80 or 90 minimum. Output is 104lm at 3000K and 80CRI when driven at 350mA or 190lm at 700mA. Record lumen density of 200lm/mm^2 can be achieved. The wide variety of CCT/CRI combinations in the LUXEON CSP HL1 enables flexibility in fixture design, whether for color tuning, beam steering or designing a complete fixture portfolio around 80CRI and 90CRI options.

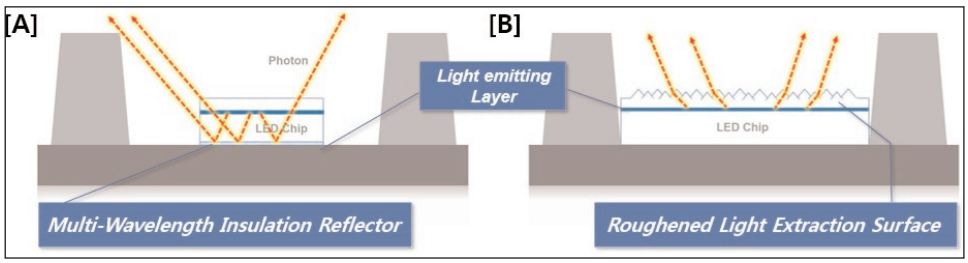
www.lumileds.com/products/high-power-leds/luxeon-csp-hl1

German court orders permanent injunction and recall of Everlight LED products for infringing Seoul Semiconductor patent

South Korean LED maker Seoul Semiconductor Co Ltd has won a patent infringement lawsuit in Germany against Mouser Electronics, a global distributor of accused LED products — 2835 (2.8mm x 3.5mm) LED packages – manufactured by Taiwan-based Everlight Electronics Co Ltd.

The District Court of Düsseldorf issued a permanent injunction against sales of the accused Everlight products and ordered the distributor to recall such products sold after February 2017 from commercial customers. The decision was issued in the first instance.

The patented technology involved is a Multi-Wavelength Insulation Reflector technology that serves to efficiently improve light reflectivity from the internal LED structure by attaching a light reflection structure to the LED chip, which would assure durability and high efficiency of lighting (see Figure A). It has been widely applied to most cost-effective mid-power LED products, such as those used in lighting, LCD backlights, mobile phone and automotive applications, where power consumption is 0.5-3W.



In December 2018, Seoul also obtained a permanent injunction against Everlight's high-power LED products and a recall was issued for such products sold after 13 July 2012 from commercial customers. This patented technology serves to efficiently extract light emitted from the internal LED structure by treating LED chip surfaces (Figure B) and applies to high-power LED products including UV and white LEDs involved in this litigation. Seoul won all 10 patent litigations against Everlight or its distributor in five major countries including Europe and Asia (Korea and Japan). Specifically, Everlight filed a patent invalidation action, but the patent office dismissed it and confirmed the validity of Seoul's patents.

"To create a fair and competitive market, we will continue enforcement efforts to prevent electronics brands, manufacturers and distributors from selling products suspected of infringement," says Seoul's founder Chung Hoon Lee. "Only then will others, including young entrepreneurs and small businesses, have a chance to have their talents recognized in the market," he adds. "We are preparing all legal actions against companies that have suspicions of infringing our patents or of unlawful access to our trade secrets by luring employees and will initiate such actions soon."

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RIT to upgrade Semiconductor and Microsystems Fabrication Laboratory via $1m New York state grant

Upgrades to cleanroom to enhance research capabilities in photonics, quantum technologies and smart systems

Rochester Institute of Technology is upgrading its Semiconductor and Microsystems Fabrication Laboratory (SMFL) to further advance its research in integrated photonics, quantum information technology, biomedical devices and sensors for smart systems. Improvements will enable the university to expand its key research, teaching, staff training and entrepreneurial capabilities.

The 2019–20 renovation project will be launched with a $1m grant from New York State's Higher Education Capital Matching Grant Program. The first phase of expansion (to begin in the 2019–20 academic year) is part of a broader project to create a versatile, multi-disciplinary user facility to meet the evolving needs of academic and industry researchers in the Rochester area and state-wide.

"Thanks to this grant, we will be able to upgrade and expand our cleanroom, making it more relevant to emerging technologies," says Doreen Edwards, dean of RIT's Kate Gleason College of Engineering. "The facility will provide our faculty and students with opportunities to work side-by-side with our industry partners who are developing new products right here in Rochester."

New York State Governor Andrew M. Cuomo announced recently that RIT was one of three local colleges receiving a portion of $2.3m in matching capital improvement grants. All funding is part of the state's emphasis on continual improvements to college and university facilities.

The 2019–20 funding allows RIT to:

- expand its research portfolio in key areas related to integrated photonics, quantum information technology, biomedical materials and devices, and sensors for smart (interconnected) systems;
- expand and improve user services available to researchers and inventors in the region;
- assist with the incubation of firms that need access to micro- and nano-fabrication facilities;
- improve the quality of hands-on education in micro- and nano-fabrication technologies at bachelor's, master's and doctoral levels;
- deliver an expanded portfolio of workforce training and talent development models to meet the needs of regional and other New York firms in the industry; and
- incubate new companies and inventors.

"This will support expansion of research initiatives within microsystems as well as the growing area of biomedical engineering and their need for microscale capabilities in fabrication and nano-materials," says Karl Hirschman, director of the SMFL and a professor in RIT's electrical and microelectronic engineering department. "This expansion will improve upon and complement recent investments made through AIM Photonics."

Originally built in 1985 as part of RIT's microelectronic engineering program, the lab has expanded considerably and is used by the engineering college's undergraduate, graduate and doctoral programs, by faculty-researchers associated with the Nanopower Labs and Future Photon Initiative as well as industrial partners. With over 10,000ft^2 of cleanroom space, the SMFL is equipped with microfabrication and metrology equipment to support research programs in semiconductor materials and devices, nano-electronics, MEMS devices and sensors, photonic devices and nanomaterials. All these systems are utilized as part of RIT's role in AIM Photonics, to advance integrated photonics for manufacturing capabilities in areas such as high-speed data and telecommunications.

We will be able to upgrade and expand our cleanroom, making it more relevant to emerging technologies. This expansion will improve upon and complement recent investments made through AIM Photonics

In 2016, the lab received a laser lithography system and a reactive ion etching system through two US National Science Foundation (NSF) major research instrumentation program grants. The laser lithography system is a multi-step, precision process to build, layer-upon-layer, the electronic circuitry on silicon wafers that is then used as the basis for electronic devices. The new system has several advantages over traditional proximity or projection optical lithography, Hirschman says. It has the ability to handle a variety of substrate shapes and sizes, make on-demand pattern changes, and implement pattern variations within a sample. Patterning can be intermixed with e-beam or optical exposure levels, providing design flexibility on pattern transfer processes.

A plasma reactive ion etching system was acquired to test and develop new materials that could complement the use of silicon for devices and improved applications related to solar energy and ultraviolet (UV) wavelength sensors.

These technologies — along with the metal-organic vapor phase epitaxy (MOVPE) system used for the growth of novel materials, thin-film crystals and nanostructures — give RIT researchers more flexibility and independence in its development and processing of integrated circuits.

www.rit.edu/engineering/facilities/semiconductor-and-microsystems-fabrication-laboratory

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Osram clears way for ams offer of €38.50 per share

The managing and supervisory boards of Osram GmbH of Munich, Germany have waived the existing standstill agreement with ams AG of Premstaetten, Austria (which designs and makes high-performance sensor and analog solutions) and signed a cooperation agreement, clearing the way for a voluntary public takeover offer by ams. The offer (expected to be valid until the beginning of October) amounts to €38.50 in cash per share, with a minimum acceptance level of 70%.

"Our shareholders now have two offers on the table, allowing them to choose between the different business concepts," says Olaf Berlien, CEO of OSRAM Licht AG.

In early July, Osram's managing board and supervisory board announced support for a legally binding public takeover offer (of €35 in cash per share) from a bidding consortium composed of US-based firms Bain Capital and The Carlyle Group, as well as signing an investor agreement that included comprehensive commitments.

"We are proud to have made brave, strategically right decisions in an extremely difficult market environment over the past few years. The interest shown by several bidders, both from the private equity sector and the industry, is testimony for this," Berlien says.

Osram says that, in addition to providing a takeover offer with a secured financing for shareholders, it is important to its managing board and supervisory board that employee interests are safeguarded, so the cooperation agreement with ams thus provides commitments for employees and essential parts of the company. ams has also committed to maintaining existing collective agreements, works agreements and similar arrangements. Existing pension plans shall also be fully retained. Munich would become co-headquarters, with global central functions. Osram would continue to operate under its current name and exist as a brand following the takeover.

Osram will also give ams further opportunity to convince its managing and supervisory boards of the business orientation, global location strategy and integration concept. For various reasons, it has not yet been possible to reach an adequate understanding on these issues. In particular, integration of an industrial group with revenue of over €3.8bn (in fiscal year 2018) and a presence in about 70 countries by a significantly smaller firm represents a challenging task, says Osram.

Osram says its consequent transformation into a high-tech photonics firm remains the only viable way to secure growth over the medium to long term. Osram will hence continue to focus on moving in this direction.

The offer document of ams still needs to be reviewed and approved by the German Federal Financial Supervisory Authority (BaFin) in accordance with the provisions of the German Securities Acquisition and Takeover Act (WpÜG).

www.ams.com
www.osram.com

Compound Semiconductor Centre wins UK award for 'Best Collaboration'

At Insider Media's 'Made in the UK' awards, Compound Semiconductor Centre (CSC) Ltd — a joint venture between Cardiff University and IQE plc that works with the university's ERDF-funded Institute for Compound Semiconductors (ICS) — won the 'Best Collaboration' title for its work developing a compound semiconductor technology cluster in South Wales.

CSC works with partners including IQE, SPTS, Microsemi, Newport Wafer Fab, Swansea University, Compound Semiconductor Applications Catapult, Cardiff Capital Region City Deal and the Welsh Government.

Launched in 2015, the South Wales-based cluster has secured investment commitments worth over £600m for innovation and manufacturing facilities to service applications including telecoms, power electronics, sensing, healthcare and quantum technologies.

The award celebrates "strong industry and academic collaboration," says CSC's managing director Dr Wyn Meredith. "CSC provides cutting-edge facilities that help researchers and industry work together and helps to position Cardiff as the UK and European leader in compound semiconductor technology. This award is testament to the growing importance of our industry sector to the regional economy," he adds.

"CSC was launched in 2015 to work with a range of partners through Cardiff's Institute for Compound Semiconductors," notes Cardiff University's deputy vice-chancellor professor Karen Holford. "CSC recently led a £1.3m UK consortium win to develop gallium nitride power applications for electric vehicles..."

CSC works to develop new materials technologies that will enable a wide range of new and emerging applications. It aims to provide a complete capability value chain from R&D through product and process innovation to high-value, large-scale manufacturing. It is Europe's first prototyping facility allowing businesses and academics to demonstrate new technologies based on compound semiconductor materials that will be production ready, allowing rapid routes to market for entrepreneurs and technology leaders.

www.cardiff.ac.uk

ACNM funding for CST Global, CSC and Swansea

A new project to scale-up novel compound semiconductor device fabrication processes has received European funding through the Avenues of Commercialisation for Nano and Micro Technologies (ACNM) initiative. The project, which should result in new fabrication processes being developed, will be a collaboration between Swansea University, Compound Semiconductor Centre (CSC) and III-V optoelectronic foundry Compound Semiconductor Technologies Global Ltd (CST Global) of Glasgow, Scotland, UK.

Susannah Heck, principal device development engineer at CST and responsible for the project explains, "The first fabrication process under consideration is a low-cost, high specification, semiconductor laser chip manufacturing platform utilising Substrate Conformal Imprint Lithography (SCIL), initially developed at the Centre for NanoHealth (CNH). An Innovate UK-funded project has already demonstrated that a SCIL-based distributed feedback (DFB) laser manufacturing platform can deliver a 30% cost reduction, with no loss of performance. ACNM funding will enable commercialization, including increasing on-wafer yield and moving from 3" to 4" epiwafers. The lasers would typically be used in high-volume markets such as Fibre-to-the-Premises (FTTP), high capacity, optical communication links in data-centres and as coherent sources for trace gas sensing.

"The second fabrication process being addressed aims to develop a high volume, chip-scale packaging concept for the integration of compound semiconductor devices on flexible substrates. Printed, conductive track processes, developed at The Welsh Centre for Printing and Coating (WCPC), will be used to deliver wire-bond free, conformal interconnects in gallium arsenide devices. These devices are used for a broad range of applications, from the integration of GaAs sensors in the high pressure (50MPa), SMART gaskets used in critical pipework joints, through to the low-cost assembly of LEDs in flexible, wearable products for the cosmetic and healthcare markets. They are also in flexible, large area, LED displays."

Although the ACNM funding is minimal, each process successfully scaled-up should gain further funding for greater commercialization.

www.compoundsemi.co.uk

Ovum notes Rockley's silicon photonics approach

In its latest silicon photonics market report, Ovum recognizes that Rockley Photonics of Pasadena, CA, USA has an approach to silicon photonics (SiPh) that is fundamentally different to other suppliers.

Rockley was formed in 2013 by a team with prior technical and commercial success with two silicon photonics firms. Founder & CEO Andrew Rickman formed the first firm to commercialize silicon photonics, Bookham Technology (which had an IPO in 2000, became Oclaro in 2009 and is now a part of Lumentum), and later became chairman of Kotura (sold to Mellanox in 2013). Rockley has developed a highly versatile, third-generation silicon photonics platform specifically designed for the optical I/O challenges facing next-generation sensor systems and communications networks.

Rockley's photonic technology platform was developed with a focus on high-volume manufacture of highly integrated optical/electronic devices for high-performance applications. Exploiting optimized waveguide dimensions, it is said to offer benefits over conventional solutions including the production of higher-density optical circuits, the ability to create more complex integration, better manufacturing tolerances, superior power handling, lower loss and higher-efficiency photonic IC interfaces. The firm says its technology can be adapted to be application specific, while simplifying manufacturing, assembly, test and validation, and optimizing power, size and cost of complex optical systems.

"Instead of trying to force the silicon chip manufacturing into a silicon photonics solution, Rockley has developed its technology focused on how the silicon chip manufacturing can be modified to be used for SiPh engines," the report says. "The result is a large waveguide photonics platform that offers multiple benefits over conventional solutions."

"Rockley started from a clean sheet and has designed a process that is bespoke for SiPh," notes Lisa Huff, principle analyst, Optical Components. "Results demonstrate that its technology enables low-power, cost-effective optical modules. By incorporating all the transceiver functions in the chip, Rockley can integrate optical transceiver functionality directly inside its OptoASIC package, delivering on the highly versatile capability of the platform," she adds.

"Because photons behave differently to electrons, silicon photonics requires bespoke processes and solutions to realize the technology's full potential," notes Rockley's founder & chief executive Andrew Rickman. "Our unique manufacturing processes, expertise and solutions put us several years ahead of the competition," he claims.

Rockley's technology is relevant to communication interconnects and is already being considered in AI compute cluster environments — liberating data from the constraints of electrical connections, notes the report. The technology also has potential for sensor applications, e.g. in healthcare, biosensing, 3D laser imaging, and autonomous vehicles. "Applying photonics to sensors can unlock extraordinary applications," Rickman concludes.

www.rockleyphotonics.com

CompoundTek delivers silicon photonics PDK in partnership with Mentor and Lumerical

Singapore-based silicon photonic (SiPh) foundry services provider CompoundTek Pte Ltd has partnered with electronic design automation (EDA) software provider Mentor (a Siemens business) and photonic simulation software provider Lumerical Inc of Vancouver, Canada to deliver its SiPh process design kit (PDK) across its global commercial customer base.

Available immediately, the PDK's predictive capabilities enable photonics designers to validate designs prior to manufacturing, enabling a reduction in the time from product design to market launches.

"Together with our design partners, this photonics design automation solution by Lumerical and Mentor, combined with CompoundTek's open SiPh manufacturing process platform, will accelerate SiPh adoption for applications ranging from datacom transceivers, bio-sensing, smart sensors, LiDAR, quantum computing and artificial intelligence," says chief operating officer KS Ang.

The PDK includes active and passive devices such as optical waveguide devices, fibre-to-waveguide couplers, high-speed waveguide germanium (Ge) photodetectors and high-speed modulators. SiPh designers can leverage these predeveloped blocks to design and verify their photonics products more quickly and efficiently before fabricating physical prototypes.

A complete design flow enabled by the PDK includes photonic simulation, schematic capture, custom layout, layout automation, and physical verification. Tools enabled include Lumerical INTERCONNECT, as well as Mentor's L-Edit Photonics, LightSuite Photonic Compiler, and Calibre platform physical verification tools.

"The development of the ecosystem is imperative to the ongoing productization of photonics," says Lumerical's chief technology officer Dr James Pond. "Successful flows must be built with the cooperation of EDA, photonic design automation, and foundries, with unrelenting focus on the customers' needs," he adds.

"Our partnership with CompoundTek and Lumerical provides our mutual customers with the ability to design complex custom photonic integrated circuits using their proprietary photonic process," says Greg Lebsack, general manager Integrated Circuit Design Solutions (ICDS). "The CompoundTek PDK supports both an automated design flow with LightSuite Photonic Compiler, an interactive design flow using L-Edit Photonics, and integrated full system simulation with Lumerical's INTERCONNECT."

In partnership with Mentor and Lumerical, CompoundTek presented live demos at the 16th International conference on Group IV Photonics (GFP2019) in Singapore (28–30 August). The partners are also presenting live demos at the China International Optoelectronic Exposition (CIOE 2019) in Shenzhen (4–7 September).

www.lumerical.com
https://compoundtek.com

CompoundTek and Luceda Photonics release PDK for IPKISS

CompoundTek has partnered with integrated photonics design automation firm Luceda Photonics of Dendermonde, Belgium, expanding its silicon photonics PDK to enable Luceda's IPKISS platform for a global commercial customer base.

Photonic IC technology is maturing fast with designers needing PDKs as the foundation of their design flow, says CompoundTek. Providing a reliable and scalable design flow, the PDKs additionally facilitate knowledge transfer between foundries and designers on layout and simulation models. The IPKISS platform combines layout, smart physical simulation and circuit-level design and simulation in one single quality-controlled PDK. The PDK can be used from IPKISS.flow, and from IPKISS.eda integrated in the Siemens/Tanner flow, enabling users to make advances in creating design flows that are more reliable and scalable, CompoundTek adds.

Pivotal to the consolidation of knowledge in the context of a fast-moving industry, the IPKISS platform is instrumental to producing a scripting environment that covers the complete photonic IC design flow up to measurement feedback for true component validation. This is suitable for niche solutions spanning interconnectivity, datacom transceivers, bio-sensing, smart sensors, light detection & ranging (LiDAR), quantum computing and artificial intelligence (AI).

The IPKISS platform is in line with CompoundTek's aim to drive the adoption of niche SiPh-based applications and in facilitating the commercialization goals of its global customer base.

"Our strategic partnership with Luceda Photonics leverages CompoundTek's open manufacturing process platform," says KS Ang CompoundTek's chief operating officer. "Backed by an ecosystem that includes our design partners and foundry, the photonics design automation solution will further accelerate time-to-market in cutting-edge SiPh solutions," he adds.

"The PDK with CompoundTek has been created following demand of some of our most important customers," says Luceda's chief technology officer Pieter Dumon. "In adding an influential foundry to our portfolio, we open new design opportunities to mature yet innovative design teams."

www.lucedaphotonics.com

POET agrees sale of DenseLight for $28m to Dynax-led concern

Singapore operation to expand to support POET and expanded market presence in China; high-volume production plant to be built in Suzhou

POET Technologies Inc of Toronto, Ontario, 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 signed a definitive agreement with respect to the sale of its Singapore-based subsidiary DenseLight Semiconductors Pte Ltd (announced in February).

In connection with the sale (which requires approval from shareholders), POET has posted the share sale agreement (SSA) on SEDAR and published a management information circular for the Annual and Special Meeting of Shareholders at 10am Eastern Time on 20 September (at Vantage Venues 150 King Street West, 27th Floor, Toronto) via the TSX Trust website (http://docs.tsxtrust.com/2042). Representatives of the buyer of DenseLight intend to be present at the meeting.

The buyer is DenseLight Semiconductor Technology (Shanghai) Co Ltd (DL Shanghai), a special-purpose company recently organized by China Prosper Group on behalf of investors. DL Shanghai was established to acquire the capital stock of DenseLight from POET for US$28m, which includes US$2m that will be paid to Oak Capital Investment Company Ltd (an affiliate of China Prosper Group) for due diligence, negotiation and other services rendered to the buyer in connection with the share sale agreement. The lead shareholders in DL Shanghai are expected to be Dynax Semiconductors (Suzhou Nengxun High Energy Semiconductor Co), one of Dynax's major shareholders, the Suzhou Xiang Cheng District Investment Fund and a developer and manufacturer of gallium arsenide (GaAs)-based fiber lasers and optical passive devices for high-powered lasers. Other shareholders include established funds and investors in the technology and communications industry in China. Dynax is said to be China's leading developer of gallium nitride (GaN)-based electronic devices for RF microwave and industrial control in 5G mobile communication and broadband communication. None of the companies or individual shareholders have material interests in businesses that are competitive with DenseLight.

The transaction is expected to close on or before 31 October, allowing for both POET shareholder approval and the activities in which DL Shanghai is currently engaged, including the transfer of ownership interests to investors and assisting with foreign currency transfers prior to the closing.

Following closing, DenseLight's operation in Singapore is expected to be expanded, both to support the preferred supply and strategic cooperation agreements negotiated with POET as part of the share sale agreement and to serve an expanded market presence in China. Future plans include the construction of a high-volume manufacturing plant in Suzhou, expansion of sales & marketing efforts in China and elsewhere, and a potential public listing for DL Shanghai in China.

At the meeting, in addition to approving resolutions related to the proposed sale of DenseLight, POET will also conduct annual business, including the election of directors and ratification of the appointment of its auditors Marcum LLP.

www.poet-technologies.com

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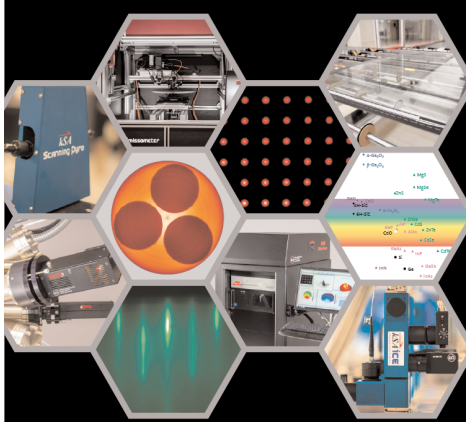
www.k-space.com

NeoPhotonics' revenue rises 3% in Q2 as Huawei shipments only partially subject to export ban

Growth driven by Western data-center interconnect market

For second-quarter 2019, NeoPhotonics Corp of San Jose, CA, USA (a vertically integrated designer and manufacturer of hybrid photonic integrated opto-electronic modules and subsystems for high-speed communications) has reported revenue of $81.7m, up 3% on $79.4m last quarter and just 1% on $81.1m a year ago.

