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Vol. 11 • Issue 4 • May/June 2016

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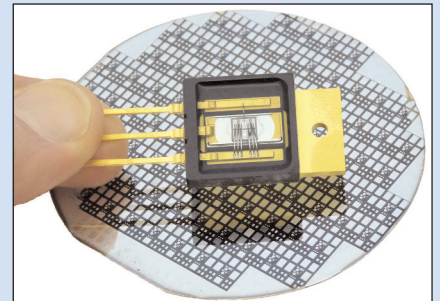
Veeco's New TurboDisc EPIK700 GaN MOCVD System

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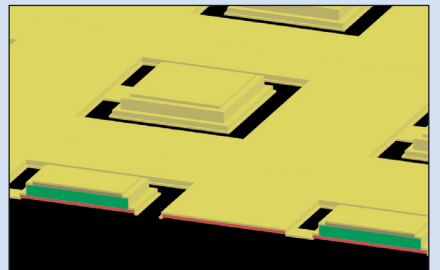
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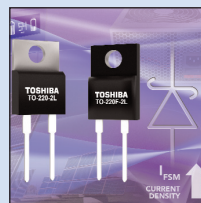
p21 Custom MMIC has moved its headquarters to new offices in Chelmsford, MA.



p24 Ascatron has raised €4m in A-round funding for final development of its first SiC products.



p66 Europe's TOP-HIT transfer printing consortium aims to boost large-scale heterogeneous integration of diverse materials and devices.



Cover: Toshiba's second-generation SiC Schottky diodes are among many new SiC and GaN wide-bandgap semiconductor product developments unveiled in May at the IEEE International Microwave Symposium (IMS) and PCIM (Power Conversion and Intelligent Motion) Europe events. **p25**

Wide-bandgap broadens out

In this issue we report developments in new products unveiled at May's IEEE International Microwave Symposium (IMS 2016) in San Francisco and the PCIM (Power Conversion and Intelligent Motion) Europe 2016 event in Nuremberg, Germany, which both highlight silicon carbide (SiC) and gallium nitride (GaN) wide-bandgap devices in particular (see pages 25–40).

For example, at PCIM Europe, circuit protection firm Littelfuse Inc — which produces silicon-based insulated-gate bipolar transistors (IGBTs) — launched its first SiC Schottky diodes. These join the SiC MOSFETs in production from Monolith Semiconductor (in which Littelfuse took a stake last December). Last year Monolith relocated from Ithaca, NY to Texas after forming a partnership for the manufacturing of its SiC switches on foundry X-FAB Texas' 150mm silicon production line. Meanwhile, silicon-focused Toshiba unveiled Schottky diodes based on its second-generation SiC technology, Rohm launched its third generation of Schottkys, and STMicroelectronics unveiled its latest-generation 650V and 1200V SiC diodes and MOSFETs, which it will scale from 4" to 6" wafers by the end of 2016.

Also at PCIM Europe, Cree spin-off Wolfspeed launched the first fully qualified commercial power module from its operation in Fayetteville, AR (formerly Arkansas Power Electronics International Inc, acquired last July). In addition, at IMS, the latest GaN-on-SiC RF devices for both military and commercial wireless applications were highlighted by not only Wolfspeed but also Qorvo and NXP. Meanwhile, Ampleon (formerly NXP's RF Power business, acquired by China's Jianguang Asset Management last December) has launched its second generation of GaN-on-SiC RF power transistors.

Regarding gallium nitride on silicon, at PCIM, GaN Systems show-cased customer systems enabled by its transistors (which will now be distributed worldwide by Richardson Electronics). Silicon-focused Intersil unveiled plans to extend its radiation-tolerant portfolio to GaN-on-Si power conversion ICs, via a collaboration with eGaN FET firm Efficient Power Conversion (EPC). Exagan (spun off from Soitec in Grenoble, France in 2014) announced a partnership to commercialize products (following alliances a year ago with Grenoble-based CEA-Leti to speed GaN-on-Si technology integration and with X-FAB Silicon Foundries of Erfurt, Germany to develop a high-volume production process for GaN-on-Si devices on 200mm silicon wafers). Epiwafer foundry IQE of Cardiff, Wales, UK has joined the GaN-on-Si Industrial Affiliation Program of research center imec in Leuven, Belgium, having fabricated 650V power diodes on imec's 200mm silicon pilot line.

Launching its latest GaN-on-Si products (for both wireless base-station and RF energy applications) at IMS was MACOM, which is also suing Germany's Infineon and US-based International Rectifier (acquired by Infineon in 2015) to defend its rights to use the patented GaN-on-Si technology developed by Nitronex (which was acquired by MACOM for \$26m in February 2014). IR collaborated with Nitronex (and hence later MACOM) for many years. MACOM now claims that Infineon has since tried to renegotiate the Nitronex-IR agreements to reduce MACOM's rights (see page 34).

Such developments are given impetus by estimates that GaN revenue for RF applications rose by nearly 50% in 2015, and will rise at a compound average annual growth rate (CAAGR) of 17.5%, more than doubling to nearly \$688.5m in 2020, according to Strategy Analytics (see page 7).

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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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- event calendar and event previews;
- suppliers' directory.

Semiconductor Today (ISSN 1752-2935) is published free of subscription charge

in a digital format 10 times per year by Juno Publishing and Media Solutions Ltd, Suite no. 133, 20 Winchcombe Street, Cheltenham GL52 2LY, UK. See: www.semiconductor-today.com/subscribe.htm

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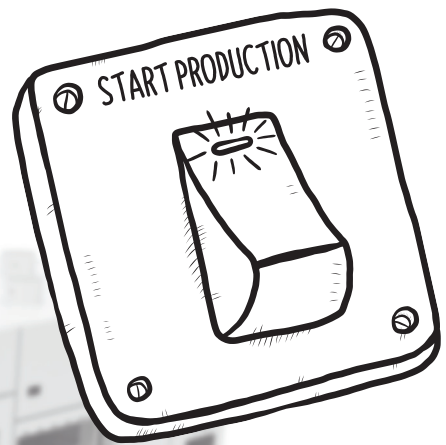
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RF power semi market rising at 15.4% to \$31bn by 2022

The RF power semiconductor market is rising at a compound annual growth rate (CAGR) of 15.4% from \$10.57bn in 2015 to \$31.26bn in 2022, according to the report 'RF Power Semiconductor Market by Product (Power Amplifiers, Passives, Switches, and Duplexers), Material (Silicon, Gallium Nitride, and Gallium Arsenide), Frequency, Application (Consumer, and Aerospace & Defense), and Geography — Global Forecast to 2022' from MarketsandMarkets.

The use of power amplifiers for long-term evolution (LTE) has increased with the growing demand for LTE. The transition to LTE requires significant investment as the core networks also need to be upgraded for the change in wireless standard. This will also drive demand for RF power devices, boosting growth. Another major factor driving growth of the RF power semiconductor market is the increased use

of smartphones.

Key role for RF power amplifiers

By device type, RF power amplifiers are expected to comprise the largest market share, dominating the RF power semiconductor market between 2016 and 2022 due to the increasing adoption of power amplifiers worldwide. The growing preference for wireless connectivity has driven the use of RF power devices in wireless connectivity. RF power amplifiers have applications in sectors such as aerospace & defense, automotive, medical, telecommunications and data communications, and consumer electronics.

Consumer applications held largest market share in 2015

By application, consumer applications are expected to comprise the largest market share, dominating the RF power semiconductor market between 2016 and 2022. The growing use of smartphones

and the demand for faster data rates are the major drivers in the consumer sector. The growth of LTE is also one of the major drivers.

APAC to hold largest market share and grow fastest

The Asia Pacific region (APAC) is expected to hold the largest market share (dominating the market between 2016 and 2022) and to grow the fastest (due to the established electronics industry and the adoption of innovative technologies). The RF power semiconductor market in Asia-Pacific is expected to grow at a high rate in consumer, telecommunications and data communications, and medical sectors, among others. The increasing number of players in the region is further expected to drive growth in APAC.

www.marketsandmarkets.com/Market-Reports/rf-power-semiconductor-market-79671536.html

VLC/Li-Fi market to reach \$101.3bn by 2024

The global VLC/Li-Fi market is expected to grow from just \$454.8m in 2015 to \$101.3bn by 2024, driven by increasing concern over cyber security, according to a report 'Visible Light Communication (VLC)/Light Fidelity (Li-Fi) Market Analysis By Component (LED, Photodetector, Microcontroller), By Application (Retail, Automotive & Transportation, Consumer Electronics, Healthcare, Defense & Security and Aviation) And Segment Forecasts To 2024' by Grand View Research Inc.

The growing need for 'green' technology solutions with low power consumption is encouraging the development of advanced communication systems, notes the report. VLC is a disruptive technology and is hence expected to seize a substantial share of the Wi-Fi market in

the near future. However, adoption is at a nascent stage, with use currently for niche applications. Extensive R&D investment can hence help market players to gain a competitive advantage.

High illumination, longer life and low power consumption of has led to implementation of the LED as a component in LiFi systems. Government promotion of smart LED bulbs in developed countries such as the USA and the UK is expected to provide a massive infrastructure base to VLC system providers.

The increasing application of indoor location-based services embedded with light fixtures in retail shops and hotels is projected to be one of the factors driving revenue growth. Several companies such as GE Lighting and ByteLight Inc as well as Koninklijk Philips N.V.

are deploying VLC installations in supermarkets, which in turn is helping retailers to gather customers' shopping histories by tracking their location details. This is helping the retailers to deliver on-site information tailored to a customer's needs.