This is below the original guidance of $88-93m, given before the US Department of Commerce's Bureau of Industry and Security (BIS) added Huawei Technologies (historically NeoPhotonics' largest customer) to its Entities List as of 21 May, banning the sale to Huawei of products subject to US Export Administration Regulations (EAR) without obtaining an appropriate export license. NeoPhotonics subsequently ceased shipments to Huawei for much of the quarter.

However, Q2 revenue exceeded the revised guidance of $75–80m due to strength in the Western data-center interconnect (DCI) market as well as the re-start of shipments of non-EAR products to Huawei near the end of the quarter.

"Since the addition of Huawei to the Entities List, we implemented processes to evaluate each of our products against the standards set forth in those regulations," notes chairman, CEO & president Tim Jenks. "Each product must be reviewed individually in a detailed, specific and rigorous process, and these reviews are ongoing," he adds. "Having consulted with our legal counsel and technical experts, we determined that certain of our products are not subject to EAR and may continue to be sold to Huawei and its affiliates. Consequently, late in the quarter, we restarted shipping certain non-EAR products to Huawei."

Huawei (including its affiliate HiSilicon Technologies) hence declined less than feared, from 49% of total revenue last quarter to 36% in Q2/2019. Demand from other customers in China rose slightly but remained within the normally expected range, so China overall fell from 57% to 48% of revenue.

After Huawei, NeoPhotonics' next four customers contributed 48% of total revenue (up from 37% last quarter). Western and rest-of-world (RoW) customers comprised 52% of revenue, consisting of 24% from the Americas (up from 18% last quarter) and 28% from the rest of the world (up from 25%). "Our business has been strong with Western customers, especially in DCI and metro markets," says Jenks. "In fact, our top five Western customers were each up by double-digit percent in sequential revenue growth, with growth coming from product shipments for 400G and 600G systems [to over 10% of High-Speed Product revenue]."

High-Speed Products (for data rates of 100G-and-above) hence rose from 86% to 89% of total revenue. "Q2 was a volatile quarter for NeoPhotonics and I am proud of our team and their continued focus and execution to extend our leadership position in high-speed digital opto-electronics while making changes needed to adjust for the Huawei ban," says Jenks.

Our top five Western customers were each up by double-digit percent in sequential revenue growth, with growth coming from product shipments for 400G and 600G systems [to over 10% of High-Speed Product revenue]

"In the case of China and Huawei, the preponderance of demand is 100-200G," he adds. "There is certainly a decrease in demand from Huawei and China for the 400G… We took a breather on the 400G growth because of the China situation with Huawei."

On a non-GAAP basis, gross margin has risen further, from 20.1% a year ago and 22.4% last quarter to 25.6%. This is at the low end of the original guidance range of 25–29% but at the high end of the revised range of 22–26%. Within this, product margins were about 32% (up 5 points from 27% last quarter due to good execution of cost reductions). Other cost of sales charges of about 6.5 points consisted of 5 points of under-utilization charges (given the volume cuts) and 1.5 points of other charges (all less than 0.5 point, the largest of which was the impact of tariffs).

Despite being up slightly from $21.8m (26.9% of revenue) a year ago, operating expenses were $22.1m (27.1% of revenue), cut from $24.2m (30.5% of revenue) last quarter (and at the low end of the revised expectation of $22–23m) due to a combination of spending reductions and project push-ups.

"In May, after the Huawei ban went in place, we executed on changes in our operations to adjust to lower revenue levels," says senior VP, finance & chief financial officer Beth Eby. "We reset our supply chain, adjusted R&D projects and reduced expenses substantively," she adds.

Driven by higher gross margin and lower spending, operating loss was $1.2m (operating margin of –1.5% of revenue), cut from $6.5m (–8.1% margin) last quarter and $5.6m (–6.9% margin).

Net loss was $1.2m ($0.03 per diluted share), cut from $9m

($0.19 per diluted share) last quarter and $6.3m ($0.14 per diluted share) a year ago, and towards the top of the revised guidance range of $0.15–0.05.

Appreciation of the US dollar relative to the Chinese yuan drove a foreign exchange (FX) gain of about $1m. Also, NeoPhotonics made a $0.82m gain on the sale of its Russia manufacturing operation (as part of its ongoing process to align business with product lines that are strongest and most profitable) — Dmitry Akhanov, representing RUSNANO, subsequently resigned from NeoPhotonics' board of directors. "We remain focused on managing the business for cash and profitability," says Eby.

Cash generated from operations was hence $0.7m (down from $8.7m last quarter). Although down from $5m last quarter, free cash flow was a better-than-expected $0.3m. However, due mostly to a $3.6m write-down of Huawei-specific inventory, net inventory fell by about $5m, from $54m (76 days) to $48.8m (67 days). During the quarter, cash and cash equivalents, short-term investments and restricted cash hence fell by about $5m, from $78.9m to $74m, due to the repayment of debt.

"Demand signals from our global customers are positive for the year," says Eby. "As a result, revenue for Q3 is expected to be solid. The supply chain constraints that we have seen for the last 6–9 months have ameliorated," she adds.

For third-quarter 2019, NeoPhotonics expects revenue to rise to $87–93m, driven by Western customers (with strong order backlogs for the firm's five largest Western customers) as well as DCI applications, despite Huawei revenue falling (although most Huawei shipments are not subject to EAR and are hence continuing, via businesses acquired in China and Japan, and development centers established there). Gross margin should be 25–29%. With OpEx of $22–23m, diluted earnings per share should range between a $0.03 loss and a $0.07 profit.

For fourth-quarter 2019, NeoPhotonics expects revenue in a similar range to Q3, and OpEx to remain at $22–23m.

Trends transcend the current Huawei ban and, coupled with the beginning of 5G wireless infrastructure deployments and continued demand with hyperscale data centers, we are optimistic about NeoPhotonics' new product prospects

"We continue to monitor changes in the Department of Commerce and BIS rules related to Huawei and their affiliates. We have not included any benefit for shipment under pending licenses in our forecast," says Eby. "However, products that we have determined are not subject to US EAR are included. These products represented a majority of our shipments to Huawei in 2018," she adds.

"In late June, administration guidance was that US firms would be allowed to sell to Huawei with a license under certain conditions," notes Jenks. "We have applied for a license to ship certain EAR products," he adds.

"Late in the second quarter, China Mobile announced the award of a tender for certain parts of its 5G network, of which Huawei won a significant share. Further, we see ongoing demand for deployments of existing [legacy] 100G and 200G systems," says Jenks.

400G will continue to deploy while our 600G products ramp through this year and next. Beyond 2020, we expect 600G will coexist with coming 800G

"Overall, the drivers for the markets we serve are well aligned with our advanced technologies, high-speed capabilities and strong presence in high-speed components. These trends transcend the current Huawei ban and, coupled with the beginning of 5G wireless infrastructure deployments and continued demand with hyperscale data centers, we are optimistic about NeoPhotonics' new product prospects," says Jenks.

"We continue to see good progress with design-ins and volume growth for our Class 40, 64Gigabaud product suite, which is aimed at 400G and 600G applications, and we have announced our Class 50 receiver and modulator aimed at 800G applications," notes Jenks.

"With higher-order modulation such as 64 QAM, the very pure light and low phase noise of our lasers becomes increasingly important. Because of this, our tunable lasers have the right performance to be the laser of choice for the higher-performance systems," he reckons. "Connecting this to specific system data rates, we anticipate that 400G will continue to deploy while our 600G products ramp through this year and next. Beyond 2020, we expect 600G will coexist with coming 800G, and we will be engaged in deployments of both. Each of these approaches requires best-in-class component performance, which NeoPhotonics delivers both with our vertically integrated indium phosphide PIC platform and our active silicon photonics platform," he adds.

"On the pluggable side of the business, we continued to make good progress with design wins and shipments of our ClearLight CFP DCO modules. At the OFC trade show in March, we demonstrated our CFP2 DCO module. Also at OFC, we demonstrated our 64GigaBaud silicon photonics-based COSA or coherent optical subassembly which, together with our already shipping nano tunable laser, provides all of the optics required for a 400 ZR pluggable module."

www.neophotonics.com

Lumentum quarterly revenue hit by Huawei ban, but telecom growth driven by ROADMs and coherent transmission modules

Greater-than-scheduled synergies from Oclaro merger help to bring profits back within original guidance ranges

For its full-year fiscal 2019 (to 29 June), optical and photonic optical component and subsystem maker Lumentum Holdings Inc of Milpitas, CA, USA has reported record revenue of $1565.3m, up 25.5% on fiscal 2018's $1247.7m.

By segment, Commercial Laser revenue grew by 3.5% from $188.5m to a record $195.1m, driven by fiber-laser sales almost doubling (aided by "unique" new products), counteracting the down market.

Optical Communications revenue grew by 29.4% from $1059.2m to $1370.2m, driven by 65% growth for Telecom products (including transport revenue rising by nearly 50%) and output more than doubling for reconfigurable optical add/drop multiplexers (ROADMs), boosted by the acquisition on 10 December 2018 of optical communications component and module maker Oclaro Inc of San Jose, CA, USA.

However, after the US Department of Commerce's Bureau of Industry and Security (BIS) added Huawei Technologies Co Ltd and 68 of its affiliates to its 'Entity List' prohibiting the sale to Huawei of products covered by the Export Administration Regulations (EAR) without obtaining an appropriate export license, on 20 May Lumentum ceased shipping to Huawei. "Subsequently, we completed a detailed analysis of the products we supply to Huawei and determined that certain products were not subject to Export Administration Regulations," notes president & CEO Alan Lowe.

Fiscal fourth-quarter 2019 revenue was correspondingly up year-on-year by 34.4% from $301.1m to $404.6m but down 6.5% on $432.9m last quarter due to an expected decline for Commercial Lasers as well as sales to Huawei falling by 25%, i.e. about $20m (primarily impacting telecoms) although that was better than the $30m+ drop initially feared (before resuming non-EAR shipments to Huawei late in the quarter after applying new business processes to ensure compliance with government requirements on an ongoing basis). Revenue was also better than mid-May's reduced guidance of $375–390m (and almost reaching the original guidance of $405–425m).

Commercial Laser segment revenue was $47.8m (11.8% of total revenue), down 13.1% on $55m last quarter and 14.9% on $56.2m a year ago, as expected due to customer inventory levels.

Optical Communications segment revenue was $356.8m (88.2% of total revenue), up 45.7% on $244.9m a year ago but down 5.6% on $377.9m last quarter. Of this:

- Telecom revenue was $227.7m, up 71% on $133.1m a year ago but down 6% on $243.4m last quarter due to the lower Huawei sales, despite revenue from coherent transmission modules rising by 10% (with sales of both ACO and DCO products growing). ROADM sales were again a record, exceeding $100m (despite geopolitical disruption), although growth was less than originally expected prior to the Huawei export ban in mid-May. Lost Huawei ROADM revenue was partially offset by redirecting manufacturing capacity to two other customers (albeit too late in the quarter — a month or so before the end — to have much impact).
- Datacom revenue was $41.5m, up 20.3% on $34.5m a year ago but down 28% on $57.3m last quarter. This was driven by the divestiture (early in fiscal Q4) of the firm's "challenged" Oclaro Japan-based datacom transceiver business. "This was a key milestone in our strategic pivot to focus exclusively on photonic chip sales in the datacom market," says Lowe. "We have seen strong engagement from customers for datacom photonic chips, including in 5G wireless applications. In many cases, new customer interest is from leading competitors who previously would not purchase from us due to us competing in the transceiver business." Datacom chip sales hence rose by 11% to a new record level.
- Industrial & Consumer revenue has risen by 13% from $77.2m last quarter to $87.6m, due to higher-than-expected revenues for both industrial diode lasers and 3D sensing VCSEL lasers. "In the case of 3D sensing, in the fourth quarter, we started ramping deliveries to support customers' product cycles expected to start this fall," notes Lowe.

"The fourth quarter was eventful to say the least, but it capped off a fiscal year during which we made significant progress toward our long-term strategic and financial goals," says Lowe.

On a non-GAAP basis, full-year fiscal 2019 gross margin rose from 2018's 38.9% to 2019's 39.5%, driven by more higher-margin products in the revenue mix, as well as increased leverage over fixed manufacturing costs.

Fourth-quarter gross margin was 38.9%, up from 37.2% a year ago but down slightly from 39% last

quarter due to the lower revenue level. By segment, Optical Communications gross margin rose further, from 34.8% a year ago and 38% last quarter to 38.3%, due to the divestiture of the lower-margin datacom transceiver product lines, plus greater Industrial & Consumer sales in the revenue mix. Commercial Lasers gross margin has fallen further, from 47.9% a year ago and 46% last quarter to 43.5%.

Full-year operating expenses have grown from $238.9m in fiscal 2018 to $297.9m in fiscal 2019 (although falling slightly as a proportion of revenue from 19.1% to 19%). However, despite rising from $58.5m (19.4% of revenue) a year ago, quarterly OpEx has been cut from $91.8m (21.2% of revenue) last quarter to $80.7m (19.9% of revenue).

Full-year operating income has grown from $246.2m (19.7% of revenue) in fiscal 2018 to $320.6m (20.5% of revenue) in fiscal 2019 (exceeding 20% for the first time). Quarterly operating income of $76.7m was down slightly from $77m last quarter but up from $53.6m a year ago, while operating margin has risen from 17.8% both a year ago and last quarter to 19% (exceeding mid-May's reduced guidance of 15.5–17% and within the original guidance range of 18–20%, despite the 7% sequential decline in revenue). From the close of the Oclaro transaction through to the end of fiscal Q4/2019, Lumentum has achieved more than the targeted $60m in (annualized) synergies. "We achieved these synergy levels earlier than we estimated when we announced the transaction by strong execution after the close of the transaction," says chief financial officer Wajid Ali.

Full-year net income has risen from $247.8m ($3.82 per diluted share) for fiscal 2018 to $304.8m ($4.25 per diluted share) for fiscal 2019. Quarterly net income has risen further, from $61.6m ($0.95 per diluted share) a year ago and $69.9m ($0.91 per diluted share) last quarter to for fiscal Q4/2019's $70.8m ($0.92 per diluted share, well above mid-May's reduced guidance of $0.65–0.77, and within the original guidance range of $0.85–1.00). During the quarter, cash and short-term investments hence rose by $71m, from $697.5m to $768.5m.

We have seen strong engagement from customers for datacom photonic chips, including in 5G wireless applications. In many cases, new customer interest is from leading competitors who previously would not purchase from us due to us competing in the transceiver business

"With market-leading positions in the growing telecom and 3D sensing markets, a datacom strategy that profitably benefits from growth in cloud and 5G wireless network deployments, a Commercial Lasers business that bucked market trends and grew to record levels, and a more profitable business model driven by the increased scale and synergies from the Oclaro acquisition, we are well positioned for revenue growth and margin expansion in fiscal 2020 and beyond," believes Lowe.

For fiscal first-quarter 2020 (to end-September), Lumentum expects sales to Huawei to be flat to down sequentially. However, Lumentum's total revenue should still grow to $435–455m, despite Commercial Lasers falling by 20% on entering the seasonally weaker fall-time period. Datacom revenue will decline due to discontinuing all remaining datacom transceivers and certain low-margin telecom product lines (which collectively contributed $31m in fiscal Q4/2019 and should decline to zero over the next few quarters). Telecom revenue is expected to be flat to slightly up sequentially (driven by strong non-Huawei demand), including continuing growth in ROADMs (mostly from the very high-end ROADMs and ROADM blades, with demand outstripping capacity) and coherent modules (ACOs and DCOs). Industrial & Consumer revenue should rise as the firm enters the seasonally strong time period for 3D sensing.

"We expect unit growth to exceed price declines as 3D sensing is expected to be incorporated in a higher percentage of end-customer models, and supply chain inventory levels appear to be more normalized when compared to last year," says Lowe. "Taking into account the accelerated fourth-quarter shipments and expectations around global smartphone volumes and our market share, we expect 3D sensing revenue in the first half of fiscal 2020 be slightly up from the first half of fiscal 2019," he adds.

Due to the stronger mix of 3D sensing, gross margin will rise. OpEx will probably stay within the range of fiscal Q4 (plus or minus a couple of million dollars). Operating margin should hence rise to 22.5–24.5%. Diluted earnings per share is expected to grow to $1.12–1.26.

Telecom customer demand outside of Huawei is strong. "However, this [non-Huawei] demand is for a different mix of products than Huawei purchases from us and for which our supply chain had been driving material. Challenges in obtaining supply of long-lead-time materials is currently the limitation," says Lowe. "Additionally impacting Telecom is an expected temporary dip in our submarine business, which has historically been a lumpy project-based business," he adds.

"We now estimate that synergies will be approximately $100m in total, or $40m higher [$10m per quarter] than our original target," notes Ali. "Additional synergies will primarily benefit cost of goods sold [COGS], as further operating expense synergies are likely to be

reinvested in new capabilities and R&D programs to fuel growth and extend our market-leadership positions," he adds. "We expect to complete the additional synergy actions over the next five quarters, although the bulk of these positive financial impacts will be realized toward the tail end of this time line... These additional COGS synergies should drive average gross margins [up by 2–2.5% alone] to the upper half of the 40–45% gross-margin range of the target model," concludes Ali.

"During the past year, we believe we have added to or extended our market and technology leadership positions in telecom and 3D sensing. We introduced many highly differentiated new products and one new design win with market-leading customers in all of our markets," says Lowe.

"Favorable consumer and media reviews for initial world-facing-enabled smartphones has caused customers' product road maps to more broadly incorporate 3D depth sensing for photography and augmented and virtual reality [AR and VR] applications," notes Lowe. "Based on customer activity, we expect major smartphone manufacturers to introduce products with new world-facing capabilities in calendar 2020. This, combined with increased customer demand for smartphones driven by future 5G availability, should drive a significant increase in 3D sensing market in calendar 2020 and 2021."

"The Oclaro acquisition has given us a first-mover advantage in a transforming industry. First, we attained a leading position in telecom transmission based on fundamental indium phosphide (InP) photonic integrated circuit (PIC) technology. This technology will be critical to our customers' ability to scale to higher network bandwidth in the future, including 800Gb/s and, eventually, higher speeds. Second, we re-vectored our datacom business to a significantly more profitable model that is based on a highly differentiated photonic chip capability," he adds.

"We expanded our datacom market focus to include 5G wireless and other high-volume applications. Finally, we improved our business model by achieving cost synergies on a more accelerated time line than originally estimated and are now increasing our annual synergy target to $100m from our initial $60m target, which we have exceeded. These additional savings will be attained over the next five quarters," says Lowe.

"Looking further out, based on expected continued strong growth and global network bandwidth and data-center traffic, the needed optical infrastructure for 5G wireless, we believe that telecom market should be strong on a multi-year basis… The strength we have seen in telecom transport over the past year is a leading indicator of future strength and demand for transmission products. We are well-positioned to capitalize on these market trends with our industry-leading telecom transmission and transport products and deep customer relationships," Lowe believes.

www.lumentum.com

Lumentum's chairman Martin A. Kaplan passes away

Lumentum has announced the passing of the chairman of its board of directors Martin A. Kaplan.

"Marty served our board with great passion and commitment and brought incredible business acumen to the company," says president & CEO Alan Lowe. "He was a mentor and a wise advisor."

Kaplan served on Lumentum's board since it was spun off from JDS Uniphase Corp in August 2015 and, prior to that, on the board of JDS Uniphase since 1997.

Finisar's CEO Michael Hurlston resigns

Fiber-optic communications component and subsystem maker Finisar Corp of Sunnyvale, CA, USA says that its CEO Michael Hurlston has resigned, in order to pursue another opportunity. He was not expected to remain with the firm following completion of its pending acquisition by optoelectronic component maker II-VI Inc of Saxonburg, PA, USA (announced on 9 November).

The board of directors has appointed chief operating officer Todd Swanson and executive VP of global operations Joseph Young to a newly formed Interim Office of the Chief Executive.

"Todd and Joe have each been with the company for well over a decade and have been critical to growth and development of Finisar into the leading company it is today," comments chairman Robert Stephens. "We have confidence in their leadership as they guide the company toward completion of the II-VI acquisition while continuing to build on Finisar's strong product portfolio."

Finisar's acquisition by II-VI remains under review by the State Administration for Market Regulation of the People's Republic of China (SAMR). The review is currently in Phase III, which ends on 17 August. Finisar will make a subsequent announcement either when SAMR approves the transaction or if Phase III expires and II-VI re-files its clearance application in order to provide additional time for SAMR to review the transaction.

www.finisar.com
www.ii-vi.com

Infinera appoints chief financial officer

Infinera Corp of Sunnyvale, CA, USA, a vertically integrated manufacturer of digital optical network systems incorporating its own indium phosphide (InP)-based photonic integrated circuits (PICs), has appointed Nancy Erba as senior VP, strategic finance & chief financial officer.

As CFO, Erba will report to CEO Tom Fallon and lead the global finance strategy, including financial planning and analysis, accounting and reporting, tax, treasury, internal audit, and investor relations. She will replace Brad Feller, who will remain through the end of September in order to assist with the smooth transition of financial reporting and other responsibilities.

Erba has over 20 years of financial experience, including management of complex merger & acquisition (M&A) integrations, pricing and sales operations. Most recently, Erba was CFO for Immersion Corp, which develops and licenses touch feedback technology (haptics). Previously, at multi-billion-dollar data storage firm Seagate Technology, she held global leadership positions spanning functions and markets. These included VP, financial planning and analysis; division CFO & VP of finance for strategic growth initiatives; and division CFO & VP of finance of the Consumer Solutions Division. Erba has a Master of Business Administration from Baylor University and a Bachelor of Arts degree in mathematics from Smith College.

Nancy Erba.

"Nancy is a seasoned finance executive with a proven track record of managing financial strategy and operations in high-growth and billion-dollar-scale public companies," comments Fallon. "As we strengthen our financial operations and continue to execute our long-term strategy to drive profitable and sustainable growth, Nancy will be a key asset to our leadership team," he adds.

"With a distinguished history of technology innovation and a customer-centric mission, the company is in an ideal position to capitalize on the next wave of market opportunities driven by growing end-user demand for network capacity and service agility," comments Erba.