Advances in the automotive industry are projected to enhance commuter safety. This is being executed through vehicle-to-vehicle (V2V) and vehicle-to-the-roadside (V2R) communication by installing LEDs in the headlights and taillights of the vehicle. However, high installation and repair costs are projected to obstruct the large-scale implementation of these systems, especially in emerging economies.

www.grandviewresearch.com/industry-analysis/visible-light-communication-market

RF GaN revenue more than doubling to \$688.5m in 2020 China LTE base-station deployments drive commercial applications over 60% of market in 2015, but defense to comprise 50% in 2020

Growing adoption of gallium nitride (GaN) technology in RF applications — coupled with the widespread deployment of LTE base-stations in China — drove an increase in RF GaN revenue of nearly 50% in 2015, according to the Strategy Analytics Advanced Semiconductor Applications (ASA) service report 'RF GaN Market Update: 2015 — 2020'. The growth in the base-station segment pushed the commercial portion of the RF GaN revenue to more than 60% of the total in 2015, with base-station applications specifically comprising nearly 55%.

"The performance advantages of GaN fit nicely with the requirements of new LTE base-station power amplifiers," notes Advanced Semiconductor Applications service director Eric Higham. "Despite an anticipated decline in the base-station power market, we anticipate that GaN revenue will increase as more equipment manufacturers convert to the technology," he adds.

"As countries undertake new platform builds and retrofits, RF GaN revenue in defense applications will grow faster than the overall market, bringing it on par with commercial

RF GaN revenue by 2020," says Asif Anwar, service director, Advanced Defense Systems service. So, driven by emerging system requirements, RF GaN revenue in the defense sector will rise from nearly 38% of the total revenue in 2015 to just short of 50% in 2020.

Continuing growth in base-station and defense applications collectively will drive RF GaN revenue to rise at a compound average annual growth rate (CAAGR) of 17.5%, more than doubling to nearly \$688.5m in 2020, forecasts the report.

www.strategyanalytics.com/

LED market to grow at CAGR of nearly 17% until 2020

The global LED market is expected to rise at a compound annual growth rate (CAGR) of nearly 17% until 2020, according to the report 'Global LED Market 2016–2020' from Technavio. The report covers four application segments — general lighting, backlighting, automotive lighting, and others — which in 2015 comprised 40.25%, 29.01%, 12.99%, and 17.75% of total revenue, respectively.

"China supports the largest LED industry in the world and accounts for close to 30% of the world production, thanks to tax benefits and subsidies provided by the government to its manufacturers," says Asif Gani, one of Technavio's lead analyst for semiconductor equipment research. "The government of India has launched similar projects for promoting energy conservation, and it is likely to draw massive investments into the sector during the forecast period," he adds.

General lighting largest market

LED revenue for general lighting was \$5.76bn in 2015. The residential market is the largest contributor to revenue. Applications of LED lights for residential purposes include lighting in bathrooms, dining rooms,

hallways, and kitchens. LED lights have emerged as the best replacement option for fluorescent lights, and are available in different styles, helping to reduce energy usage.

In the USA, domestic users enjoy federal tax credits (residential energy-efficiency tax credits) for improving the energy efficiency of their homes. Similar incentives formulated by governments across the world will likely boost market growth until 2020.

Backlighting second largest

The LED market in the backlighting segment amounted to \$4.15bn in 2015. The market is witnessing the growing adoption of organic light-emitting diode (OLED) technology in applications such as smartphones and televisions. OLEDs provide high-quality picture content as well as an overall thin frame. Most LED companies are facing challenges in the market due to price wars and the oversupply of LED chips from the Chinese market, which has made companies shift from traditional LEDs to OLEDs.

For example, prominent vendors like Samsung have drawn their focus away from the LED TV market. Similarly, Osram and Lite-On have

found growth opportunities in the infrared (IR) LED market. Osram's third major business segment is IR components, and this is helping the firm to develop comprehensive in-house products such as IR LED and IR laser technology.

LEDs in automotive lighting

The LED market in the automotive lighting segment amounted to \$1.86bn in 2015. Although LED certification for automotive use takes a long time and the entry barrier for the supply chain is high, the profits are attractive, notes Technavio. This will likely draw many companies into this segment. Daytime running lights (DRLs) and high/low-beam headlights are the two major applications in automotive lighting, which are expected to yield high growth during the forecast period. As consumers prefer automotive headlights for their aesthetic appeal and small size, the demand for LEDs is expected to surge. As the prices of LED lights see a further decline, the adoption of automotive LED lighting systems will gradually shift from premium- to medium-priced car models in the future, concludes Technavio.

www.technavio.com

Qorvo reports better-than-expected quarterly results Diversification and highly integrated solutions to drive growth

For its fiscal fourth-quarter 2016 (to 2 April), Qorvo Inc of Greensboro, NC and Hillsboro, OR, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has reported revenue of \$607.1m, down 2% on \$620.7m last quarter and 4% on \$633.9m a year ago, but exceeding guidance of \$600m (and much better than typical seasonality). This reflects increased demand for the firm's highly integrated solutions and a return to growth in the broad target markets for Infrastructure & Defense Products (IDP).

IDP revenue grew further to \$142m, up 9% on \$130m last quarter and 1.4% on \$140m a year ago. "IDP has repositioned its diverse portfolio of businesses to accelerate growth and we've begun to see the benefit of that sharpened focus," notes president & CEO Bob Bruggeworth. In Wireless Infrastructure, revenue grew by over 25% sequentially, indicating a continued recovery to more historic levels in base-station business. "We enjoyed increasing demand for Qorvo's high-frequency and high-power solutions across both infrastructure deployments and advanced defense application."

Mobile Products' revenue fell further to \$465m, down 5% on \$489m last quarter (which had itself fallen 15% sequentially after a late reduction in demand from Qorvo's largest customer) and down 5.7% on \$493m a year ago. However, Qorvo saw content gains in the Samsung Galaxy as well as smartphone program ramps.

"During the March quarter, Qorvo enjoyed strong customer demand for our highly integrated solutions, led by products incorporating our premium filters," notes Bruggeworth, citing the firm's expanding family of tightly integrated compact RF Fusion solutions that "leverage our BAW [bulk acoustic wave] and temperature-compensated SAW [surface acoustic wave] filters, our

low-loss, high-throw-count SOI [silicon-on-insulator] switches, and our high-performance, low-noise amplifiers [LNAs] to deliver performance that's unmatched by competitive solutions". Specifically, in the China market, the deployment of carrier aggregation and the migration to full-mode devices is increasing demand for the firm's RF Flex solutions, BAW-based quadplexers, and a broad variety of antenna control solutions. "We expect these highly integrated solutions will continue to drive our growth," says Bruggeworth. "Looking into calendar 2017, our customers in China are asking us to integrate our premium filters into RF Flex to reduce complexity and enhance smartphone performance as carrier aggregation proliferates and bands and modes are added," he adds. "This strongly favors our broad product portfolio and integration capabilities."

During the quarter, Qorvo had three 10%-or-more customers: the largest (representing the collective demand from multiple subcontractors for this end customer) at about 33% of revenue (down from 37% a year ago), plus China-based telecoms equipment maker Huawei Technologies Co Ltd (a customer for both Mobile Products and Infrastructure & Defense Products), and now joined by South Korea's Samsung (after greater-than-expected growth).

On a non-GAAP basis, gross margin was 50%, down slightly on 50.4% a year ago but recovering from 47.9% last quarter after resolving a yield issue on a few components.

Operating expenses were \$142.9m, up from \$139.8m last quarter but cut from \$150.2m a year ago (and below the forecasted \$150m), reflecting reduced variable compensation expense.

Net income has fallen from \$167.2m (\$1.11. per diluted share) a year ago and \$148m (\$1.03 per diluted share) last quarter to \$142.6m (\$1.04 per diluted share).

Cash flow from operations was \$160.5m. Capital expenditure was \$84.4m (above the forecasted \$60–70m), primarily to address growth and demand for premium filters. Hence free cash flow was \$76.1m. After announcing a \$500m accelerated share repurchase (ASR) program on 17 February, during the quarter Qorvo repurchased about 10 million shares of common stock (although, since the purchase occurred about halfway through the quarter, the impact on the March-quarter share count was about 5 million shares). Overall, total cash and investments hence fell from over \$1bn to \$613m.

Strategic highlights of the quarter are listed as:

- delivering high-volume shipments of BAW-based multiplexers enabling carrier aggregation in 4G LTE devices in support of China-based performance-tier smartphone market;
- securing multiple design wins with a leading China-based smartphone maker, supporting an upcoming premium-tier marquee smartphone platform with high-band, mid-band and low-band RF Fusion, an envelope tracking (ET) power management integrated circuit (PMIC), multiple switches, and multiple antenna control solutions;
- expanding its product portfolio and achieving multiple design wins across antenna control solutions, aperture tuners, impedance tuners, low-noise amplifiers, and discrete switches;
- robust design-win activity in mobile Wi-Fi with RF Fusion integrated front-end modules (iFEMs) and multiple Wi-Fi design wins for automotive applications;
- securing a reference design on Quantenna's QSR10G Wi-Fi solution, which enables the industry's first 10G Wave 3 solution through a True 8x8 MIMO configuration for 5GHz networks with a 4x4 MIMO configuration for 2.4GHz networks; and

► ● expanding the firm's gallium nitride (GaN) product portfolio and capturing large international design wins for products in both defense and commercial (base-station) applications (a market that Qorvo expects will grow at about 25% year-over-year).

"Qorvo's strong financial performance affords us multiple opportunities to invest our cash," says chief financial officer Steve Buhaly:

● Qorvo acquired GreenPeak Technologies of Utrecht, The Netherlands (a provider of ultra-low-power, short-range RF solutions) to expand into the rapidly growing Internet of Things market. "GreenPeak has an expanding business [with markets targeted to grow at about 60% between now and 2020] and customers all over the globe, a great number of who are already purchasing high-power solutions from Qorvo," says Bruggeworth. GreenPeak will become a part of IDP (as part of IDP's ongoing migration from a high single-digit growth rate to a mid-teens growth rate, comparable to the Mobile sector) and will be run by its founder & CEO Cees Links, a "recognized industry leader who was instrumental in the development and adoption of Wi-Fi technology", he adds. "We expect GreenPeak's ultra-low-power RF solutions and SOCs [systems-on-a-chip] for the connected home and Internet of Things to nicely complement IDP's industry-leading portfolio of high-power solutions."