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Emcore's quarterly revenue falls by 20.8% due to soft CATV demand and Huawei-impacted chip sales

Focus shifted to smaller subset of higher-margin products, while chip business being redesigned to fit with Aerospace & Defense product line

For its fiscal third-quarter 2019 (to end-June), Emcore Corp of Alhambra, CA, USA – which provides indium phosphide (InP)-based optical chips, components, subsystems and systems for the broadband and specialty fiber-optics markets – has reported revenue of $17.2m, down 20.8% on $21.7m last quarter and 2.8% on $17.7m a year ago. This is within 11 July's revised guidance range of $17–17.5m but below its original guidance of $20–22m.

Broadband products fell from 65% of total revenue last quarter 57%, as spending by MSOs (multi-service operators) remained unusually soft in the cable TV sector (which fell from 49% to 40% of total revenue) despite their prior indications that spending would pick up from the seasonally soft fiscal Q2. "Low capital spending by the CATV service providers, coupled with the China trade dispute, created significant headwinds for Emcore in Q3 which will continue into Q4," says president & CEO Jeffrey Rittichier.

Chip product sales fell from 16% of revenue last quarter to 11%. "The ongoing trade disputes with China are having a material impact on the demand for our chip products, most notably for GPON and those products sold into the Huawei supply chain," notes Rittichier.

Navigation products jumped from 19% of revenue to 33%. "Emcore's Aerospace & Defense [fiber-optic gyroscope-based] products performed well over the quarter," says Rittichier. Within the SatCom product line (now part of Aerospace & Defense), revenue more than doubled year-on-year. "These high-frequency communication products are almost exclusively purchased by the same tier-1 Aerospace & Defense customers that purchase our inertial navigation systems," notes Rittichier. "Applications for these products have moved substantially beyond their roots in satellite ground stations and are now used in Navy ships, radar systems and similar applications, significantly expanding the market opportunities that we see," he adds. "We received the first half of an estimated $6m project to modernize FAA air-traffic control towers and should start shipping these products in fiscal Q1/2020."

"Emcore has been working on its transition from CATV to Aerospace & Defense for several years now. While our Q3 results reflected strong headwinds to our CATV and chip products, our Aerospace & Defense offerings performed extremely well, showing 100% year-over-year growth," Rittichier notes. "Raytheon is now Emcore's largest customer, and Aerospace & Defense will be our largest product family in Q4."

Also, on 19 June Emcore announced the acquisition of Systron Donner Inertial (SDI) of Concord, CA, USA — which designs and makes quartz MEMS gyroscopes and accelerometers for customers such as Raytheon, Lockheed Martin, Rockwell Collins and other tier-1 contractors — for $22.8m in cash plus about 811,000 shares of stock. "These navigation products complement Emcore's fiber-optic navigation products and will increase our serviceable market by at least $500m," says Rittichier.

On a non-GAAP basis, gross margin was 22.3%, up from just 7.3% a year ago but down from 27.3% last quarter. However, this was due largely to $3.3m of under-absorption in manufacturing facilities related to the softer-than-expected demand from cable TV and chip products. Otherwise, gross margin would have risen to about 35%.

Operating expenses were $9.3m, $1m higher than last quarter due to additional investment in Aerospace & Defense and the inclusion of SDI operating expenses for the last three weeks of the quarter.

Operating loss was $5.1m (operating margin of –29.7%), an improvement on $6.9m (–39.1% margin) a year ago but worsening from $2.2m (–10.1% margin) last quarter due mainly to the lower gross margin, plus the partial period inclusion of SDI's results.

Pre-tax loss was $5m ($0.18 per diluted share), worsening from $2m ($0.07 per diluted share) last quarter but an improvement from $6.7m ($0.26 per diluted share) a year ago.

Capital expenditure (CapEx) was $3m (cut from $3.6m last quarter). Depreciation was steady at $1.8m. During the quarter, cash, cash equivalents and restricted cash hence fell by $30.1m, from $50.7m to $20.6m. The largest contributor to this decline was the purchase of Systron Donner Inertial for $22.8m on 19 June, plus a combination of lower-than-expected volumes and continued investment in Emcore's fab and modernization of its campus.

"Where aerospace and defense was just an R&D initiative a few years ago, it's become our largest opportunity. What started out as organic growth of our fiber-optic gyro products has been accelerated by the purchase of SDI and strengthened by a redesigned SatCom product line," says Rittichier. "We're adjusting our cable TV strategy to maximize profits as quickly as possible while our chip business is being redesigned to be strategically congruent with our Aerospace & Defense product line."

For fiscal fourth-quarter 2019 (to end-September), Emcore expects revenue to rise to $22–24m, reflecting strong growth in navigation products (to more than half of total revenue, including a full quarter's worth of contribution from SDI), offset by continuing softness in

cable TV and chip markets.

"[For the chip business], an anti-American stance has been taken for many new design-ins in China, threatening to limit future opportunities to only those products that cannot be sourced from China, Taiwan, Korea or Japan," comments Rittichier. "Given the ongoing uncertainty around mid- to long-term demand within this market, we've chosen to exit many of the lower-margin segments earlier than planned and focused our efforts on a smaller subset of higher-margin products," he adds. "This trade dispute will not end anytime soon. Consequently, we are also working to change our supply chain strategy to minimize the impact of additional tariffs."

"While both [major publicly traded] MSOs indicated that capital expenditures will increase in the second half of the calendar year, we remain skeptical that this will occur and have factored out any improvement in the current quarter," says Rittichier. "Infrastructure demand has hit an eight-year low, which is consistent with the historical bottom of cable TV cycles. We expect the demand to improve from these levels, consistent with the comments from the MSOs, but don't believe that this will occur before calendar Q4. Consequently, we are going to take aggressive actions to create a smaller, more profitable cable TV business going forward," he adds.

"The current Emcore business (excluding contributions from SDI) is running with a breakeven point of about $24m," notes Rittichier. "Pricing has not changed in the cable TV market nor has the competitive situation. This dictates that we need to match the breakeven point of Emcore's legacy business to the new market realities. I'm committed to making an impact on this in the current quarter," he adds.

"To achieve this, we're taking four major actions to reduce our breakeven point for legacy Alhambra products. First, we're moving to an EMS [electronic manufacturing services] model for manufacturing, which will eliminate the under-absorption from the EA facility within three quarters. Secondly, we're reducing the wafer fab operations to a single shift to reduce fab under-absorption as we emphasize our higher-margin chip products. Third, we're going to adjust the size of the organization. Fourth, we're working to accelerate the synergies between our two facilities in California [Alhambra and now Concord] to maximize cost savings and our opportunities," says Rittichier.

"The combination of the trade dispute and cyclical cable TV weakness demands that we speed up our timetable to resize and move to an EMS manufacturing model for cable television while retooling our chip business," Rittichier explains. "In 2015, we began to automate our assembly & test processes in China and completed that work in 2017, making it possible now to move to a true variable-cost EMS model for cable TV manufacturing within approximately 9 months from now, with testing and qualification taking up the majority of the time line. During this period, we expect to see a gradual improvement in absorption as the EA facility shrinks its role. Beyond our move to EMS, we also plan to make additional changes in our staff to align expenses with revenue," he adds. "In addition, we are in the midst of working on alternatives to monetize our Concord, California facility. While we will ultimately consolidate certain functions between our two California facilities, Concord has very important strategic value for Emcore."

"When complete, the sum total of the various actions we're taking should gain us $15–20m in cash," says Rittichier. "This should provide us with a steady improvement in gross margin over the next three quarters, culminating in a return to the mid-30s when these initiatives are complete."

In the December quarter, based on what MSOs say about capital spending, Emcore expects CATV business to improve, perhaps significantly.

"We continue to forecast that SDI will generate cash and profits in the December quarter, as previously indicated, and generate additional cost synergies with Alhambra," says Rittichier. "Between these initiatives and a scaled-back CapEx plan, which we are still reformulating, we expect to have the cash that we need to meet the ongoing needs for the business."

Emcore appoints chief financial officer

Emcore has appointed Tom Minichiello as chief financial officer.

Mark Gordon will continue in his current position as interim principal financial & accounting officer until Minichiello joins the firm, when Gordon will serve as director of accounting.

"Tom is a seasoned CFO with significant experience that aligns with our future vision," comments president & CEO Jeffrey Rittichier. "Tom's extensive background in the finance functions of publicly traded technology companies and his wealth of strategic and operational expertise makes him a natural choice... Tom will provide the leadership and support we need to drive improved financial results."

Minichiello most recently served as senior VP, CFO, treasurer & secretary for Westell Technologies, a publicly traded provider of network infrastructure and remote monitoring solutions. Before that, he had a 12-year career at optical networking equipment provider Tellabs, transforming its global finance function and guiding the business through critical periods of strategic change and growth. Previously, he had financial leadership roles at Andrew Corp, Phelps Dodge, and United Technologies.

www.emcore.com

Alta Devices scaling up solar production to meet demand for low-earth orbit SmallSats

Alta Devices of Sunnyvale, CA, USA (a subsidiary of Hanergy Thin Film Power Group Ltd of Beijing, China) is scaling up solar production to meet growing demand for small satellites. With tens of thousands of low-earth orbiting (LEO) SmallSats expected to be launched over the next decade, Alta Devices says that its solar material has the potential to meet the specific needs of this boom.

Solar is the single most expensive hardware component in a small satellite. Alta Devices has developed proprietary equipment to mass produce its thin-film gallium arsenide (GaAs). This equipment is being scaled up for production at much higher volumes and lower cost than other space solar manufacturers, and Alta claims that its ability to produce at this scale is unique and can substantially lower the cost of each SmallSat.

Furthermore, Alta's flexible solar cells provide high mechanical and design flexibility for the satellite industry. The technology can be mounted to thin, flexible, low-mass deployable structures, allowing creative design approaches to maximizing the solar array. These include coiled carbon-fiber booms, flat-packed, polymer-based accordioned arrays, or even inflatable structures. This allows more compact design of the high-power solar arrays required to power high-speed LEO communication satellites.

Finally, traditional photovoltaic assemblies (PVAs) are composed of hundreds or thousands of small solar cells, each protected with a tile of glass, connected to each other through individual metallic welds, which are then carefully grouted to prevent electrical arcing and attack from the space environment. In contrast, Alta's space product will consist of flexible, glass-free units that are 10–100 times larger, eliminating breakage, lowering cost and having no exposed electrical interconnects. Alta says that its space product will enable bonding to customer substrates using a large-area, high-volume vacuum bonding process, as opposed to mounting individual cells or CICs (coverglass interconnected cells).

Overall, the firm's goal is to provide LEO satellite manufacturers with a better balance of solar conversion efficiency, reduced array weight, cell durability, speed of deployment, and cost compared with conventional space solar cells.

SmallSat market for LEO constellations

According to filings disclosed by the Federal Communications Commission, over 15,000 LEO SmallSats are planned for deployment in the near future. Applications include communications, scientific research, military intelligence, remote sensing, and new technology development.

Over the coming years, Alta plans to produce tens of megawatts of solar cells. Manufacturing will take place at Alta's corporate facility in Sunnyvale and at an international manufacturing facility. In April, Alta's solar cells were used on a mission to power over 60 ThinSats launched from the NASA Wallops Flight Facility in Virginia. The firm is also working with satellite manufacturers for the deployment of its technology on several upcoming launches.

"Now that we are established in the HALE [high-altitude long-endurance] UAV/HAPS [unmanned aerial vehicle/high-altitude pseudo satellite] market, we are committed to enabling LEO satellite projects with our unique technology," says CEO Jian Ding. "We believe our solution will meet the needs of this fast-growing market."

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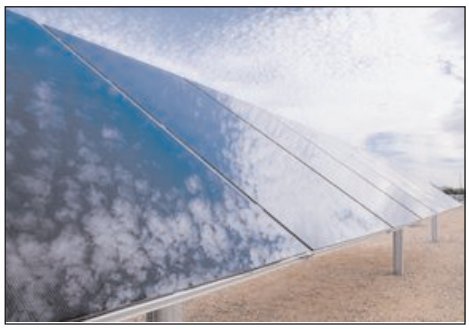
First Solar's 150MW$_{AC}$ Sun Streams 2 project to power Microsoft data centers in Arizona

First Solar Inc of Tempe, AZ, USA says the 150MW$_{AC}$ Sun Streams 2 photovoltaic (PV) solar plant that it is developing and constructing in Maricopa County will power (under a 20-year agreement) new energy-efficient data centers being built by Microsoft Corp in Goodyear and El Mirage, Arizona.

The plant will use First Solar's proprietary Series 6 cadmium telluride (CdTe) thin-film photovoltaic module technology, which has a carbon footprint up to six times lower than conventionally manufactured crystalline silicon PV panels, it is reckoned. To meet the demand for Series 6 modules, First Solar is expanding its manufacturing capacity with its second facility in the USA — representing nearly $1bn in cumulative investment — expected to start production in early 2020. Once the facility in Perrysburg, Ohio is operational, First Solar is expected to be the western hemisphere's largest solar module manufacturer.

"First Solar's high-tech factories, which are some of the most sophisticated and sustainable facilities of their type in the world, are enabled by Microsoft technologies and the Microsoft Azure cloud platform, including Azure IoT Hub and SQL Data Warehouse," notes Brian Janous, general manager of Energy and Sustainability at Microsoft. "The Series 6 modules produced by these factories will power Sun Streams 2 which, in turn, will be used to deliver renewable energy to our world-class data centers in Arizona," he adds.



First Solar's Series 6 solar modules.

Once operational in 2021, the Sun Streams 2 project will displace 190,000 metric tons of CO_2 annually (equivalent to taking 37,000 cars off the road every year and saving 356 million liters of water annually, based on Arizona averages). The air quality benefits of the project will amount to more than $12.5m in avoided healthcare costs annually, it is reckoned.

Construction of Sun Streams 2 should begin in late-2019 and provide up to 500 construction jobs. Aligned with Arizona's renewable energy policy, the project will contribute significant economic benefits to Maricopa County, including increased tax revenues to support local schools.

These data centers will be "important drivers of local investment and economic growth," says Kathryn Arbeit, First Solar's VP of project development. "This collaboration with Microsoft demonstrates just how large-scale solar can unlock value for local communities that benefit not only from the generation of jobs but also from the tax revenues for the county."

www.firstsolar.com

First Solar's sales rise 10% in Q2 to $585m

For second-quarter 2019, First Solar Inc of Tempe, AZ, USA — which makes thin-film photovoltaic modules based on cadmium telluride (CdTe) as well as providing engineering, procurement & construction (EPC) services — has reported net sales of $585m, up 10% on $532m last quarter (due primarily to increased module and system sales in the USA and Australia) and up 89% on $309.3m a year ago.

Operating expenses of $85.8m are down on $95.6m a year ago but up from $76.8m last quarter.

Net loss has been cut to $18.5m ($0.18 per share), from $67.6m ($0.64 per share) last quarter and $48.5m ($0.46 per share) a year ago.

Cash, restricted cash and marketable securities fell from $2.3bn to $2.1bn (including net cash of $1.7bn), due mainly to continued capital investments in Series 6 manufacturing capacity.

"We continued to make significant progress in our Series 6 transition during Q2, with improvements across all manufacturing metrics," says CEO Mark Widmar. "We had record module production and shipments during the second quarter, and with our recent bookings success we are now essentially sold out through 2020, with significant bookings visibility into 2021."

For full-year 2019, First Solar still expects revenue of $3.5–3.7bn, with shipments of 5.4–5.6GW (year-to-date net bookings are 4.3GWDC). However, guidance for gross margin has been increased from 18–19% to 18.5–19.5% (despite including ramp-up costs of $60–70m, rather than the previously expected $45–55m). Guidance for operating expenses has been cut from $370–390m to $360–380m (including production start-up expenses being reduced from $70–80m to $55–65m). Operating income guidance has hence been raised from $260–310m to $290–340m. However, guidance remains unchanged for earnings per share of $2.25–2.75, capital expenditure of $650–750m, and net cash balance (cash, restricted cash and marketable securities minus debt at the end of 2019) of $1.7–1.9bn.

Fraunhofer ISE sets efficiency records for silicon-based monolithic triple-junction solar cells

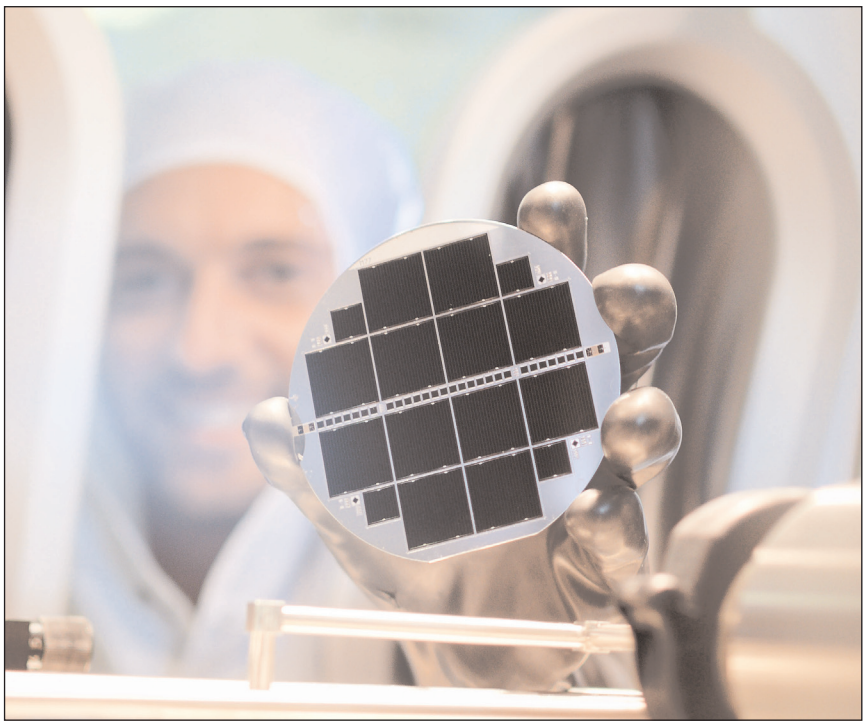
The wafer-bonded cell efficiency record has been raised from 33.3% to 34.1%, while the directly deposited cell record has been set at 24.3%.

The Fraunhofer Institute for Solar Energy Systems ISE of Freiburg, Germany has again raised the energy conversion efficiency record for monolithic triple-junction solar cells made of silicon and III–V semiconductor materials.

The record for a monolithic multi-junction solar cell manufactured by wafer bonding has been increased from 33.3% to 34.1%.

Fraunhofer ISE has also achieved an efficiency record of 24.3% for a solar cell with the III–V layers deposited directly on the silicon.

"Monolithic multi-junction solar cells are a source of hope for the further development of the silicon solar cells dominating the field today because they can lead to significantly higher efficiency values," says institute director Dr Andreas Bett. "We believe that we can achieve efficiency values of 36%, which would substantially exceed the physical limit of 29.4% offered by a pure silicon solar cell," he adds. The high efficiency allows for more output per surface area, allowing savings in solar cell and module materials — an important aspect in regard to the sustainability of photovoltaics.



Triple-junction solar cells made of III–V semiconductors and silicon.

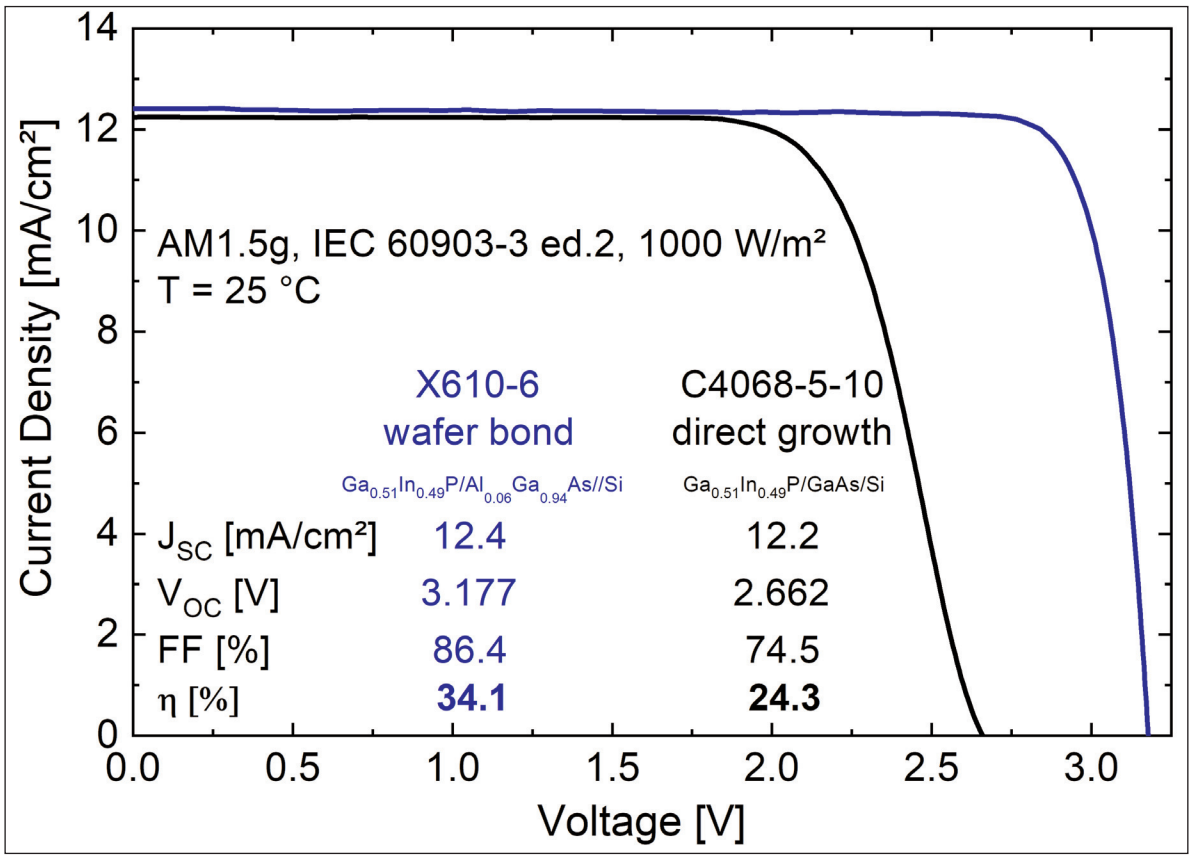
For the production of multi-junction photovoltaic cells, thin III–V semiconductor layers only a few microns thick are deposited on a silicon solar cell. To optimally exploit the sun's energy, the different layers absorb light from different spectral ranges: gallium indium phosphide (GaInP) in the 300–660nm range (visible light), aluminium gallium arsenide (AlGaAs) in the 600–840nm range (near infrared light) and silicon in the 800–1200nm range (long-wavelength light). This enables significantly increased efficiencies compared with single-junction silicon solar cells. Like existing conventional silicon solar cells, these cells each have a contact on the front and rear sides, allowing easy integration in solar modules.

Bonded multi-junction photovoltaic cells: 34.1% efficiency

Already well established in microelectronics, the process of direct wafer bonding is employed for creating a monolithic multi-junction solar cell. This involves depositing the III–V layers on a gallium arsenide substrate in an initial step, after which an ion beam is used to deoxidize the surfaces in a high-vacuum chamber before they are pressed together under pressure. The atoms in the III–V semiconductor layers form a bond with the silicon, forming a single unit. Now stacked on top of each other, the GaInP, AlGaAs and silicon sub-cells are interconnected via tunnel diodes. The GaAs substrate is subsequently removed using wet chemistry, a nanostructured rear-side contact is attached and an anti-reflection coating and a contact

grid are applied to the front side.

"In contrast to earlier results, the deposition conditions were improved and a new cell structure was introduced for the uppermost sub-cell made of GaInP which enables even better visible light conversion than before," says Dr Frank Dimroth, head of department III–V Photovoltaics and Concentrator Technology at Fraunhofer ISE. "With an efficiency of 34.1%, the cell demonstrates the immense potential of this technology." The former record for this cell class was 33.3% efficiency.



IV characteristics of both of the new III–V/silicon triple-junction solar cells, measured at Fraunhofer ISE CalLab PV Cells under AM1.5g standard test conditions. The cells each have an area of 4cm².

Multi-junction photovoltaic cell with directly deposited semiconductor layers: 24.3% efficiency

Directly depositing the III–V layers (GaInP/GaAs) on the silicon solar cells involves considerably fewer process steps than wafer bonding and avoids the use of expensive GaAs substrates, so it is quite advantageous in industrial implementation. Nonetheless, the atomic structure must be very carefully controlled to ensure that the gallium and phosphorous atoms are arranged on the correct lattice sites at the interface to the silicon material. Defects in the semiconductor layers can also have an adverse effect on the cells' efficiency. "We were able to make major progress in this area — current generation in the three sub-cells is now barely affected by these defects, which has enabled us to realize 24.3% efficiency for this technology for the first time," says Dimroth.

Deposition conditions were improved and a new cell structure was introduced for the uppermost sub-cell made of GaInP which enables even better visible light conversion than before. With an efficiency of 34.1%, the cell demonstrates the immense potential of this technology

"The potential is comparable to that of the wafer-bonded cells," he adds. "We've got our work cut out for us in the coming years in order to prove that this is the case." In December 2018, Fraunhofer ISE introduced this type of solar cell with an efficiency record of 22.3%.

In heading toward the industrial mass production of monolithic multi-junction photovoltaic cells, Fraunhofer ISE researchers see particular challenges in finding an affordable process for manufacturing the III–V layers. Direct growth on silicon is currently the most promising approach, but other methods are being researched where the GaAs substrates can be recycled many times over after the semiconductor layers are transferred to the silicon. For cost-effective solar cell production new deposition machines with higher throughput and deposition area will be required. These are all methods that researchers at ISE will pursue in the coming years.

Work on wafer-bonded solar cells is funded by the German Federal Ministry for Economic Affairs and Energy (PoTaSi project, FKz. 0324247). Work on directly grown cells, in which partners Aixtron SE, TU Ilmenau and Philipps-Universität Marburg were involved, was funded by the German Federal Ministry of Education and Research (MehrSi project, FKz. 03SF0525A). ■

www.ise.fraunhofer.de

UCLA demos first antimonide-based SAM-APDs for x-ray and gamma-ray detection beyond 50keV

GaSb/AlAsSb separate absorption and multiplication avalanche photodiodes show photo-peaks up to 59.5keV.

A collaborative effort between the University of California at Los Angeles (UCLA) Department of Electrical and Computer Engineering, Department of Molecular and Medical Pharmacology and the California NanoSystem Institute (CNSI) has developed the first antimonide (Sb)-based separate absorption and multiplication avalanche photodiodes (SAM-APDs) that are capable of mapping the energy spectra of x-ray and gamma-ray photons. Under exposure to 241Am radioactive sources, the detectors show photo-peaks up to 59.5keV with a full-width half-maximum of 1.283keV (B.-C. Juang et al, 'Energy-Sensitive GaSb/AlAsSb Separate Absorption and Multiplication Avalanche Photodiodes for X-Ray and Gamma-Ray Detection', Adv. Opt. Mater. 7, 1900107, 2019).

Gamma-rays are generated from the radioactive decay of atomic nuclei. Their energy can range from a few kiloelectron volts (keV) to several Megaelectron volts (MeV), so their application spans many different areas such as astronomy, medical equipment for therapy, sterilization, and radiological security. The UCLA project is funded by the Defense Threat Reduction Agency and US National Science Foundation (NSF).

In these reported detectors, gallium antimonide (GaSb) is used to absorb incoming gamma-rays and excite carriers. Aluminium arsenide antimonide (AlAsSb) is used to make multiplication regions to populate carriers by avalanching (through impact ionization, a breakdown mechanism that can generate very large current, triggered by accelerating a small number of carriers in high electric field and multiplying them). GaSb/AlAsSb SAM-APDs are hence super-sensitive to convert incoming radiation signals into electrical signals.

"Choosing a proper material for the gamma-ray absorption layer is very critical to make high-performance detectors," says lead researcher Dr Bor-Chau Juang. "We used GaSb because it can offer very good

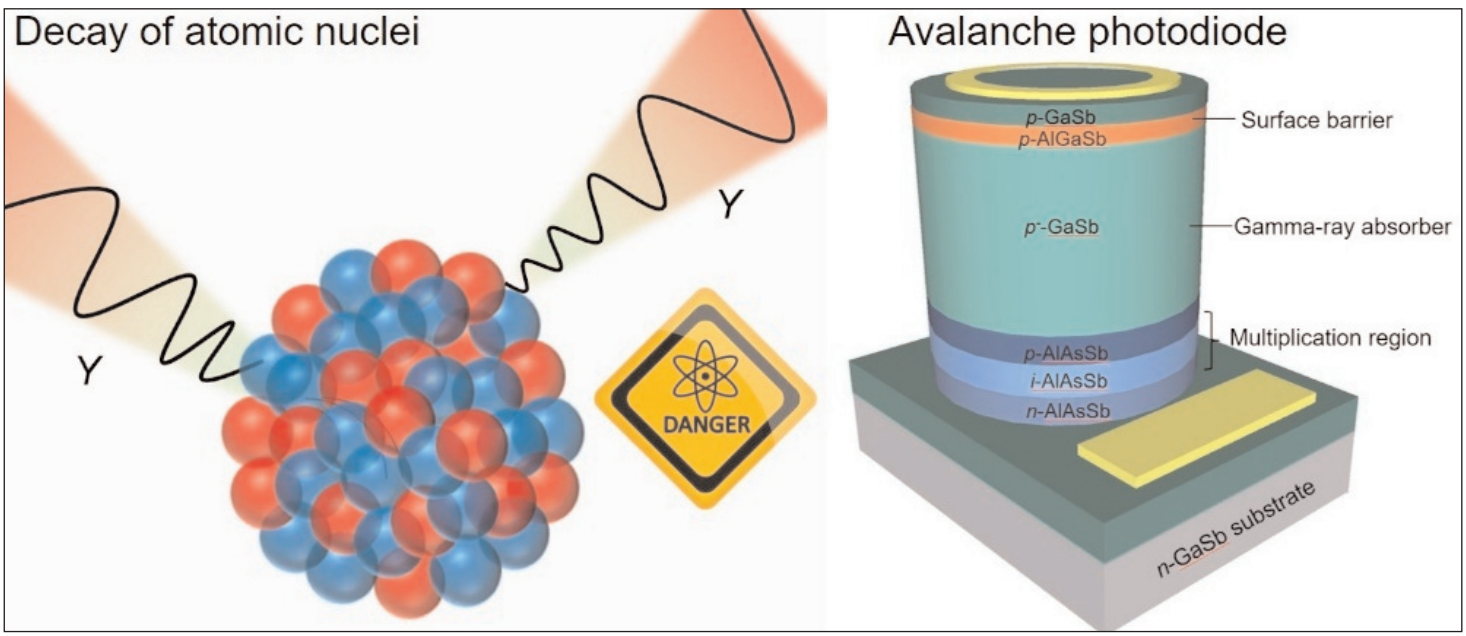


Figure 1. (Left) Gamma-rays arise from decay of atomic nuclei. (Right) Device architecture of GaSb/AlAsSb SAM-APDs.

absorption efficiency and efficiently stop high-energy photons due to its high atomic number," he adds.

"Due to the SAM structure of our detectors, we can get internal gain and thus higher signal-to-noise ratio (SNR). AlAsSb is a large-bandgap semiconductor material and lattice matched with GaSb. We have done lots of device modeling to optimize our detector structure," says Dr Dingkun Ren, the senior material and device researcher. "Also, there is a large dissimilarity in both pair creation energy and absorption efficiency for GaSb and AlAsSb. As a result, noise photopeaks can be significantly eliminated."

"The GaSb/AlAsSb heterostructures grown by our molecular-beam epitaxy (MBE) system show extremely high quality," says CNSI technical director Dr Baolai Liang. "The growth parameters were carefully designed," he adds.

Led by professor Diana L. Huffaker, professor Arion F. Chatziioannou and Dr Baolai Liang, the study paves the way to achieving efficient detection of high-energy photons for x-ray and gamma-ray spectroscopy by Sb-related semiconductor nanostructures. "Our work builds a solid foundation to advance the development of gamma-ray SAM-APDs," says Liang. "We welcome more collaborations to carry on this research." ■

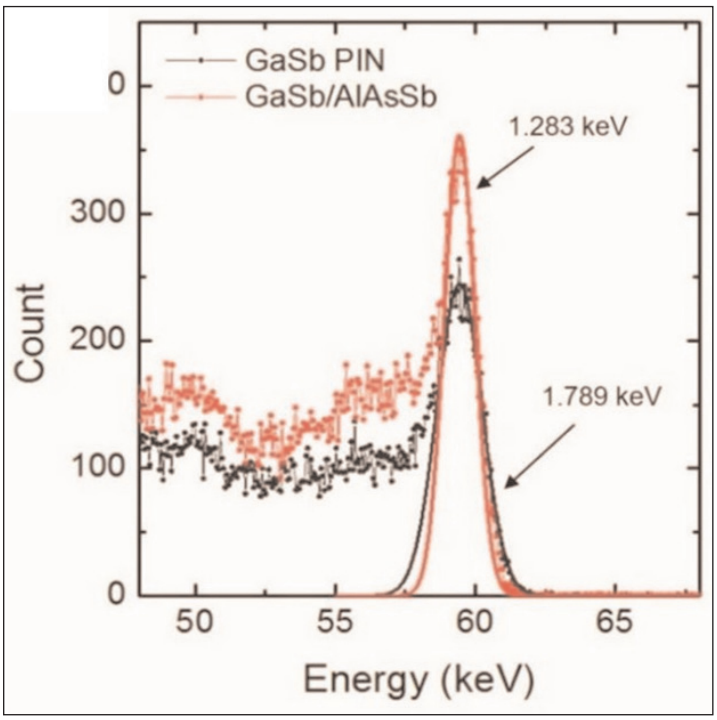


Figure 2. Photopeaks from GaSb/AlAsSb SAM-APDs show higher SNR than those from GaSb photodiodes.

https://doi.org/10.1002/adom.201900107

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Ultra-low-power LEDs for IoTs and smart dust

Researchers focus on low current injection region to improve efficiency.

IBM T J Watson Research Center and University of California Berkeley in the USA report on extending high efficiency to lower-current light-emitting diode (LED) performance [Ning Li et al, Nature Photonics, vol13 (2019) p588].

The researchers see opportunities for ultra-low-power (LP) performance leading to wireless communication in smart dust and sensor networks, low-cost block chain and authentication security, and medical applications. They further reference 'Internet of Things' (IoT) development of low-cost, self-powered dust-sized components with power requirements limited to the microwatt level due to energy supply considerations. Unfortunately, radio-frequency devices need milliwatt-level input power and suffer a size mismatch between antennas and wavelengths.

"Miniaturization to this dust-sized platform is possible because of the remarkable advancements in micro-electronics technology and micro-packaging, which allow system-level integration of energy-harvesting devices, microprocessors and memories, and wireless communication devices, all within a small footprint," the team comments.

The epitaxial structures were grown by metal-organic chemical vapor deposition (MOCVD) on semi-insulating gallium arsenide. The emission layer consisted of a strained single indium gallium arsenide ($In_{0.2}Ga_{0.8}As$) quantum well in indium gallium phosphide ($In_{0.49}Ga_{0.51}P$) barriers. The barriers featured 50nm undoped confinement layers and 200nm lightly-doped materials next to the heavily doped contacts (1000nm n-GaAs buffer, 30nm p-GaAs).

The team designed the structure to reduce the interface recombination velocity and increase hole density in the well at low current injection (Figure 1). The high-quality interface reduced non-radiative recombination there. A large valence band offset with the barriers created a deep well for holes to gather in, exceeding the electron density. The high hole concentration favors radiative over non-radiative recombination.

Fabrication included wet etching of circular mesas. The mesa sidewalls were passivated with atomic layer deposition (ALD) aluminium oxide. The GaAs substrate was transparent to the emission from the well, enabling the use of flip-chip assembly onto silicon with light extraction through the back-side of the chips.

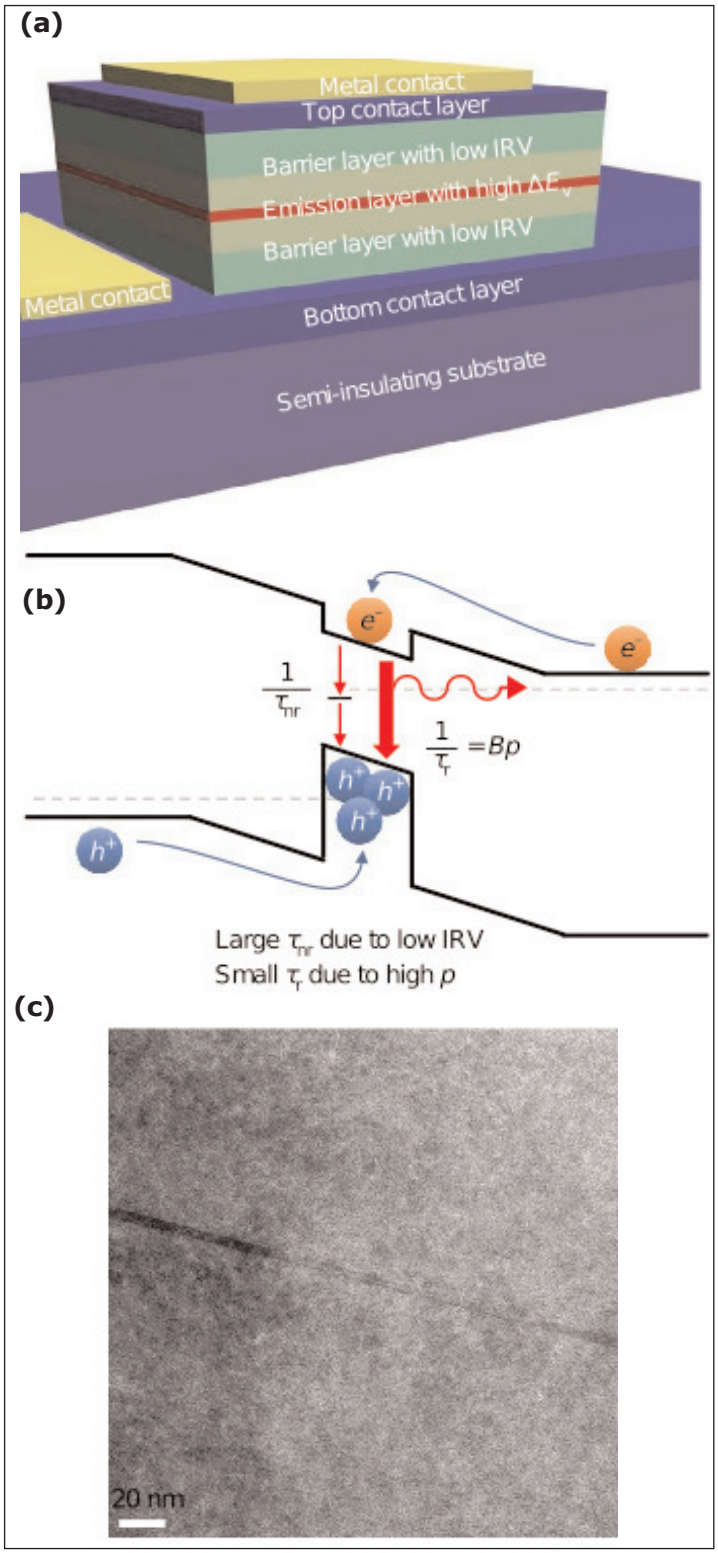

Figure 1. Structure and design of LP-LED: schematic representation of structure (a) and band diagram (b) with high valence-band offset; (c) cross-sectional transmission electron microscopy image of epilayers.

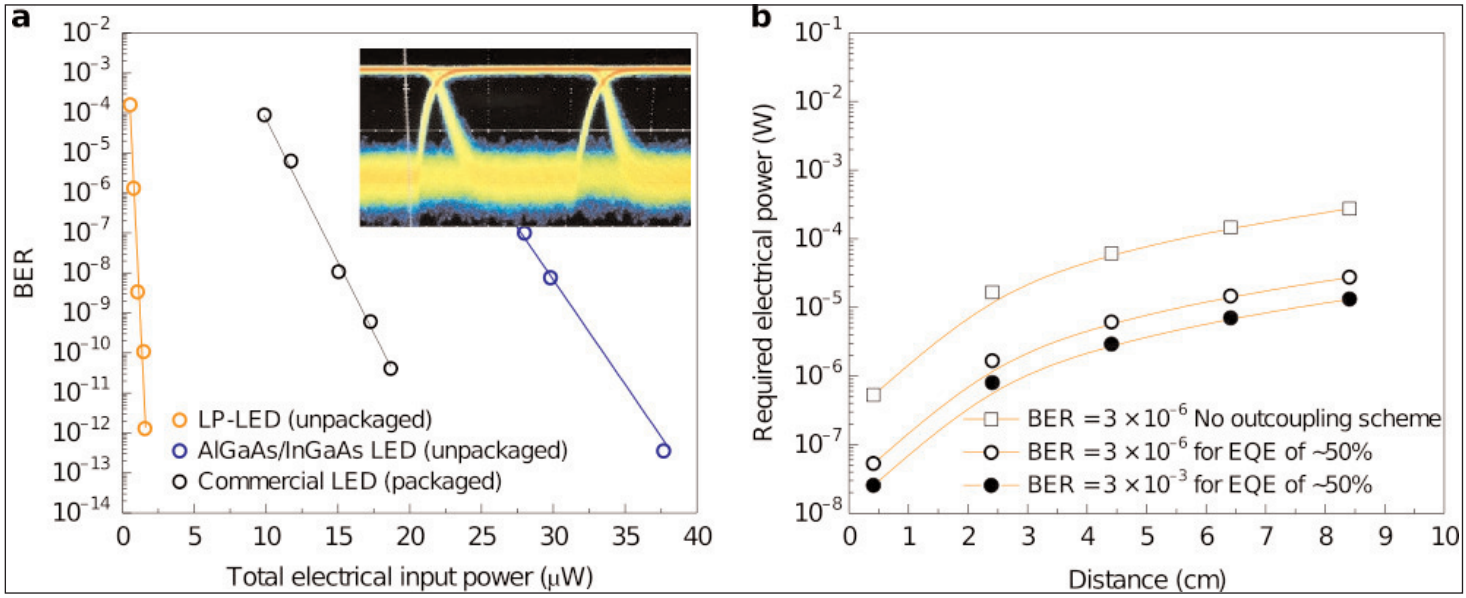

Figure 2. Data transmission performance at low current and voltage: (a) bit-error rate (BER) versus input power for unpackaged LP and AlGaAs/InGaAs LEDs, and commercial packaged device. Inset: eye diagram of LP-LED at 1μW input power and 1V bias. (b) Required electrical input power for the LP-LED versus distance to reach BERs of $3x10^{-6}$ and $3x10^{-3}$ without and with enhanced light outcoupling. Clock frequency 1MHz.

The devices were compared with LEDs fabricated from three other structures: $Al_{0.2}Ga_{0.8}As/In_{0.2}Ga_{0.8}As$ and $Al_{0.3}Ga_{0.7}As/GaAs$ barrier/single quantum wells, and a commercial multiple quantum well product. The in-house comparison devices used the same barrier/well thicknesses as the LP-LED.

The InGaAs/InGaP LP-LED achieved 80% of the peak efficiency at 0.1μA injection (1mA/cm^2) and 40% at 1nA (10μA/cm^2). The comparison device efficiencies fell off rapidly in the range 0.1–1mA.

The LP performance was improved by increasing the device diameter from 120μm to 960μm. The larger-diameter LP-LED was able to maintain near peak efficiency below 0.1mA/cm^2 injection density [my calculation: 0.64mA]. The improved performance was attributed to reduced non-radiative recombination at mesa side walls.

The researchers commented: "Previously reported devices only reach high efficiency at currents on the scale of millliamps, while our device has near-unity efficiency at a low current of 1μA." Although the device demonstrated a peak external quantum efficiency of only 7%, this was limited by light extraction out of the GaAs substrate. Optical simulations suggest that, even with perfect 100% internal quantum efficiency, only 8% of the light could be extracted.

The estimated internal quantum efficiency remained high — more than 90% at 1V forward bias — even well below the photon voltage of 1.3V (photon energy/electron charge), equivalent to a wavelength of 954nm in the near-infrared range (750–1400nm). The 1V level is easily achievable with mainstream silicon complementary metal-oxide-semiconductor (CMOS) circuitry, unlike the higher 1.3V level that needs special charge pumping and current drivers.

The researchers comment: "Although conventional LEDs commonly show some light emission when biased below the photon voltage, efficiency is very low because the non-radiative process dominates."

The team also speculates that electroluminescent cooling could be achieved if the light extraction was better than 93%, which they say is achievable in some schemes aimed at avoiding light being trapped in the device.

Free-space data transmission also showed much improved bit-error rates for given operating power (Figure 2). The team comments: "A detector noise analysis shows that the required optical power is quite low with proper optical filtering and the right photodetector. This yields significant transmitter power savings (>100x) compared to conventional LEDs at distances of 0–10cm, relevant for many low-power IoT and smart dust applications. Compared with the previously reported best RF transmitters with small footprint, the power consumption is orders of magnitude lower for the LP-LED."

Asynchronous transmission of a text file from a computer to a smartphone was also demonstrated. The average current was 0.92μA and the voltage swing was 0–1.2V. The average power consumption was 1.1μW. The transmitted 1Mbyte text file was error-free, giving a bit-error rate of less than 10^{-6}. The transmission rate of 100kb/s was limited by the phone software.