● Qorvo began production of 6" temperature-compensated SAW filters in Florida and 6" SAW filters in Greensboro in order to support a marquee smartphone this calendar year. The firm is also in the final days of qualifying its 8" BAW process in Texas [Richardson]. "We are investing in our BAW capacity to support increasing customer forecasts. Our acquisition of a former Maxim plant just a few miles from our existing operation in Richardson will provide low-cost cleanroom capacity for the next leg of BAW growth," explains Buhaly. "Our BAW-based hexaplexer proto-

types are demonstrating excellent performance, and we've begun to sample a highly integrated RF Fusion that incorporates our hexaplexers. We see strong growth and increasing customer pull for these types of solutions in the coming years," adds Bruggeworth. "We recently acquired cleanroom space near our Richardson [Texas] campus to support customer demand for BAW filters, whether they be in discrete implementations, quadplexers, pentaplexers, hexaplexers, diversity receive modules or other highly integrated RF solutions." The facility is already fully operational, and Qorvo aims to incrementally convert it to BAW in the second half of calendar 2017 to support customer programs. "As the industry's leading supplier of SAW, temp-comp SAW and BAW devices, we are adding capacity to keep pace with the increasing customer demand for our high-, mid- and low-band products. In fact, Qorvo will soon be in production with low-band PADs, mid-band PADs and high-band PADs [power amplifier duplexers] all in premium-tier marquee LTE smartphones," says Bruggeworth.

● Since the beginning of fiscal 2016, Qorvo has returned about \$1.3bn to shareholders through share repurchases. Qorvo expects to repurchase an estimated 0.5 million shares in the June quarter to complete its accelerated share repurchase program. The ASR is part of Qorvo's \$1bn share repurchase program approved in November 2015, of which about \$250m remains authorized for future repurchases.

"We prioritize our uses of cash by investing in our business to drive growth, returning capital to share-

holders through share repurchases, and exploring opportunities for M&A to supplement growth in IDP," notes Bruggeworth.

For fiscal first-quarter 2017 (to end-June 2016), Qorvo expects revenue (excluding GreenPeak) to grow 7% sequentially to \$650m, with Mobile Products up significantly (outside of Qorvo's largest customer), driven primarily by continued content growth in China. Gross margin should be steady at 50%, despite variable compensation expense rising back to normal (driving OpEx back above \$150m), aided by a higher mix of Mobile products seasonally in the June quarter. Diluted EPS should rise to \$1.05.

"I think we have, with that growth rate, a good opportunity to see fiscal year 2017 earnings per share getting pretty close to \$5 per share," says Buhaly. Achieving the firm's long-term model of 55% gross margin will be aided by the migration of BAW filters from 6" to 8" wafers, and SAW and TC-SAW filters from 4" to 6" wafers (which each reduce cost per die by as much as a third). "We'll be consolidating our GaAs production into a single foundry over the next year and a half, and insourcing assembling & test for part of our Mobile business (the part that used to belong to TriQuint) — each of these have a significant impact," says Buhaly. "These will occur throughout the year, but the financial impact will be mostly in fiscal 2018," he adds. "We have a fair amount of fixed costs, and we will see scale benefits as we continue to grow to the market at what we expect will be a 10–15% rate."

www.qorvo.com

Qorvo has appointed Mark J. Murphy as chief financial officer, reporting to president & CEO Bob Bruggeworth. He succeeds Steven J. Buhaly, who previously announced his retirement from the firm in 2016 and will remain as an advisor until 31 July.

"Mark brings proven public company finance and operating expertise from several large and complex global companies and will play a critical role in helping us execute our strategic vision for Qorvo's growth," says Bruggeworth.

Qorvo's new small-cell PAs expand capacity and enhance efficiency of LTE/LTE-Advanced networks

Qorvo Inc of Greensboro, NC and Hillsboro, OR, USA (which provides core technologies and RF solutions for mobile, infrastructure and aerospace/defense applications) has launched a family of multi-stage power amplifiers (PAs) for small-cell base-stations to improve connectivity, expand capacity and minimize disruptions on LTE/LTE-Advanced networks. The eight new PAs cover 3GPP bands between 1.8–2.4GHz and are pin-for-pin compatible.

Qorvo's newest family of small-cell PAs targets distributed antenna systems (DAS). The firm says that systems using these PAs can eliminate the need for linearization or digital pre-distortion (DPD) correction, reducing system complexity.

"Multi-mode, multi-band small-cell base-stations pose significant RF challenges in terms of size, power-added efficiency, and co-existence between WLAN and cellular frequency bands," says Sumit Tomar, general manager of Qorvo's Wire-

less Infrastructure business unit. "Qorvo has worked closely with customers to address these RF challenges to create a portfolio of PAs, low-noise amplifiers (LNAs), filters and duplexers to enable carrier aggregation in small-cell base-stations," he adds.

"While mobile operators continue to deploy outdoor macro-cell sites to increase capacity, the wireless industry is transitioning to in-building wireless solutions," comments Earl Lum, president of EJM Wireless Research LLC. "LTE/LTE-Advanced drives the need to extend wireless signal coverage indoors for corporate offices, hospitals, shopping malls, and other enterprise clients," he adds. "Distributed antenna systems and carrier-grade OEM small-cell solutions like Ericsson Radio Dot, Huawei LampSite, Nokia Flexi Zone and ZTE's Qcell are key technologies that address the ever growing in-building wireless coverage/capacity problem."