The device was flip-chip bonded to solder bumps on silicon. Such a silicon carrier could also contain a microprocessor, memory, power, receiver, and other electronic systems. The present device fitted a 1mmx1mm format. ■

https://doi.org/10.1038/s41566-019-0463-x

Author: Mike Cooke

High-power polarized-light vertical-cavity surface-emitting laser

Researchers achieve 60% power boost over previous devices aimed at silicon photonic integrated circuit sensor application.

Researchers based in Sweden, Belgium and Ireland have developed 850nm-wavelength vertical-cavity surface-emitting lasers (VCSELs) with a single-mode transverse polarized light output power up to a claimed record of 6.5mW [Erik Hagland et al, Optics Express, vol27, p18892, 2019]. The team from Chalmers University of Technology and OptiGOT AB in Sweden, Ghent University-imec in Belgium and Tyndall National Institute in Ireland reports: "The output power is more than 60% higher than previously achieved."

The high power was attained by using a relatively large oxide aperture. The epitaxial material design aimed for low resistance, low optical loss and high slope efficiency in the resulting VCSELs.

The polarization was selected using a grating etched into the top surface of the device. The researchers designed the VCSEL for use in silicon photonic integrated circuits (PICs) in a tilted flip-chip format over a grating coupler (Figure 1).

The work is part of the European PIX4life project (https://pix4life.eu) with the VCSEL providing the light source for a short-wavelength sensor PIC. PIX4life provides a silicon nitride-based photonic integrated platform pilot line for life science and biomedical applications.

The team comments: "The integration technique enables independent optimization of VCSEL performance, eliminates optical feedback to the VCSEL, and facilitates unidirectional coupling without resorting to more complex grating couplers or optical designs needed for normal incidence."

Grating couplers are polarization sensitive. The team also suggests that many other applications could benefit from its VCSEL's power, spectral purity, polarization and beam properties.

The VCSEL material was grown on gallium arsenide (GaAs) substrates using metal-organic chemical vapor deposition (MOCVD) — see Figure 2. The active region consisted of indium gallium arsenide (InGaAs) quantum wells in aluminium gallium arsenide (AlGaAs) barriers. The distributed Bragg reflectors (DBRs) were constructed from AlGaAs pairs with different Al content, giving contrasting refractive index values: 29 pairs on the n-side and 21 pairs on the p-side. The interfaces between the different layers of the DBR were graded, and doping was modulated to reduce electrical resistance and optical losses. The active region was capped with high-Al-content AlGaN, which formed the basis for the oxide aperture that provided lateral optical and electrical confinement.

The top DBR had a final layer that was a half-wavelength rather than a quarter-wavelength, reducing its reflectively and allowing radiation to exit the device.

Optical simulations were performed to optimize the LP01 $E_{\perp}$ polarized emission. The calculations suggested values for the oxide aperture and mode-filter diameters of 5μm and 3μm, respectively. The optimum mode filter structure was 120nm and 59nm pitch and depth, respectively.

The grating fill factor was 55% (grating-tooth width/pitch). In fact, the simulations suggested that a fill factor of 80–90% would give the highest polarization-mode selectivity, but the grating fabrication process was higher quality at ~50%. Even so, the selectivity with 55% fill gave 270/cm threshold gain difference.

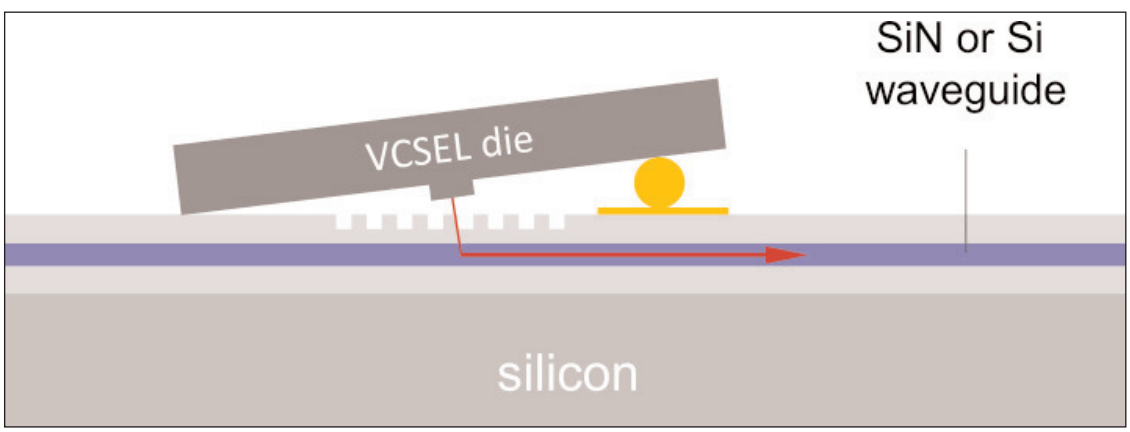

Figure 1. Flip-chip integration of VCSEL die at angle over grating coupler on silicon photonic integrated circuit.

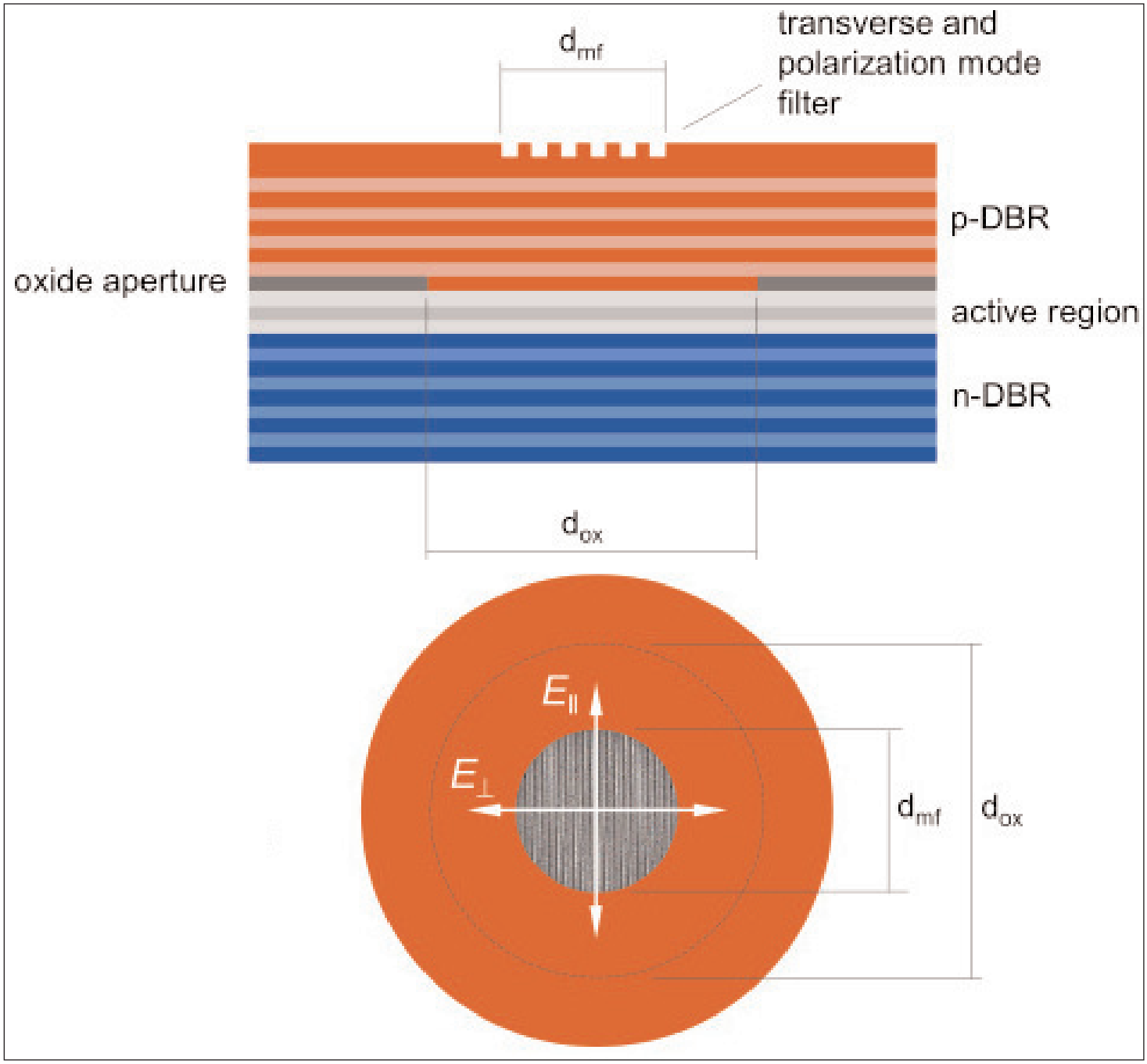

Figure 2. Oxide-confined VCSEL with transverse and polarization mode filter etched into surface. Diameters of oxide aperture (d_{ox}) and mode filter (d_{mf}) are indicated and two orthogonal polarization states ($E_{\perp}$ and $E_{||}$) are defined. Left: side view. Right: top view.

The VCSELs were fabricated with mesa etching, selective oxidation of the aperture, and contact/pad metalization. The contacts were placed on the top side to enable flip-chip processing onto the PIC system. The mode-filter grating was defined by electron-beam lithography and metal alignment marks, defining both the grating and mesa. The trench depth of the grating was achieved by precise argon ion milling.

The light output was measured with a collimating anti-reflection coated lens between the VCSEL and calibrated large-area detector. The threshold current was 0.4mA. The slope efficiency came in at 1.2W/A. The peak power was 6.5mW before thermal roll-over.

Measurements with a polarizer in the light path showed orthogonal polarization suppression ratios better than 20dB when the current was above 4mA. Spectral analysis gave a 30dB+ suppression factor for higher-order transverse modes at 1mA injection. The 30dB+ trend continued up to 10mA.

The beam profile was found to be near-Gaussian. The $1/e^2$ full-width was 15° at 2mA and 16° at 10mA. The corresponding full-widths at half-maximum were 9° and 10°. The slight increase in beam width was attributed to thermal lensing effects. ■

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Author: Mike Cooke

Electrically driven germanium-tin vertical-cavity surface emitter

Researchers use silicon-on-insulator platform with potential for scalable electronic-photonic integrated circuits.

Researchers in Taiwan and the USA claim the first electrically injected germanium-tin alloy (GeSn) vertical-cavity surface emitter on a silicon-on-insulator (SOI) platform [Bo-Jun Huang et al, ACS Photonics, vol6, issue8,, (June 2019), p1931]. It is hoped that combining elements from group-IV of the Periodic Table will lead to easier integration with mainstream complementary metal-oxide-semiconductor (CMOS) silicon integrated electronics.

The team from Taiwan's National Chung Cheng University, University of Massachusetts–Boston in the USA, and National Taiwan University comments: "Our demonstration paves the way toward the realization of room-temperature, electrically injected GeSn lasers to open up new avenues for functional scalable electronic–photonic integrated circuits."

The problem is that the direct-bandgap transitions needed to produce photons are difficult to arrange in group-IV semiconductors. Generally, the lowest points of the conduction band are away from the symmetric central Γ point with zero quasi-momentum. However, progress has been

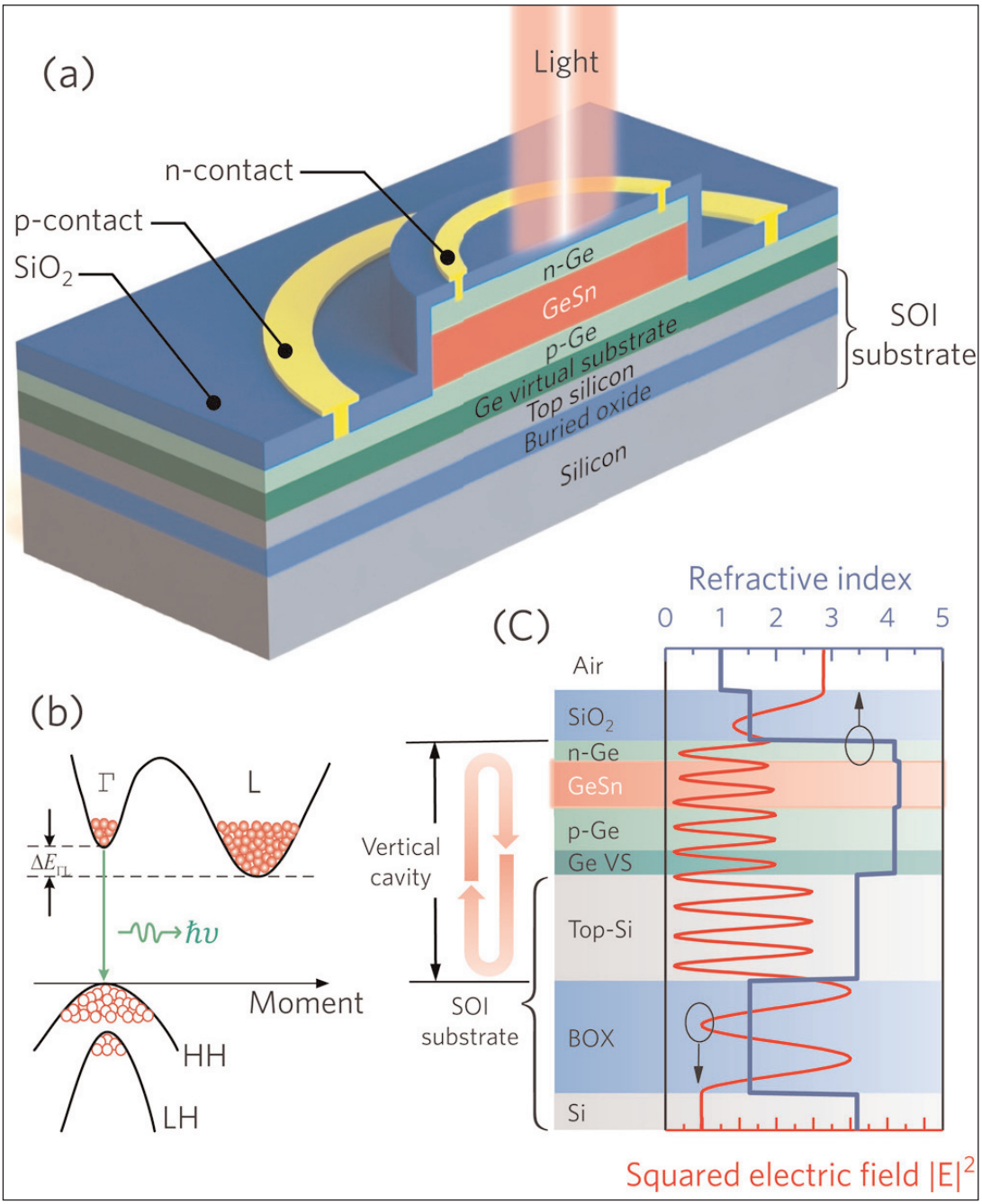

Figure 1. Three-dimensional schematic diagram of GeSn p–i–n heterodiode vertical-cavity surface emitter on SOI substrate (not to scale). (b) Schematic band diagram of $Ge_{0.969}Sn_{0.031}$ active layer. (c) Refractive-index profile and field pattern $|E|^2$ of device simulated by finite-element method (FEM).

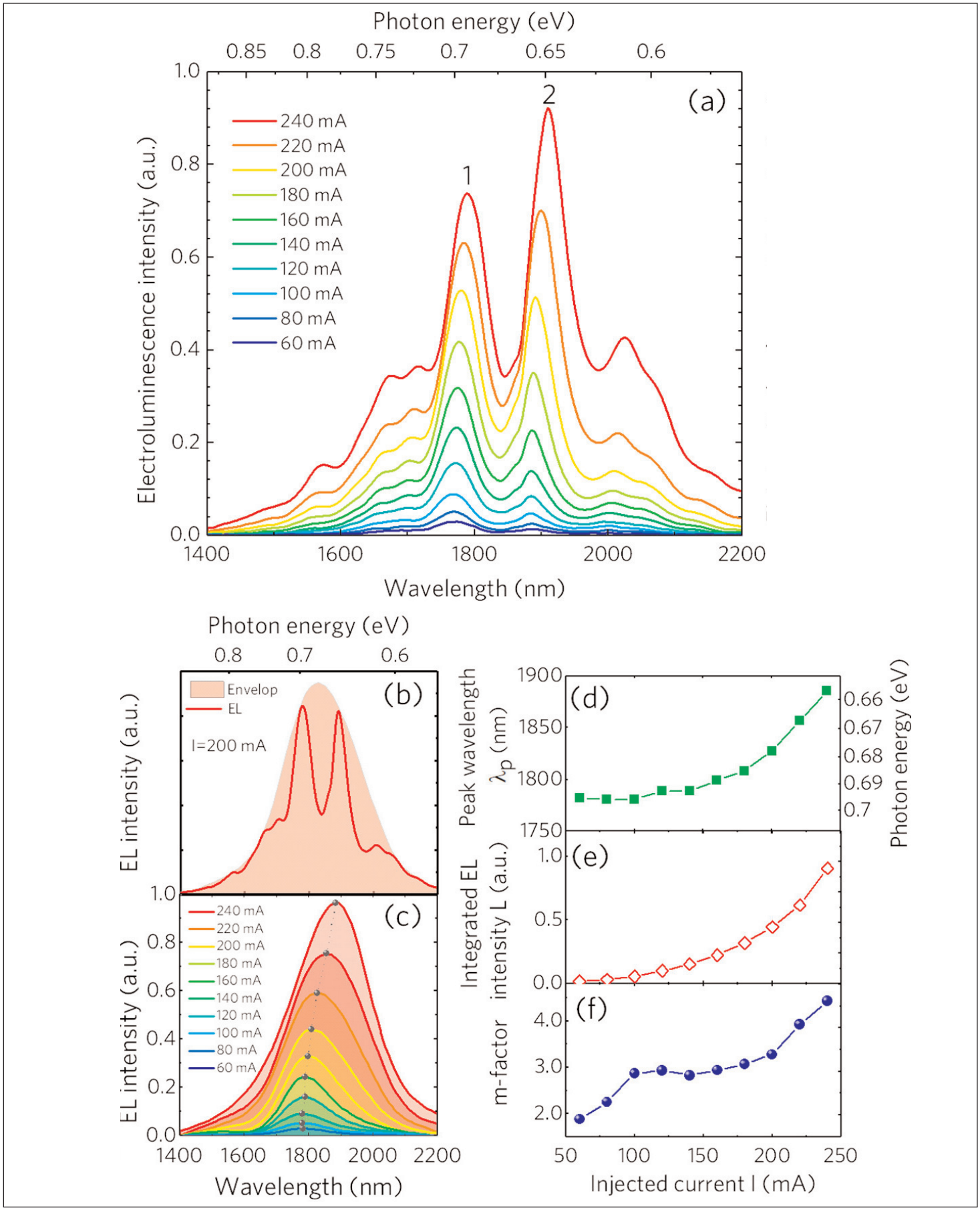

Figure 2. (a) Room-temperature EL spectra of GeSn-on-SOI device under different injected currents. (b) EL spectrum and mode envelopes at 200mA. (c) Mode envelopes at different injected currents. Peak wavelength of mode envelope (λ_p) indicated by gray dots. (d) Peak wavelength of mode envelope, (e) integrated EL intensity, and (f) m-factor as function of injected current.

made in the GeSn system in reducing the difference between the Γ point and the L-direction valleys, using strain and doping effects.

In the reported work, the researchers added electroluminescent enhancement from a vertical-cavity structure to give better optical confinement with suppressed radiation loss. Eventually it is hoped that vertical-cavity surface-emitting lasers (VCSELs) could be possible. Such devices would power SOI photonic systems targeted at applications such as fiber-optic telecommunication, light-detection & ranging (LiDAR), and chip-scale optical interconnection. The emission wavelengths fell mainly in the range 1600-2200nm, falling in the short-wavelength infrared (1400-3000nm).

The LED structure was based on a double-barrier heterostructure design (Figure 1). The active GeSn layer was compressively strained to give a direct transition between the conduction and heavy-hole bands. The barriers were constituted from the 400nm p-type and 180nm n-type Ge contact layers.

Light was trapped between the buried oxide of the silicon-on-insulator substrate and silicon dioxide deposited during device fabrication. The trapping was based on reflection due to the low ~1.45 refractive index of the silicon dioxide and the high ~4.2 value for the Ge/GeSn layers. The reflection thus created a Fabry-Perot vertical cavity, enhancing light extraction.

The epitaxial material for the device came from low-temperature solid-source molecular beam epitaxy (SS-MBE). The 170nm Ge 'virtual substrate' layer transitioned from the SOI substrate to a strain-relaxed state according to inspection of the interfaces by cross-sectional transmission electron microscopy.

Secondary-ion mass spectroscopy (SIMS) and x-ray analyses gave a 3.1% Sn fraction and 0.454% compressive strain in the 440nm pseudomorphic GeSn active layer. The SOI substrate consisted of a 2.5μm top silicon layer on 1μm oxide. The p- and n-type Ge layers were doped with boron and antimony, respectively.

A comparison sample grown on silicon substrate had a 4.5% Sn fraction/0.659 compressive strain 420nm GeSn layer.

The researchers fabricated LEDs with a 200μm-diameter circular mesa and 420nm-thick SiO_2 passivation. Ring-shaped ohmic contact pads were constructed from chromium/gold. The processing was CMOS compatible, according to the team.

The LEDs' on/off current ratio was 200 between +1V and −1V. The electroluminescence (EL) of an LED grown on silicon consisted of a peak at 1900nm wavelength with 250nm full-width at half-maximum (FWHM). This corresponds to the direct transition energy of 650meV, say the researchers. The reflectivity ripple of ~240nm free spectral range was attributed to interference between reflections from different layer interfaces.

The SOI-substrate LED emitted a series of peaks with FWHM around 66nm. The reflectivity free spectral range (FSR) was also shorter at around 110nm. The reflectivity dips matched the emission peaks.

The researchers comment: "Thus, comparing the EL and reflectivity spectra between the GeSn-on-SOI and GeSn-on-Si devices provides direct evidence for the longitudinal resonant cavity modes in the GeSn vertical cavity on SOI. In addition, despite the smaller Sn composition, the peak and integrated EL intensities of the GeSn-on-SOI devices are 6.31 and 3.7 times higher than those of the GeSn-on-Si device, highlighting the important EL enhancement owing to the cavity effect."

The strongest peaks were around 1780nm and 1880nm, the relative importance of which varied with continuous-wave injection current (Figure 2). The researchers extracted quality factors for the cavity of 33 and 31 for the 1780nm and 1880nm wavelengths, respectively.

The researchers see the bandgap narrowing due to Joule heating effects. The band edge thus moves out of the 1780nm region into the 1880nm cavity resonance corresponding to lower-energy photons. Joule heating may also play a role in reducing the energy difference between the lower-energy indirect conduction-band valley (L) and the slightly higher direct valley (Γ). With a smaller energy difference, and higher temperature, more electrons can be excited into the Γ valley with potential for fast recombination into photons.

Although positive net optical gain was not achieved by the vertical-cavity structure, the gain for the longer-wavelength peak (~1880nm) did approach 0 as the injection current neared 200mA. The near zero gain "implies important absorption bleaching in the cavity toward achieving optical gain." The gain then falls off due to further bandgap narrowing at high currents of ~240mA. Positive net optical gain would be needed for laser devices.

The researchers performed simulations that suggested that increased operating temperatures allied with low Sn content in the active region could create a direct bandgap. "These analyses suggest that our GeSn light emitter can perform better at elevated temperatures, thereby being suitable for silicon-integrated circuits in which the operation temperature can go up to 150°C (423K) due to the Joule heating effect", the team writes.

According to the researchers, even without lasing capability, the vertical-cavity light emitter could find use in GHz-level direct modulation short-reach optical communications. The team sees prospects for room-temperature high-data-rate chip-to-chip or board-to-board free-space optical interconnects. The suggested link arrays would consist of vertical-cavity transmitters and receivers with or without lenses for optical beam formation. ■

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Annealing to tune output wavelength of quantum dot lasers on silicon

Selective deposition of silicon- and titanium-dioxide dielectric caps enables a 37nm wavelength shift between lasers.

The UK's University College London and Beijing University of Technology in China have realized indium arsenide (InAs) quantum dot (QD) lasers on silicon with output wavelengths of 1275nm and 1313nm [Mengya Liao et al, Semicond. Sci. Technol., vol34, p085004, 2019].

Selective deposition of silicon dioxide (SiO_2) and titanium dioxide (TiO_2) before annealing enabled the difference in wavelength by allowing various intermixing of the indium arsenide dots with the surrounding gallium arsenide (GaAs) matrix, tailoring the energy bandgap.

The researchers see the work as potentially enabling silicon-based optical integrated circuits targeting faster transmission speed, higher throughput and lower power dissipation, compared with copper-based information communication systems. QDs are one method for reducing the impact of defects on light emission arising from integration of III-V materials on silicon.

The QDs were grown by molecular beam epitaxy (MBE) on (001) n-type Si offcut 4° in the [110] direction (Figure 1). The dots were grown in well structures (DWELLs) with the InAs dots formed spontaneously from depositing a 2nm InGaAs wetting layer, 3-monolayer InAs and 6nm InGaAs cap. A top layer of dots was found to have a density of 3x108/cm^2, according to atomic force microscopy.

Threading dislocation density in the active region was suppressed from ~10^9/cm^2 to ~10^7/cm^2 using three five-period InGaAs/GaAs dislocation filter layers (DFLs) as part of the buffer structure. The growth on silicon was initiated using 6nm aluminium arsenide (AlAs) as nucleation for the III-V growth.

Photoluminescence was used to optimize a rapid thermal annealing (RTA) process with silicon dioxide (SiO_2) and titanium dioxide (TiO_2) top layers. The material used for the optimization study had thinner 100nm cladding layers.

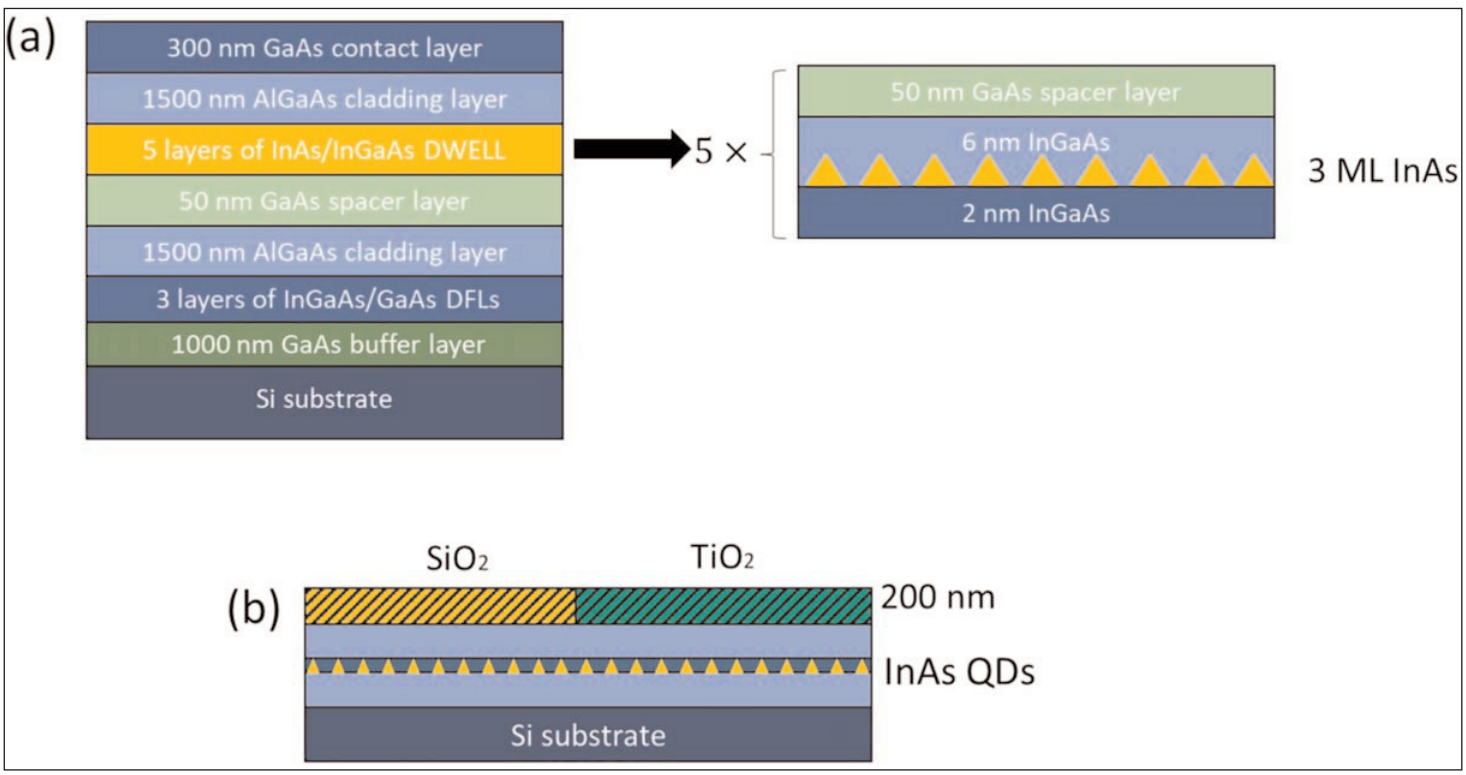

Figure 1. (a) Schematic of InAs/GaAs DWELL laser structure directly grown on silicon substrate. (b) Schematic of SiO_2 and TiO_2 dielectric layers on III–V/Si QDs for selective-area intermixing.

At 700°C, an RTA duration of 30 seconds was found to give the highest intensity with SiO_2 cap. The researchers attribute the increase to reduced threading dislocations through interaction and self-annihilation.

The peak wavelength was found to blue shift to shorter wavelengths, from ~1308nm as-grown to ~1294nm with 60-second RTA. The small shift is attributed to intermixing of In and Ga, increasing the bandgap. The full-width at half maximum (FWHM) also tended to narrow as the duration increased, from ~56nm at 5 seconds to ~50nm at 60 seconds. The narrower peaks indicate more homogeneous QD sizes after annealing, according to the researchers.

The 700°C anneal was also found to give the highest PL intensity when the temperature was varied up to 800°C. The team says that, while annealing reduces threading dislocations, annealing at too high a temperature degrades the epitaxial material quality.

Capping with TiO_2 before RTA produced somewhat different PL results due to the larger thermal expansion coefficient restricting inter-diffusion rates in the DWELL structure. The highest intensity response was again at 700°C. The blue-shift compared with the as-grown sample was much smaller than for SiO_2 capping: ~6.4nm for 30-second RTA at 725°C, compared with ~34nm for SiO_2 top layer under the same RTA process.

Broad-area laser bars were produced with platinum/titanium/gold p-type and nickel/germanium-gold/nickel/gold n-type Ohmic contacts. The cavity length was 3mm. The bar width was 25μm. The devices were tested on copper heat-sinks. The facets were not coated. The RTA SiO_2/TiO_2 capping layers were removed before laser bar fabrication. The RTA process for the fabricated bars was at 725°C for 30 seconds.

The different caps resulted in the lasing peaks which differed by 37nm in wavelength (Figure 2). The threshold currents were 150mA and 175mA for the TiO_2- and SiO_2-cap devices, respectively. The measurements were made under pulsed conditions with 1μs width and 1% duty cycle. The corresponding output powers (at 400mA)/slope efficiencies were 10mW/0.0563W/A and 7.23mW/0.0499W/A.

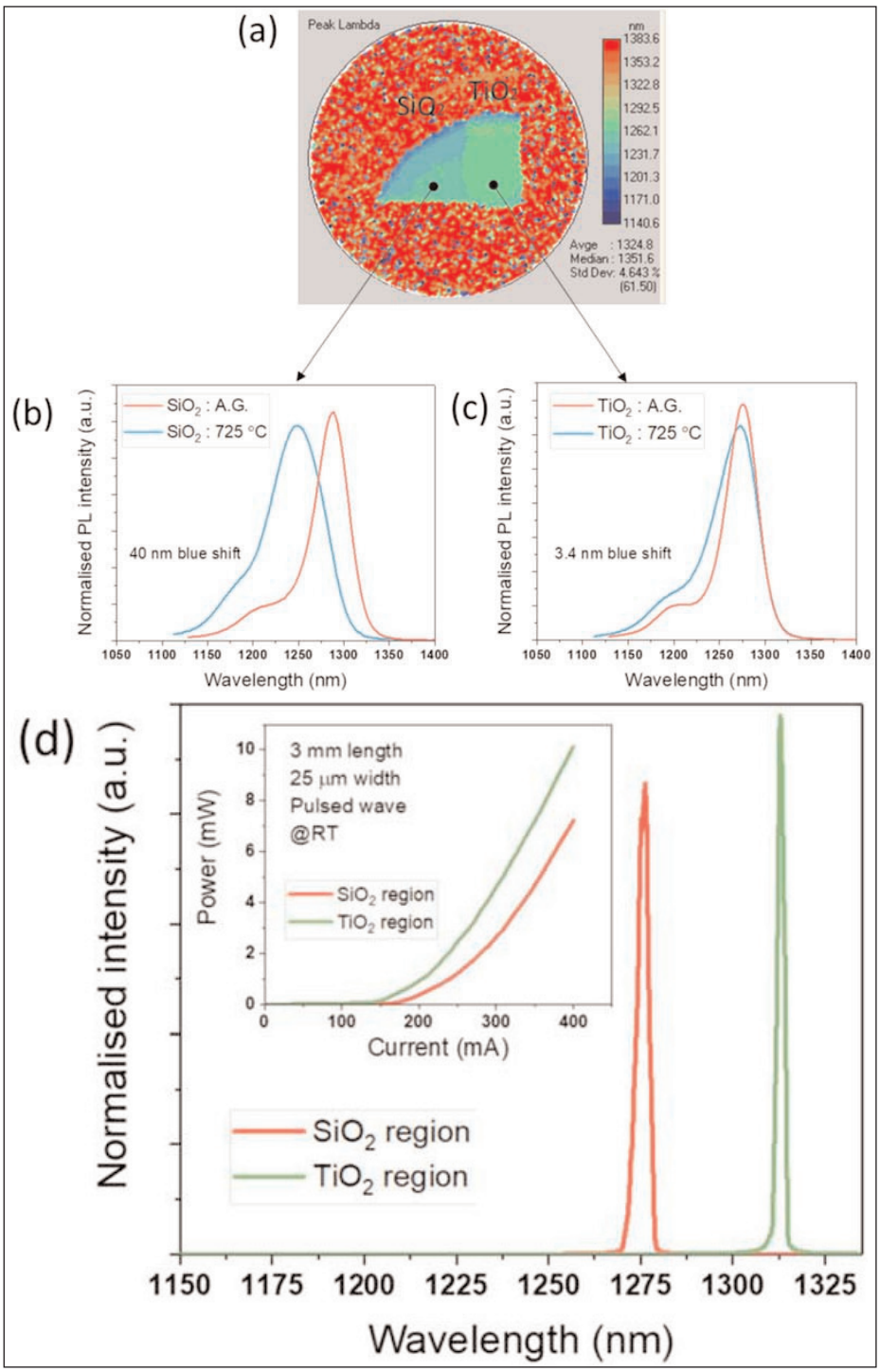

Figure 2. (a) PL mappings of InAs/GaAs DWELL laser sample on silicon for selective-area intermixing at 725°C for 30 seconds. Comparison of PL spectra of InAs/GaAs DWELL laser sample before and after the RTA process in (b) SiO_2-capped region and (c) TiO_2-capped region. (d) Normalized emission spectra of QD lasers on silicon for as-grown and after RTA under pulsed operation. Inset: light–current QD laser curves for as-grown material and after RTA processes.

The reduced performance with SiO_2 cap was attributed to material degradation from intermixing of the InAs and GaAs in the DWELLs. ■

https://iopscience.iop.org/article/10.1088/1361-6641/ab2c24

Author: Mike Cooke

Gallium nitride quantum well HEMTs

Researchers make first study of off-state breakdown with a view to radio frequency high-power applications.

Cornell University in the USA has reported on what it claims is the first study of off-state breakdown in gallium nitride (GaN) quantum well high-electron-mobility transistors (QW-HEMTs) [Austin Hickman et al, IEEE Electron Device Letters, vol40, issue 8 (August 2019), p1293]. The well was situated in aluminium nitride (AlN) barriers. The devices contrast with more conventional III-nitride transistor structures with a thick GaN layer, thin top AlGaN barrier and, sometimes, an AlGaN back barrier.

The researchers see the QW-HEMTs as having potential for high-power radio frequency applications. They explain: "GaN's wide bandgap, large critical fields, high electron mobility, and excellent thermal conductivity enable low on-resistance and high breakdown voltages in GaN high-electron-mobility transistors."

The researchers used plasma-assisted molecular beam epitaxy (MBE) to create strained GaN QW structures in unstrained AlN barriers on 6H polytype silicon carbide (SiC). The layer sequence was: 350nm AlN buffer, 30nm GaN channel, 4nm AlN barrier, and 2nm GaN cap passivation.

The channel consisted of a two-dimensional electron gas (2DEG) near the AlN/GaN top barrier interface, which forms due to contrast in the charge polarization effects in GaN and AlN. The electron density and mobility were measured at 2.9×10^{13}/cm^2 and 630cm^2/V-s, respectively, using the Hall effect. Other reports of AlN/GaN/AlN 2DEG mobility have reached 700cm^2/V-s.

The team comments: "Several factors may be playing a role in the mobility limitation, including the high electron concentration that may increase the electron effective mass, increased interface roughness scattering, and the possibility for a 2D hole gas (2DHG) at the GaN channel/AlN buffer interface."

The HEMT was fabricated in a gate-last process (Figure 1) with etching and MBE regrowth of the heavily doped n^{++}-GaN ohmic source/drain contacts, mesa etching 20nm into the AlN buffer for electrical isolation, deposition of titanium/gold (Ti/Au) source/drain electrodes and nickel/gold (Ni/Au) gate, passivation with 40nm low-power plasma-enhanced chemical vapor deposition (PECVD) silicon nitride (SiN), and buffered oxide etch through the passivation for contact probing.

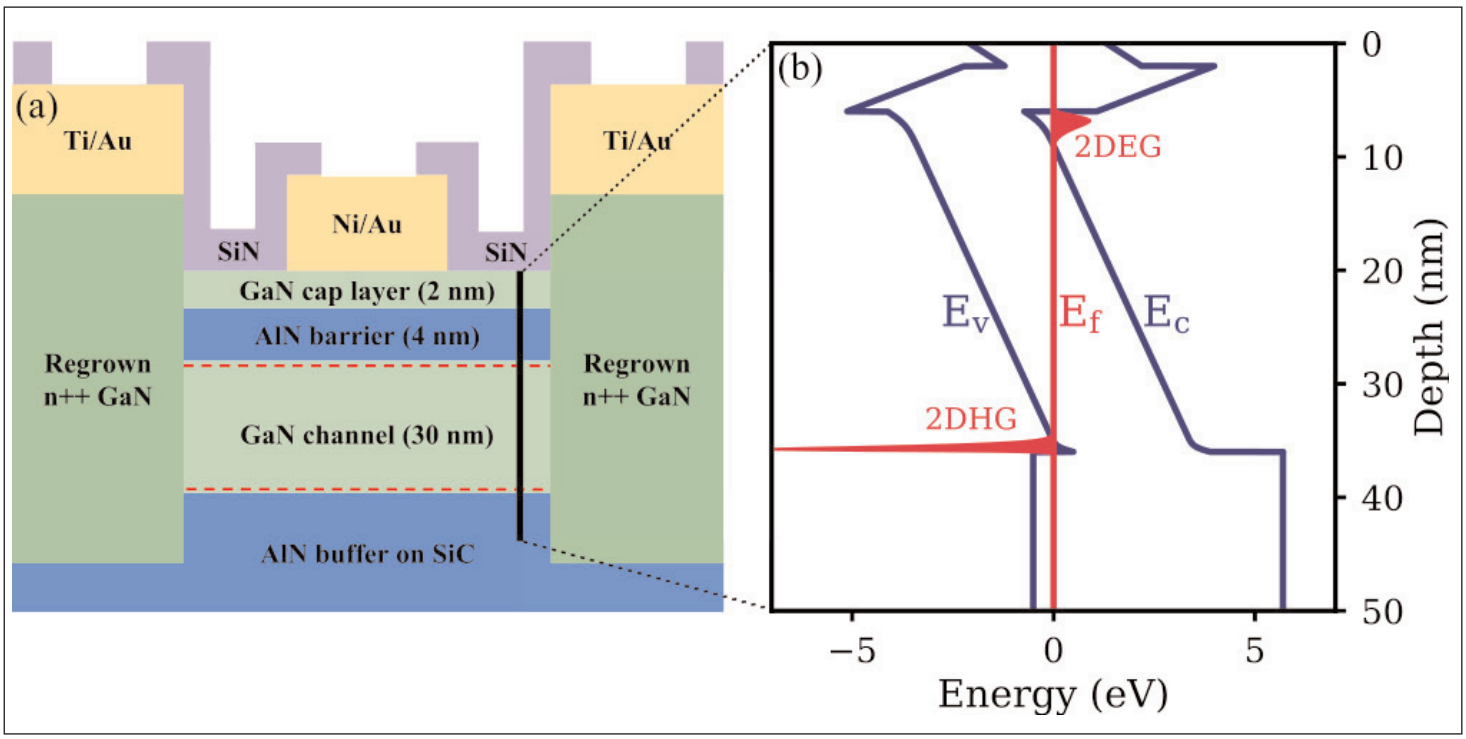

Figure 1. (a) Cross-sectional representation of processed QW HEMT, and (b) corresponding simulated energy band diagram.

Transfer-length method and Hall measurements after fabrication indicated an increase in sheet resistance (510Ω/square, 50% greater than the as-grown value) and a reduction in electron mobility (410cm^2/V-s). The electron concentration was 3x10^{13}/cm^2. The contact resistance of source/drain to the 2DEG was 0.13Ω-mm, described as "excellent" by the researchers. The increase in sheet resistance was likely due to surface damage, which could be avoided by altering the silicon dioxide deposited as a hard mask during fabrication.

The on/off current ratio was 10^4 — without passivation a value of 10^9 was achieved. The passivated device also achieved a peak transconductance of 0.6S/mm. "This is the highest transconductance reported for devices on the AlN/GaN/AlN heterostructure platform and shows their high promise," according to the team.

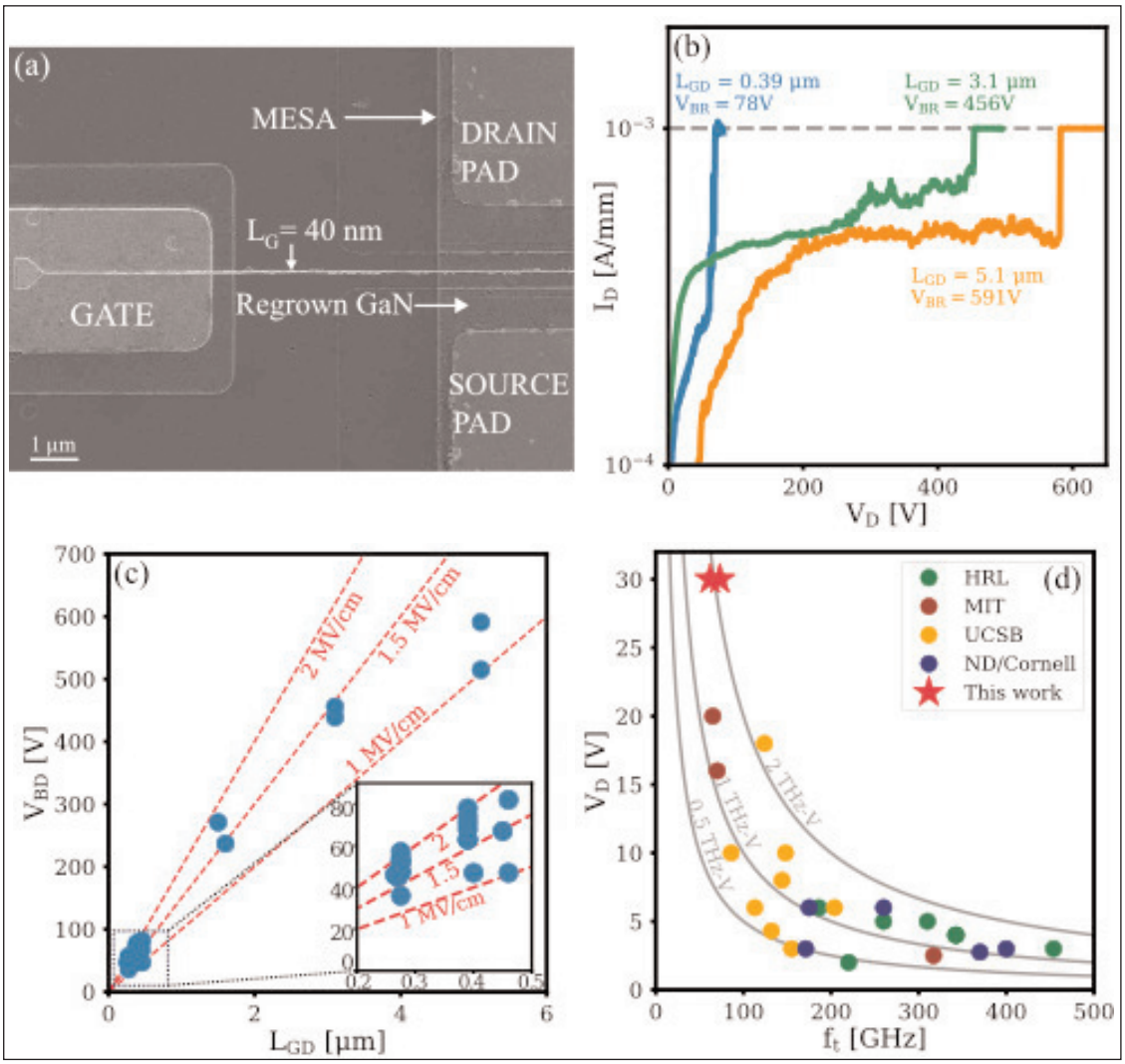

Figure 2. (a) Scanning electron microscope image of short-channel QW HEMT with 40nm gate length. (b) Hard breakdown for three HEMTs with varied gate-drain separations. (c) Breakdown voltage scaling as function of gate-drain separation from 0.27 to 5.1µm. (d) Johnson figure of merit benchmark plot comparing QW HEMT to state-of-the-art GaN HEMTs with submicron L_{GD} and no field plate.