Qorvo's multi-stage PAs integrate matching in a low-cost surface-mount package to allow for compact system design. With linear performance of -47dBc ACLR (adjacent channel power ratio) using a 20MHz LTE signal, the TQP92xx product family (1.805–1.88GHz band 3 TQP9218, 1.93–2.0GHz band 2/25 QPA9219, 2.01–2.17GHz band 1/4/10/34/66 TQP9221 and 2.3–2.4GHz band 30/40 TQP9224) provides 24dBm average linear power, and the TQP94xx family (1.805–1.88GHz band 3 TQP9418, 1.93–2.0GHz band 2/25 QPA9419, 2.01–2.17GHz band 1/4/10/34/66 TQP9421 and 2.3–2.4GHz band 30/40 TQP9424) provides 27dBm average linear power. All listed products are in production and available now.

Qorvo's small-cell products were showcased at the IEEE International Microwave Symposium (IMS 2016) in San Francisco (22–27 May).

www.qorvo.com

Qorvo unveils ZigBee 3.0 software development kit

At the CES Asia 2016 consumer electronics show in Shanghai (11–13 May), Qorvo announced the availability of a ZigBee 3.0 software development kit (SDK) for smart home gateways that incorporate the new GP712 radio communication controller chip from GreenPeak Technologies (now the Low Power Wireless business unit of Qorvo, after the firm's acquisition last month). The ZigBee 3.0 SDK allows application developers to program a GP712-equipped gateway to communicate seamlessly with various sensors, controllers and systems within the smart home.

The ZigBee 3.0 SDK includes simplified software development models (APIs) that enable quick development of GP712-equipped gateway products as part of complete, end-to-end systems for the

smart home. The SDK architecture is fully scalable and flexible, enabling smooth integration of upcoming standards such as Thread. When combined with the GP712, the SDK allows gateway manufacturers to remain protocol agnostic and support multiple communication stacks in a single device.

"Our new SDK allows application developers to quickly build a ZigBee 3.0-enabled gateway that functions as the heart of the integrated smart home," says GreenPeak's founder & former CEO Cees Links (now general manager of Qorvo's Low Power Wireless business unit). "GP712-enabled gateways serve as the central point for information gathering and routing of communication between sensors, controllers and smart phone apps," he adds. "Smart services like home monitor-

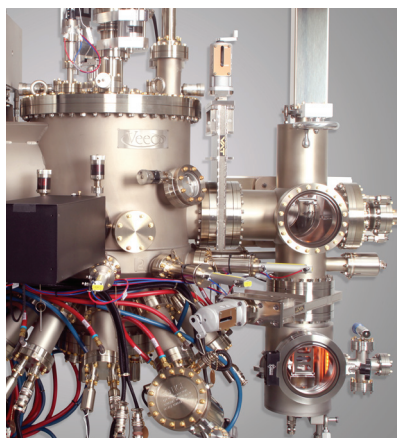
ing, senior lifestyle, HVAC and lighting that use different communication standards will be around for some time. This SDK adds protocol intelligence to the gateway, enabling it to communicate simultaneously using a variety of technologies, and helps ensure compatibility with current and future standards...

This important addition to our portfolio will allow the smart home market to continue to grow in a future-proof way."

The GP712 radio communication controller chip enables optimal coexistence of multiple smart home systems based on the IEEE 802.15.4 standard, supporting ZigBee 3.0, Thread, ZigBee RF4CE and ZigBee Green Power in a single radio. True multi-channel support enables the protocol stacks to seamlessly communicate on different channels.

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Skyworks launches amplifier family for small-cell infrastructure market, targeting 5G

Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) has launched a suite of high-performance amplifiers specifically addressing the rapidly growing small-cell infrastructure market.

As mobile devices and applications supporting the Internet of Things (IoT) transition to 5G technologies, there will be an immediate and substantial increase in network load and an unprecedented deployment of small-cell systems to help improve network performance, says Skyworks. The firm's newest products hence provide infrastructure OEMs with an entire portfolio of solutions for next-generation global cellular networks that address multiple bands.

The new SKY66184-11, SKY66185-11 and SKY66186-11 are compact devices designed for

FDD/TDD small-cell base-stations and cover major LTE bands. High gain and high linearity for optimal performance with what is claimed to be excellent output return loss make them easy to use and minimize the number of external components. The solutions include an integrated coupler for output power monitoring and only require a single 3.3V power supply.

"Skyworks is enabling small-cell infrastructure OEMs to radically simplify their system architecture," says David Stasey, VP & general manager of Diversified Analog Solutions for Skyworks.

"Specifically, our innovative devices meet stringent band requirements in the global

The small-cell market is estimated to grow from \$1bn in 2015 to \$6.7bn by 2020

landscape and provide our customers with unmatched amplifier efficiency and a lower bill of materials," he claims. "As a result, service providers and consumers can enjoy better network efficiency and lower costs."