The drain current reached 2.3A/mm with 1.3Ω-mm on-resistance. Under pulsed operation, the dispersion in current performance was around 15%. Frequency-dependent measurements in the range 0.05–40GHz gave cut-off (f_T) and maximum oscillation (f_{max}) frequencies of 161GHz and 70GHz, respectively. The researchers comment: "Both f_T and f_{max} values are records for HEMTs on the AlN platform. Further scaling of gate length and incorporation of a T-gate geometry are expected to dramatically increase f_T and f_{max} for the QW HEMT."

Breakdown (V_{BR}) at 1mA/mm drain current density (I_D) with the gate pinched off at less than –8V was 591V in a device with 5.1µm gate-drain distance (L_{GD}, Figure 2). The average electric field at breakdown was 1.16MV/cm. All other devices also had average breakdown fields greater than 1MV/cm. The field increased to 2MV/cm for a 390nm gate–drain distance, giving a breakdown voltage of 78V. "This is among the largest breakdown voltages reported for a submicron channel nitride HEMT, demonstrating the potential of QW HEMTs for extremely high-power operation in RF applications," the team reports.

The gate and drain currents were roughly similar during the breakdown measurements. "This indicates the off-state drain current and breakdown is dominated by gate-drain leakage and not avalanche or channel breakdown, and is far from the material limits," the team explains. The researcher suggest that a refined SiN passivation focused on limiting gate leakage could improve breakdown performance.

Two devices with 80nm gate length and 460µm gate–drain distance demonstrated Johnson figures of merit (V_Dxf_T) of 2.2THz-V and 1.9THz-V with 30V drain bias (V_D). The small-signals cut-offs were 73GHz and 62GHz, respectively. These are claimed to be among the highest reported. ■

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Author: Mike Cooke

High-electron-mobility III-nitride on 3C SiC template on silicon

Researchers work towards comparable electrical characteristics to epitaxial layers on conventional 4H-SiC substrates.

Germany's Fraunhofer Institute for Applied Solid State Physics (IAF) reports on progress in growing III-nitride heterostructures on 3C polytype silicon carbide (SiC) on silicon substrates [Stefano Leone et al, J. Appl. Phys., vol125, p235701, 2019]. The team wanted to show that such heterostructures could achieve comparable electrical characteristics to epitaxial layers on 4H SiC substrates.

III-nitride heterostructures are used in high-electron-mobility transistors (HEMTs) aimed at high power density and/or radio frequency (RF) performance. These heterostructures consisting of aluminium (AlN) and gallium (GaN) nitride alloys are typically grown on 4H polytype SiC. Although 4H-SiC has many attractive features for high-power RF applications such as small lattice mismatch and small thermal expansion mismatch as well as and high thermal conductivity, substrates are prohibitively expensive.

The 3C-SiC on Si option promises to reduce material costs and provide economies of scale from much larger-diameter substrates (300mm versus 100mm). GaN has better lattice and thermal expansion match ups with 3C-SiC compared with silicon. In terms of thermal expansion, GaN's coefficient is 5.6×10^{-6}/K, which compares with 2.6×10^{-6}/K for Si and 4.5×10^{-6}/K for 3C-SiC. The lattice parameters for GaN and the (111) planes of Si and 3C-SiC are 0.319nm, 0.384nm and 0.329nm, respectively.

The researchers comment: "We believe that, by developing the material quality and characteristics of the 3C-SiC templates, we could transfer our optimized epitaxial process on such templates and make more cost-effective HEMT heterostructures available for the RF market."

The III-nitride metal-organic chemical vapor deposition (MOCVD) was carried out on 100mm-diameter 3C-SiC on Si substrates supplied by three companies.

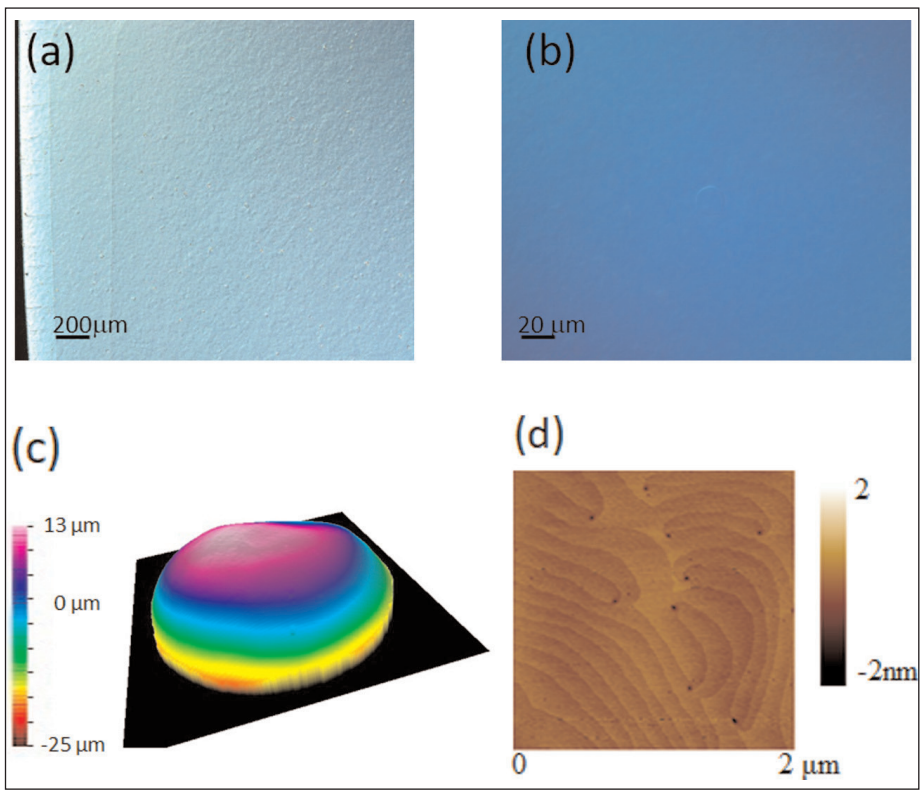

Figure 1. Morphology of 5µm-thick AlGaN/GaN epitaxial structure deposited on 3C-SiC/Si template, and images obtained by optical microscopy at: (a) 50x (wafer edge visible on left), (b) 500x magnifications, (c) three-dimensional plot of wafer bow, equal to +30µm, and (d) atomic force microscopy on 2µmx2µm area with 0.13nm root-mean-square roughness.

The silicon was (111) oriented. The 3C-SiC layers were targeted to be around 2µm thick, variously doped n- and p-type. The n-type doping was unintentional, while boron provided the p-doping. The researchers also wanted semi-insulating and thicker 3C SiC substrates, but such was unavailable from the suppliers at the time. Also, only one supplier was able to supply wafers with crack-free 2µm SiC.

Semi-insulating 3C-SiC is much desired for RF applications targeting the 10–100GHz range, particularly for AlGaN/GaN HEMTs in millimeter-wave monolithic module integrated circuits (MMICs). The team reported that it was working with the vendors, targeting crack-free 20µm thick semi-insulating 3C-SiC layers on highly resistive silicon.

"Since the paper was accepted," Stefano Leone, the lead author, reports, "we have now managed to get semi-insulating 3C-SiC layers with highly resistive substrates, and we have manufactured some transmission line model (TLM) structures with a great RF performance."

Table 1. Characteristics of similar HEMT structures on different substrates.

Characteristics		4H-SiC	Si (111)	3C-SiC/Si(111)
Structural	FWHM GaN 00.2 (arcsec)	130	600	350
	FWHM GaN 10.2 (arcsec)	180	900	650
	Bow (μm)	10	30	30
Electrical	N_{min} (/cm^3)	1.3x10^{10}	7x10^{12}	1x10^{13}
	N_s (/cm^2)	6x10^{12}	4x10^{12}	9x10^{12}
	R_s Ω/square)	390	681	310
	μ (cm^2/V-s)	1530	1360	1400

The MOCVD tool used in the epitaxial research was capable of holding multiple wafers and performing in-situ process monitoring. The group-III metals Ga and Al were supplied using trimethyl precursors. The nitrogen came in ammonia (NH_3) molecular form. The carrier gas was hydrogen. Insulating GaN was created using iron doping with ferrocene (bis-cyclopentadienyl-iron $(C_5H_5)_2Fe$) precursor.

The deposition was carried out at low pressures of 50–300mbar. Temperatures were in the range 1000–1200°C. The layer sequence was aimed at high-electron-mobility channel formation: nucleation, strain management, iron-doped insulating GaN, unintentionally doped GaN buffer, AlGaN barrier, and GaN cap. The researchers achieved smooth 5μm-thick epitaxial layers on 2μm-thick 3C-SiC without cracks. The wafer bow could be reduced to less than 50μm (Figure 1).

Low-temperature AlN interlayers were inserted into the GaN buffer to reduce wafer curvature and avoid cracking of the epitaxial layers. The AlN was used to counteract strain effects arising from thermal expansion and lattice mismatching with the underlying substrate. The researchers hope in future to implement a thick AlGaN transition layer approach on 3C-SiC/Si that is usually used in depositing on silicon for gradual transition from the compressive stress of the substrate to the GaN buffer layer. This would remove the need for the AlN interlayers, improving the GaN crystal quality and material properties.

The researchers report: "One of the main findings was that slow temperature ramps and a moderate desorption temperature were necessary to prevent cracking of the 3C-SiC layer itself. Nitridation of the surface, rather than an Al-preflow, led to better crystal quality. A thin nucleation layer (<60nm) of pure AlN or even $Al_{0.7}Ga_{0.3}N$ proved itself to be good enough to achieve a good crystal quality of the GaN layers, while keeping a good strain management of the epitaxial structure."

High-electron-mobility structures with more than 10nm barrier and cap with Al content around 30% was subjected to capacitance-voltage and Hall measurement characterization (Table 1) to extract sheet carrier density (N_s), minimum carrier concentration (N_{min}), sheet resistance (R_s) and mobility (μ). These results were compared with structures on 4H SiC and (111) Si.

The 4H-SiC had an N_{min} value three orders of magnitude lower than the 3C-SiC/Si sample. The researchers suggest that this is due to a higher density of dislocations and stacking faults, as indicated by x-ray analysis showing narrower full-width at half maximum (FWHM) values for rocking curves for diffraction off the 00.2 and 10.2 planes.

The team comments: "The outcome of this study is that the lateral isolation of the GaN buffer is good and similar to what is achieved on 4H-SiC, and the vertical isolation of the buffer is suitable for RF applications [Figure 2]. A big role in achieving this target is probably played also from the material quality of the GaN layers, which can be further improved by tuning the epitaxial growth conditions and also by having 3C-SiC templates with higher crystal quality, and especially a lower density of dislocations and stacking faults, which are known to be present in high density on 3C-SiC layers."

The researchers also suggest that vertical high-power devices with 650–1200V ratings could be possible with low-carrier-concentration GaN buffers with improved vertical isolation capabilities on conducting 3C-SiC/Si substrates. ■

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Author: Mike Cooke

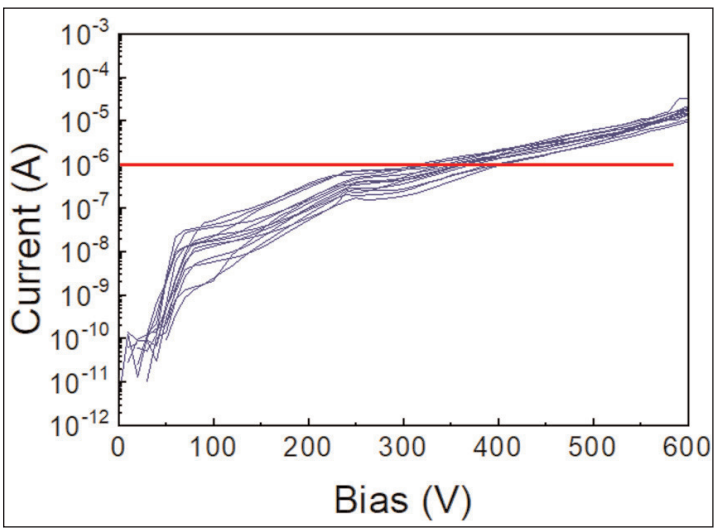

Figure 2. Vertical buffer isolation mapping's measurement across GaN on 3C-SiC-HEMT epiwafer, using 75μm-diameter circular ohmic contact. For 1μA vertical current, isolation voltage is in range 310V and 410V.

Conductive penetration of aluminium nitride buffers on silicon substrates

Filling spontaneous via-holes with low-resistance n-AlGaN enables the first successful fully vertical Schottky diode fabrication on silicon.

Noriko Kurose and Yoshinobu Aoyagi of Ritsumeikan University in Japan claim the first successful fabrication of fully vertical n-type aluminium gallium nitride (n-AlGaN) Schottky diodes on silicon (Si) substrate [J. Appl. Phys., vol125, p205110, 2019]. The device was achieved by creating a conducting path through the normally insulating AlN buffer layer that is needed to grow III–nitride materials on (111)-oriented Si. The conduction was enabled by filling spontaneously formed via holes in the AlN (v-AlN) with n-AlGaN.

Kurose and Aoyagi suggest that the technique could also lead to other vertical high-power devices on silicon, such as vertical n-AlGaN field-effect transistors (FETs), bipolar devices, light-emitting diodes (LEDs), and sensors. Vertical structures push peak electric fields away from the surface of devices where failure often occurs. Production on silicon substrates would substantially reduce manufacturing costs. Further benefit could arise from monolithic integration of III–nitride power structures and silicon control circuitry.

Kurose and Aoyagi used horizontal metal-organic chemical vapor deposition (MOCVD) with trimethyl-gallium (TMG), trimethyl-aluminium (TMA), tetraethyl-silicon (TESi) and ammonia (NH_3) precursors in hydrogen carrier gas. The silicon substrates were (111) crystal oriented and doped n-type with anti-mony.

The initial MOCVD growth (Figure 1) generated spontaneous via holes in the AlN nucleation layer. The hole density was (2.5-3.0)x10^7/cm^2, according to optical microscope inspection on samples grown at TMA flow rates of 7 and 8 standard cubic centimeters per minute (sccm). The hole sizes came in the ranges

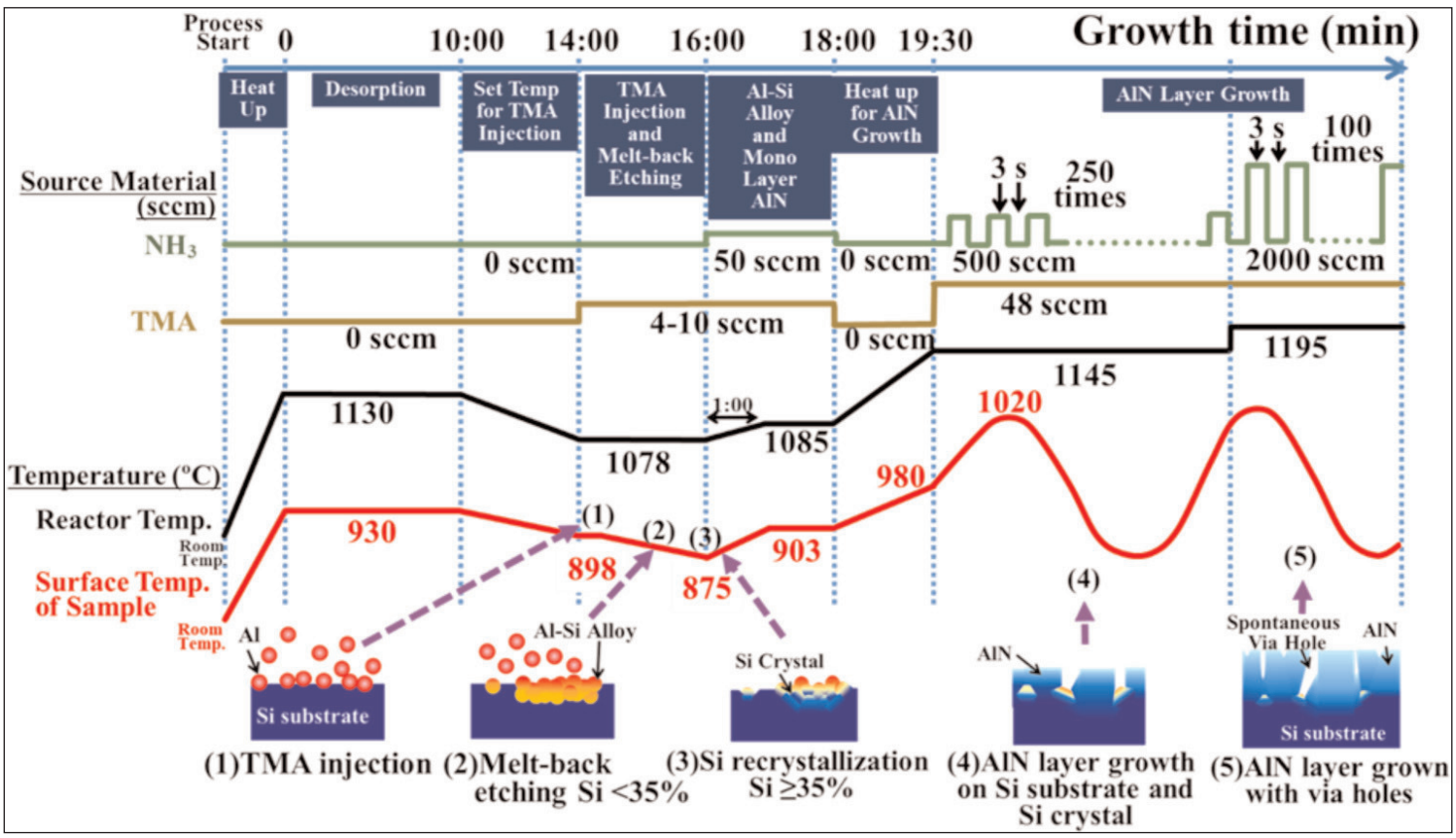

Figure 1. Epitaxial-growth chart and schematic views of cross section of grown layer.

400–800nm and 500–1000nm, respectively. The depth of the holes were about 80nm, according to atomic force microscopy.

These via holes in the insulating AlN buffer were filled with conductive n-AlGaN using alternate-growth-mode MOCVD where the source materials are fed in in-sequence. The method enhances lateral migration of surface atoms as the growth proceeds.

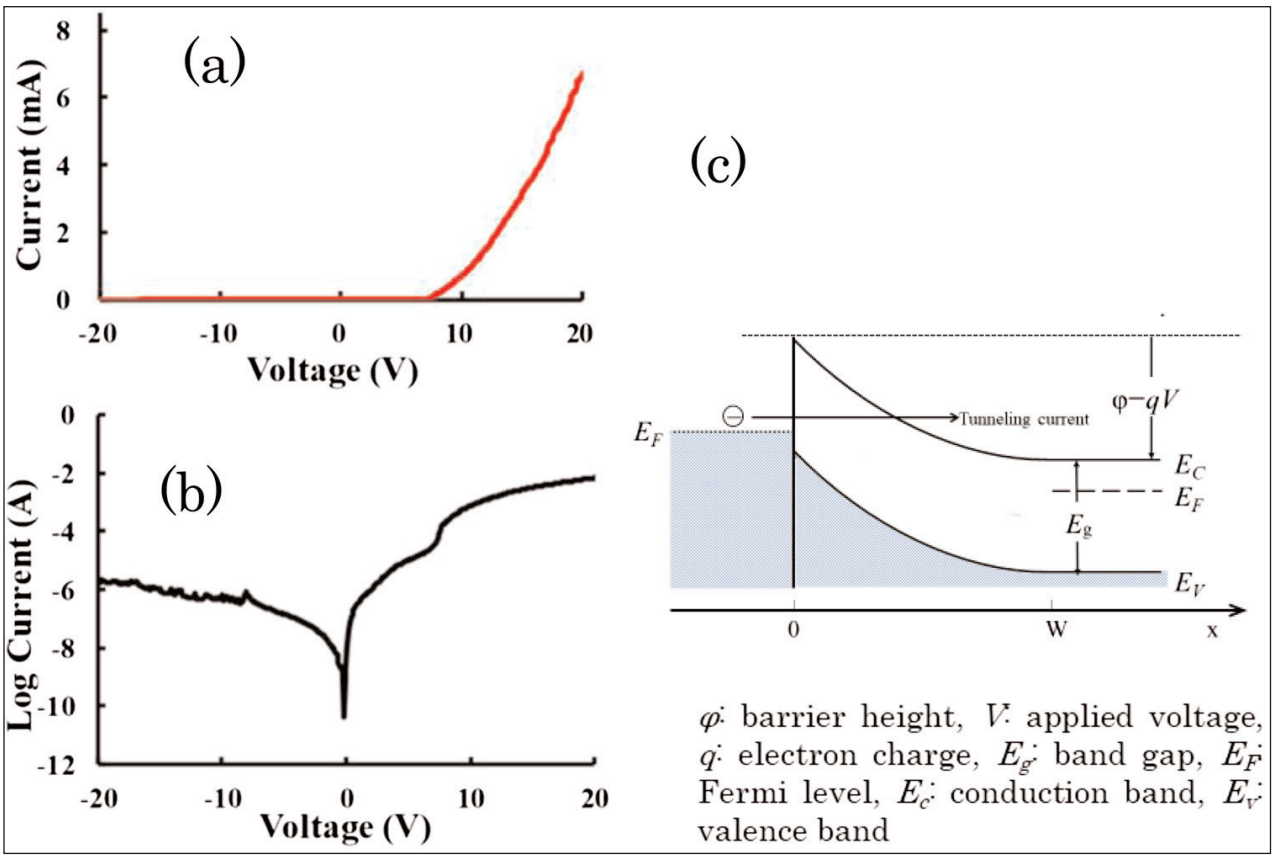

Figure 2. Current-voltage (I–V) characteristics of vertical Schottky diode fabricated on v-AlN: (a) linear plot, (b) logarithmic plot, and (c) band diagram.