According to a February estimate by the Small Cell Forum, the global small-cell market is estimated to grow from \$1bn in annual equipment sales in 2015 to \$6.7bn by 2020, with small cells accounting for 85% of the radio access network (RAN) hardware in a mobile operator's network.

Skyworks showcased its new products and broad market solutions portfolio at the IEEE International Microwave Symposium (IMS 2016) in San Francisco (24–26 May), including giving live demonstrations of the SKY66184-11.

www.skyworksinc.com/Products/969/Amplifiers_for_Small_Cell_Applications

Front-end modules powering Iotera's GPS-enabled tracking devices

Skyworks' front-end modules are being used by Iotera Inc of Redwood City, CA, USA, which provides wireless technologies for Internet of Things (IoT) applications, across its family of IOTA GPS-enabled tracking products. Initially deployed for tracking pets, the devices are now being utilized to protect vehicles, bicycles and other personal items.

Tracking is becoming an increasingly important opportunity as the Internet of Things explosion proliferates and encompasses a wide range of new and previously unimagined applications ranging from smart meters and connected vehicles, to security systems and industrial uses. Skyworks says that its connectivity solutions extend the range and maximize battery life in these types of devices.

"Skyworks is intensely focused on enabling a broad range of applications spanning the Internet of

Things," says John O'Neill, VP of broad markets. "This partnership is yet another example of how Skyworks is leveraging its broad product portfolio and systems expertise to create a first-mover advantage for new applications," he adds.

"Skyworks has been a vital partner as we developed our proprietary platform," notes Iotera's CEO Ben Wild. "Their solutions have enabled us to build the world's smallest, real-time GPS tracking devices with industry-leading battery life."

Iotera's IOTA GPS-enabled trackers use Skyworks' SE2435L, a highly integrated RF front-end module designed for high-power industrial, scientific & medical (ISM)-band applications. Other applications include smart meters, in-home appliances and smart thermostats. The device includes an integrated power amplifier,

a low-noise amplifier (LNA) and antenna switching with transmit/receive diversity function.

Long-range device tracking without the need for monthly fees is quickly growing in popularity as people become aware of these products and services. According to an April Global Market Insights report, the consumer global pet-wearable market alone is expected to exceed \$2bn by 2023, driven largely by the rising demand for remote monitoring and tracking of pets. More broadly, IDC is expecting global wearable device shipments to grow by 128% from 76.1 million units in 2015 to 173.4 million by 2019. In the industrial segment, General Electric estimates connected industrial machinery will add \$10–15 trillion to the global GDP within the next 20 years.

www.iotera.com
www.skyworksinc.com/Product/938/SE2435L

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Skyworks' quarterly revenue up slightly year-on-year OpEx control grows margin and earnings in seasonally down quarter

For fiscal second-quarter 2016 (to 1 April), Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) has reported revenue of \$775.1m, down 16% on \$926.8m last quarter but up 1.7% on \$762.1m a year ago.

As a proportion of total revenue, power amplifiers (PAs) comprised 17%, integrated mobile systems (IMS) 58%, and broad markets 25%. "We saw healthy growth in both integrated mobile systems and broad markets," says chief financial officer & executive VP Donald W. Palette. "Our broad markets portfolio grew over 18% year-over-year."

On a non-GAAP basis, gross margin was 50.8%, down from 51.4% last quarter but up on 46.7% a year ago.

Operating expenses were less than the expected \$109.5m, falling back to \$108.6m (\$73.1m on R&D and \$35.5m on SG&A).

"Our gross margin initiatives and operating expense discipline enabled us to both expand margins and earnings in a seasonally down quarter," notes chairman & CEO David J. Aldrich.

Operating income was \$285m (operating margin of 36.8%), down from \$366.6m (margin of 39.6%) last quarter but up on \$258.9m (operating margin of 34%) a year ago. Likewise, net income was \$242.3m (\$1.25 per diluted share, \$0.01 better than guidance), down on \$311.2m (\$1.60 per diluted share) last quarter but up on \$224.6m (\$1.15 per diluted share) a year ago.

Cash flow generated from operations was \$154.5m. Skyworks invested \$37m in capital expenditure (cut from \$79.5m last quarter), with depreciation of \$53.6m. The firm also repurchased 2 million shares of its common stock at an average price of just over \$67.50 a share. During the quarter, cash and cash equivalents hence fell from \$1233m

to \$1177m (while Skyworks has no debt). "Given our confidence in our long-term business trends, we expect to continue to be very active with our share repurchase activity at current levels," says Palette.

Also, Skyworks' board of directors has declared a cash dividend of \$0.26 per share of common stock, payable on 2 June to stockholders of record at the close of business on 12 May.

"Driven by our increasing diversification and differentiated product portfolio, we delivered another solid financial performance for the second fiscal quarter of 2016, posting year-over-year growth in revenue, profitability and earnings, even as we navigated through a combination of inventory adjustments and forecast reductions at one of our major customers," summarizes Aldrich.