Scanning electron microscope cross sections of the material showed filling of the via holes with n-AlGaN. Above the via holes. voids tended to form in the overlying n-AlGaN material. A further n-AlGaN layer with somewhat different growth conditions closed the voids and gave a flat surface on which quantum wells and GaN contact layers could be grown.

The voids are seen as being helpful in "reducing the bowing of the epitaxial layer on the Si substrate" and for avoiding cracks in the device layers. Measurements of curvature showed an increase during the AlN growth to 70/km and a decrease to negative values when the n-AlGaN with voids is grown. After cooling, the curvature returned to +70/km. This contrasts with n-AlGaN grown on n-AlN without via holes: the curvature continued increasing to a total of +190/km. This final value was unaffected by cooling.

Vertical conduction structures were made from n-AlGaN layers on v-AlN and non-v-AlN buffers. Ohmic contact metals were applied to both the top n-AlGaN (titanium/aluminium/titanium/gold) and bottom silicon (silver/gold) substrate, followed by sintering. The v-AlN structure demonstrated a low resistance of 33Ω, while the non-v-AlN resistance was 7200Ω. The electrode area was 0.75mm^2.

The researchers extracted the specific resistivity of the v-AlN buffer as 100mΩ-cm^2, which compares with the non-v-AlN's 54,000mΩ-cm^2.

Schottky diodes were also produced with the n-AlGaN electrode replaced with nickel/gold. The layers between the electrodes consisted of 500μm silicon substrate, 300nm v-AlN, and 1μm n-Al0.3Ga0.7N. The forward/reverse current ratio for ±20V bias was ~10^4 (Figure 2). The extracted ideality factor of the Schottky diode was 60 while the barrier height was 0.44eV.

The series resistance was estimated to be 900Ω. The forward current density at 20V bias was 4.9A/cm^2.

The researchers comment: "These values do not indicate a very good Schottky diode performance. This may result from leakage current and/or a high series resistance from our state-of-the-art phase of development of the fully vertical Schottky diode on the silicon substrate using v-AlN."

Comparing the performance of the Schottky and Ohmic devices, the team says that the series resistance mainly originated in the Schottky contact. The thinness of the n-AlGaN layer with unterminated threading dislocations, giving a high leakage current, was blamed for the poor performance. A further effect reducing performance was a high current arising from high fields at the Schottky-electrode edge. ■

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Author: Mike Cooke

Indium arsenide and gallium antimonide fins on 300mm silicon

Researchers look to vertical nanowire tunnel field-effect transistor applications.

The Imec microelectronics research center in Belgium has been assessing indium arsenide (InAs) and gallium antimonide (GaSb) growth in shallow trench isolation structures on 300mm-diameter silicon substrates [Y. Mols et al, J. Appl. Phys., vol125, p245107, 2019]. The team sees the resulting fins as potentially forming the basis for vertical nanowire (VNW) tunnel field-effect transistors (TFETs).

The researchers are seeking ways to implement complementary metal-oxide-semiconductor (CMOS) ultra-large-scale integration (ULSI) using high-mobility III-V materials such as InAs and GaSb on a large-diameter silicon platform. The aim is to deliver high drive currents at low supply voltage, reducing power consumption.

Such applications require high-quality crystalline material. A big challenge to this is the large lattice mismatch of at least 8% between the III-V materials and silicon. The mismatch results in the generation of many defects in the growing crystal structures to relieve built-up strain.

One technique that has been used to block these defects from reaching the device levels has been aspect ratio trapping, where the crystal growth is initiated in trenches. The defects propagate to and terminate at the trench wall.

Fin structures are used in gate-all-around transistors and, it is hoped, in future vertical nanowire TFETs. The vertical transistor structure should result in even more compact circuitry.

IMEC performed metal-organic vapor phase epitaxy (MOVPE) on 300mm silicon wafers with silicon dioxide shallow trench isolation structures with V-grooves at the base presenting {111} facets of the underlying silicon crystal structure. The silicon wafer was (001) oriented and p-type doped.

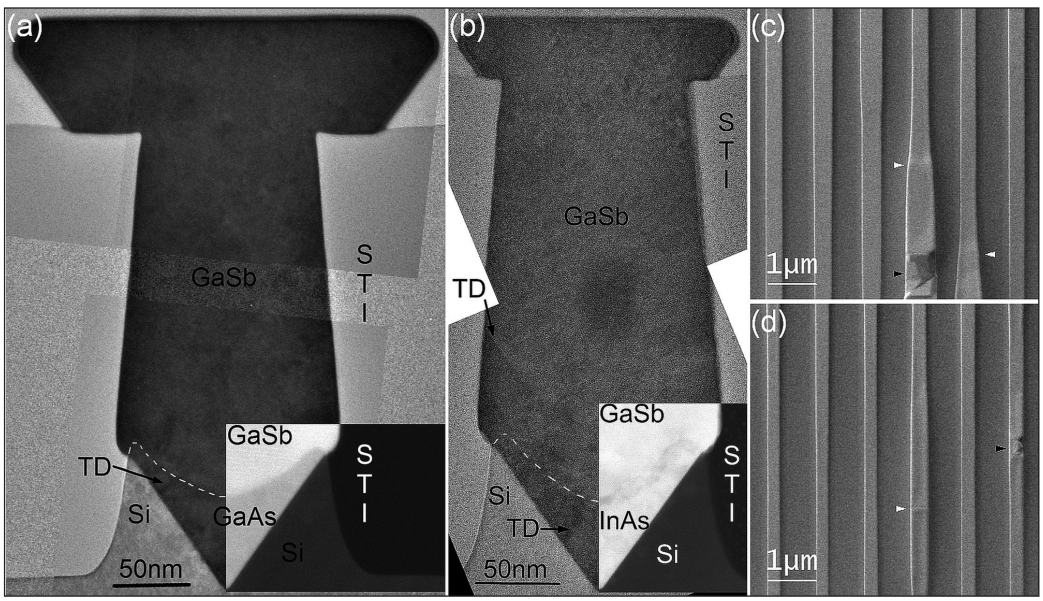

Figure 1. (Stitched) Cross-section TEM images of GaSb on (a) GaAs and (b) InAs seed. Dashed line at left bottom half of the V-groove is a guide to the eye, indicating the GaSb/seed interface. High-angle annular dark-field (HAADF) scanning transmission electron microscopy (STEM) overlay at bottom right half of the V-groove in both images clearly shows contrast difference for the GaAs/GaSb interface; using the dashed line one can also vaguely distinguish the InAs/GaSb interface. Top-view SEM of GaSb fins on (c) GaAs and (d) InAs seed. Black arrows indicate pits and white arrows the potential sites where along-trench stacking faults or nano-twins reach the surface.

The device areas were partitioned into 600μmx600μm blocks with different trench formations. The main work for the paper focused on 100nm-wide trenches. The trench length was 10μm.

The III-V seed was formed in the groove by first introducing tertiarybutylarsine (TBAs) in the MOVPE reactor, followed by the group-III metal (Ga, In) in trimethyl form (TMGa, TMIn). InAs fins were seeded at 380°C, followed by a ramp to 530°C. At the same time, the V/III ratio was reduced from 60 to 45. Once the trench was almost full, the temperature was reduced to 480°C in a TBAs environment. The final InAs fin had a flat (001) top surface.

For GaSb fins, direct growth on silicon either failed or resulted in poor-quality material. Instead, GaSb fins

were grown on top of 150nm gallium arsenide (GaAs) deposited in two steps, with the low-temperature step having a V/III ratio of 50. The high-temperature GaAs buffer was grown at 580°C with a V/III ratio of 15. The top surface was (001). The antimonide growth was at 500°C or 530°C. The temperature ramp to the lower value was carried out under TBAs. The V/III was around 1 for the GaSb deposition.

The researchers comment that the GaSb long-range quality was poor. They attribute this to the 8% lattice mismatch between GaAs and GaSb. Further, the trench was effectively shallower for GaSb growth, reducing aspect ratio trapping effects. The higher growth temperature of 530°C reduced the pit/defect density per length of fin from 1.8/μm to 0.3/μm.

To increase the aspect ratio for GaSb growth, the team performed antimonide MOVPE on low-temperature GaAs and InAs seed layers (Figure 1). During the ramp up to 530°C for the GaSb growth, the V-shape of the seed layer relaxed to a more rounded shape. The new setup resulted in a reduction in pit density to 0.03/μm along the fins with both types of seed.

To study conductivity properties, the researchers added silane (SiH_4) as silicon precursor to the growth, giving n-InAs and p-GaSb doping. Scanning electron microscopy (SEM) bar regions were produced with 5mm-long trenches of various widths.

These were used for micro-4-point-probe (μ4PP) measurements on a microHALL-A300 tool from Capres (www.capres.com/Default.aspx?ID=59). The n-InAs fins were grown at 500°C on undoped low-temperature InAs seeds; the p-GaSb at 530°C on undoped low-temperature InAs or GaAs seeds.

An injection current of 1μA was used. The resistance results were normalized using the dimensions of the fins to give resistivity values (Figure 2). Increased doping reduced resistivity. In turn, the resistivity was not changed by growing the fins in wider trenches.

Simulations suggest that the resistivity for source/drain regions of vertical nanowire TFETs with InAs fins should be of the order 0.00005Ω-cm. The demonstrated InAs fins achieved 0.001Ω-cm, a factor of 20 too high. The simulations suggest that InAs channels need the resistivity to be less than 0.0027Ω-cm, which is met by the demonstrated fins, even when undoped.

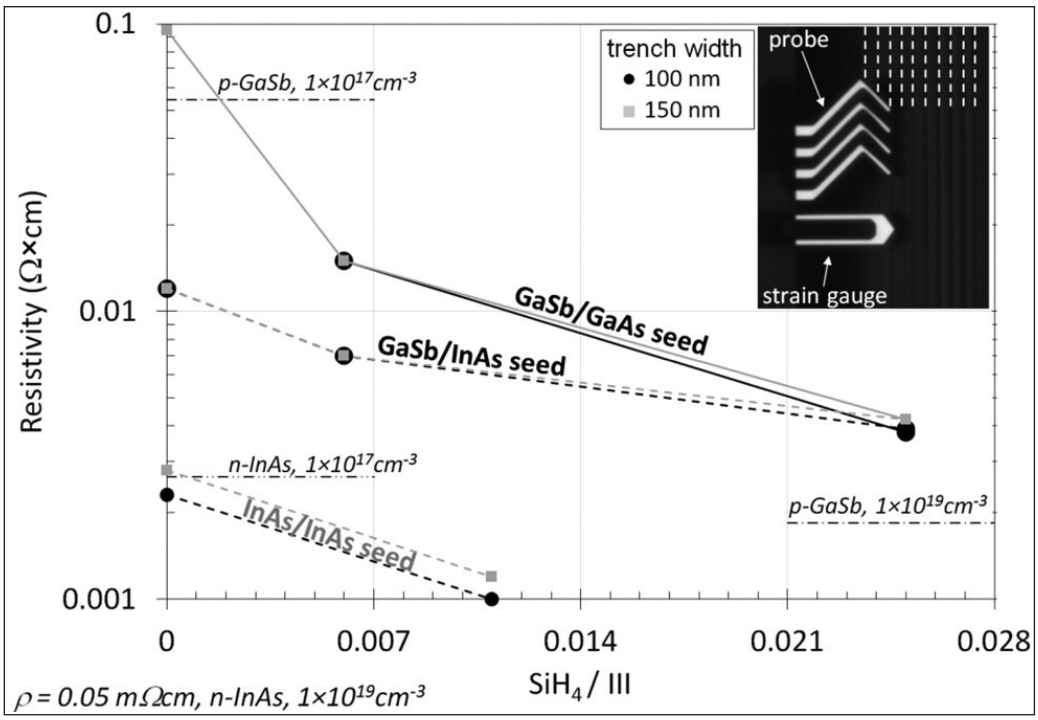

Figure 2. Measured resistivity for GaSb and InAs fins as a function of SiH_4/III (III = TMGa or TMIn) and trench width (lines are a guide for the eye). Dashed-dotted lines represent some simulated resistivities needed for vertical nanowire TFET operation. Inset: μ4PP (8μm interprobe distance) and strain gauge contacting fin. Fins represented by darker lines with location indicated by dashed lines; lighter lines oxide.

For GaSb, the S/D requirement is 0.0018Ω-cm, which is a factor of 2 lower than the demonstrations. There was reduced resistivity when the GaSb was grown on InAs seeds. The researchers suggest that this could be due to a local two-dimensional electron gas (2DEG) forming as a result of a broken bandgap at the GaSb/InAs interface, boosting conductivity. One suspects that this could be unhelpful from the point of view of vertical nanowire TFETs.

The researchers comment: "Without a direct measurement of the carrier concentration and/or mobility of our material, no statements can be made on whether the background doping level is lower or if defects possibly increase the resistance."

Normally, one would apply Hall measurements in a magnetic field to determine these parameters. "Unfortunately, with this microprobe configuration, it is not possible to perform a μ-Hall measurement on the fins because the current flow is confined in one direction by the narrow width of the fins," the team explains.

While the researchers search for techniques to extract these values, they suggest that the measured resistivities for GaSb and InAs "look very promising for VNW TFET fabrication". ■

https://doi.org/10.1063/1.5096015

Author: Mike Cooke

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Cambridge CB4 3NP,
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Tel: +44 (0)1223 352244
Fax: +44 (0)1223 352444
www.camchem.co.uk

Intelligent Epitaxy Technology Inc
1250 E Collins Blvd,
Richardson,
TX 75081-2401,
USA
Tel: +1 972 234 0068
Fax: +1 972 234 0069
www.intelliepi.com

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Fax: +33 1 45 10 69 53
www.ommic.fr

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Place Marcel Rebuffat, Parc de Villejust, 91971 Courtabouef,
France
Tel: +33 (0)1 69 31 61 30
Fax: +33 (0)1 69 31 61 79
www.picogiga.com

5 Deposition materials

Akzo Nobel High Purity Metalorganics
www.akzonobel.com/hpmo
Asia Pacific:
Akzo Nobel (Asia) Co Ltd,
Shanghai,
China
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Fax: +86 21 3360 7739
metalorganicsAP@akzonobel.com
Americas:
AkzoNobel Functional Chemicals,
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USA
Tel. +31 800 828 7929 (US only)
Tel: +1 312 544 7000
Fax: +1 312 544 7188
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www.camchem.co.uk

Dow Electronic Materials
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USA
Tel: +1 978 557 1700
Fax: +1 978 557 1701
www.metalorganics.com

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Fax: +1 510 790 6241
www.mathesontrigas.com

Mining & Chemical Products Ltd
(see section 1 for full contact details)

Praxair Electronics
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NY 10962,
USA
Tel: +1 845 398 8242
Fax: +1 845 398 8304
www.praxair.com/electronics

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Wirral, Merseyside CH62 3QF,
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Tel: +44 151 334 2774
Fax: +44 151 334 6422
www.safchitech.com

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

6 Deposition equipment

AIXTRON SE
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Fax: +33 (0) 1 39 47 45 62
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Fax: +1 952 934 2737
www.svta.com

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7 Wafer processing materials

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www.airproducts.com/compound

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MA 02464, USA
Tel: +1 617 965 5511
Fax: +1 617 965 5818
www.microchem.com

Praxair Electronics
(see section 5 for full contact details)

8 Wafer processing equipment

EV Group
DI Erich Thallner Strasse 1,
St. Florian/Inn, 4782,
Austria
Tel: +43 7712 5311 0
Fax: +43 7712 5311 4600
www.EVGroup.com

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Old Kilpatrick,
near Glasgow G60 5EU,
Scotland, UK
Tel: +44 (0) 1389 875 444
Fax: +44 (0) 1389 879 042
www.logitech.uk.com

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

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

SPTS Technology Ltd
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UK
Tel: +44 (0)1633 414000
Fax: +44 (0)1633 414141
www.spts.com

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

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

9 Materials & metals

Goodfellow Cambridge Ltd
Ermine Business Park,
Huntingdon,
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Fax: +44 (0) 1480 424900
www.goodfellow.com

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10 Gas and liquid handling equipment

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(see section 7 for full contact details)

Cambridge Fluid Systems
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Tel: +44 (0)1954 786800
Fax: +44 (0)1954 786818
www.cambridge-fluid.com

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

SAES Pure Gas Inc
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11 Process monitoring and control

Conax Technologies
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www.wepcontrol.com

12 Inspection equipment

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

13 Characterization equipment

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

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

14 Chip test equipment

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

15 Assembly/packaging materials

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

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

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

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

16 Assembly/packaging equipment

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

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

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

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

17 Assembly/packaging foundry

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

18 Chip foundry

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

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

19 Facility equipment

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

20 Facility consumables

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

21 Computer hardware & software

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

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

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

22 Used equipment

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

23 Services

Henry Butcher International
Brownlow House, 50–51
High Holborn, London WC1V 6EG,
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www.henrybutcher.com

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24 Consulting

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E-mail: jean-luc.ledys@neuf.fr

25 Resources

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San Jose,
CA 95134,
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21st Conference on Power Electronics and Applications (and Exhibition), EPE'19 ECCE (Energy Conversion Congress & Expo) Europe
Genova, Italy
E-mail: info@epe2019.com
www.epe2019.com

4–6 September 2019
Executive Forums: Silicon Photonics, LiDAR, 3D Sensing & Infrared Imaging, alongside 21st China International Optoelectronic Exposition (CIOE 2019)
Shenzhen, China
E-mail: derek.deng@cioe.cn
www.i-micronews.com/executive-forums-on-photonics-2019

4–7 September 2019
CIOE 2019: 21st China International Optoelectronic Exposition
Shenzhen Convention & Exhibition Center, China
E-mail: cioe@cioe.cn
www.cioe.cn/en

18–20 September 2019
SEMICON Taiwan 2019
Taipei Nangang Exhibition Centre, Taiwan
E-mail: semicontaiwan@semi.org
www.semicontaiwan.org

22–25 September 2019
35th North American Conference on Molecular Beam Epitaxy (NAMBE 2019)
Ketchum, ID, USA
E-mail: della@avs.org
www.nambe2019.avs.org

22–26 September 2019
45th European Conference on Optical Communications (ECOC 2019)
Dublin, Ireland
E-mail: ecoc2019@thiet.org
www.ecoc2019.org

23–25 September 2019
Strategic Materials Conference—SMC 2019
Doubletree by Hilton, San Jose, CA, USA
E-mail: ltso@semi.org
www.semi.org/en/connect/events/strategic-materials-conference-smc

24–26 September 2019
19th International Metrology Congress (CIM 2019)
Paris, France
E-mail: info@cfmetrologie.com
www.cim2019.com

29 September – 3 October 2019
Eleventh Annual Energy Conversion Congress and Exposition (ECCE 2019)
Baltimore, MD, USA
E-mail: ecce@courtesyassoc.com
www.ieee-ecce.org/2019

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29 September – 4 October 2019
International Conference on Silicon Carbide and Related Materials (ICSCRM 2019)
Kyoto International Conference Center, Japan
E-mail: icscrm2019-regist@or.knt.co.jp
www.icscrm2019.org

29 September – 4 October 2019
22nd European Microwave Week (EuMW 2019) including:
49th European Microwave Conference (EuMC 2019)
14th European Microwave Integrated Circuits Conference (EuMIC 2019)
Paris Expo Porte de Versailles, Paris, France
E-mail: eumwreg@itnint.com
www.eumweek.com

30 September – 3 October 2019
SCTE-ISBE Cable-Tec Expo 2019
Ernest N Morial Convention Center, New Orleans, LA, USA
E-mail: expo@scte.org
https://expo.scte.org

6–11 October 2019
22nd European Microwave Week (EuMW 2019)
Paris Expo Porte de Versailles,
Paris, France
E-mail: eumwreg@itnint.com
www.eumweek.com

17–19 October 2019
LASER World of PHOTONICS INDIA 2019
Bombay Exhibition Centre (BEC),
India
E-mail: info@world-of-photonics-india.com
www.world-of-photonics-india.com

20–22 October 2019
9th Annual World Congress of Nano Science & Technology 2019 (Nano S&T-2019) – Small World, Big Thinking, Big Pattern, and Great Development
Suzhou, China
E-mail: selina@bitconferences.com
www.bitcongress.com/nano2019

29–31 October 2019
7th IEEE Workshop on Wide Bandgap Power Devices & Applications (WiPDA 2019)
Marriott Stateview Hotel,
North Carolina State University (NCSU) campus,
Raleigh, NC, USA
E-mail: rodriguesrostan@ieee.org
www.wipda.org

3–6 November 2019
2019 IEEE BiCMOS and Compound Semiconductor Integrated Circuits and Technology Symposium (BCICTS)
Loew's Vanderbilt Hotel,
Nashville, TN, USA
E-mail: bruce.green@nxp.com
www.bcicts.org

5–8 November 2019
5th International Conference on Advanced Electromaterials (ICAE 2019)
— Symposium 8, 'Materials and Devices for Power Electronics'
Ramada Plaza Jeju Hotel, Jeju Korea
E-mail: secretary@icae.kr
www.icae.kr

7 November 2019
Interlligent UK's 2019 RF & Microwave Design Seminar
Møller Centre, Cambridge, UK
E-mail: info@interlligent.co.uk
www.eventbrite.co.uk/e/interlligent-uks-2019-rf-microwave-design-seminar-tickets-59049393325

12–15 November 2019
SEMICON Europa 2019, co-located with productronica
Munich, Germany
E-mail: SEMICONEuropa@semi.org
www.semiconeuropa.org

9–11 December 2019
65th IEEE International Electron Devices Meeting (IEDM 2019)
San Francisco, CA USA
E-mail: info@ieee-iedm.org
www.ieee-iedm.org

2–6 February 2020
IEEE International Solid- State Circuits Conference (ISSCC 2020)
San Francisco, CA, USA
E-mail: Isscinfo@yesevents.com
www.isscc.org

12–14 March 2020
International Conference on Nano Research and Development (ICNRD-2020) – Breakthrough and Innovation in Nano Science and Technology
Grand Copthorne Waterfront Hotel,
Singapore
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www.istci.org/ICNRD2020/Program.asp

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