Business highlights cited during fiscal second-quarter 2016 include the following:

- delivering the world's first front-end solution optimized for LTE Cat-M (machine-to-machine) applications;
- partnering with leading infrastructure provider to deliver the first commercial Gigabit LTE system;
- unveiling SkyBlue (technology that enhances RF power capability and efficiency in front-end solutions);
- powering Huawei's P9 flagship LTE platform with 10 solutions;
- expanding the list of OEMs leveraging SkyOne integrated platform;
- increasing blended content by 20% across Samsung's Galaxy S7 smartphones;
- supporting next-generation launches at Lenovo, OPPO, Vivo, Xiaomi and ZTE;
- powering Cisco's large enterprise access point system with 16 analog solutions;
- enabling Iotera's GPS industrial tracking devices; and
- leveraging connectivity modules to power Arris and Liberty Global set-top boxes.

"Looking ahead, we are well positioned to continue capitalizing on the powerful connectivity and Internet of Things trends as we deliver higher-value solutions with superior performance and functionality across new markets, applications and customers," says Aldrich.

"We continue to expect IMS to remain our strongest growth segment, followed by broad markets, while power amplifier products continue to decline as a percentage of our revenue as the market shifts towards higher-value integrated solutions," says Palette.

"During the June quarter we expect to be impacted by an inventory adjustment at a large customer, partially offset with gains across broad markets and crisp operational execution," says Palette.

Hence, for its fiscal third-quarter 2016, Skyworks expects revenue to fall to \$750m (down on \$810m a year previously), with softness at the firm's largest customer being partially offset by strong year-on-year growth at Samsung, in China, and across the broad markets. Nevertheless, gross margin should rise to 51%. "Our strong gross margin outlook in the face of current market conditions highlights the benefits of our higher-value integrated systems, along with our scale and flexible manufacturing operations," notes Palette. Operating expenses should be roughly level at \$108.5m. Diluted earnings per share should fall to \$1.21.

"Looking ahead, we see opportunity for additional margin improvement, as we continue to ramp our custom solutions and leverage our recent capital investments," says Palette. "We recommend modeling a 60% incremental gross margin off of the third-quarter baseline," he adds. "We continue to target a goal of at least 53% gross margin for the company, and have a number of initiatives in place to accelerate our progress towards achieving this."

www.skyworksinc.com

Skyworks names Liam Griffin as chief executive officer; David Aldrich to become executive chairman

Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) says that its board of directors has appointed president Liam K. Griffin as CEO. Griffin was also elected to the board. David J. Aldrich, CEO since 2000, will assume the newly established role of executive chairman and continue to serve as chairman of the board.

Skyworks says that it has substantially outpaced the broader semiconductor market, growing revenue at a 25% annual rate from \$1.1bn in fiscal 2010 to over \$3.2bn in fiscal 2015. In parallel, the firm has maintained a leadership succession planning process to ensure that the organization continues to follow this path in future.

"Liam Griffin has become Skyworks' chief executive officer as we capitalize on the enormous global mobility and Internet of Things opportunities ahead of us," says Aldrich. "Liam has a demonstrated track record of success, and our proven partnership over 15 years makes him my logical successor. He is a highly energetic and motivating leader who is widely respected

amongst our customers, partners, suppliers and investors as well as the entire Skyworks employee base," he adds. "Liam has the unique ability to translate challenging operational plans into market outperformance through his intense focus and unyielding tenacity."

As executive chairman, Aldrich will support the management transition and work with the leadership team to develop long-term strategy. Aldrich has served as CEO of Skyworks and its predecessor Alpha Industries since 2000. Annual revenue grew from \$126m in 1999, when he became president & CEO, to over \$3.2bn as of fiscal 2015, while operating income increased 7477%.

Griffin joined Skyworks in August 2001 as head of sales & marketing. His responsibilities have continuously expanded with his leadership of Skyworks' business units, R&D efforts and operations.

Aldrich will support the management transition and work with the leadership team to develop long-term strategy

In 2011, he was promoted to executive VP and in May 2014 was named president. Griffin has been a key architect of the strategy to cement the firm's position in mobile communications while diversifying across the Internet of Things.

Before joining Skyworks, Griffin was VP of worldwide sales at Dover Corp and held product management and process engineering positions at AT&T's Microelectronics and Network Systems businesses. Griffin received a Bachelor of Science degree in mechanical engineering from the University of Massachusetts and a Master of Business Administration degree from Boston University.

"Over the past 17 years, Dave Aldrich's vision and leadership have built Skyworks into one of the largest and fastest-growing semiconductor companies in the world," comments Griffin. "We have created an awesome platform for analog, mixed-signal and RF product integration leveraging our OEM relationships and operational scale," he adds. "I look forward to continuing to work closely with Dave and building upon all of his achievements."

www.skyworksinc.com

Skyworks adds next-generation Wi-Fi front-end modules to extend connectivity range and boost smartphone performance

Skyworks has expanded its mobile connectivity product portfolio by adding several new wireless networking solutions. The new front-end modules leverage proprietary design techniques to extend the range of connected devices and improve overall system performance — in a much smaller footprint than alternative options available currently on the market, it is claimed.

According to Cisco VNI Mobile, smartphones and phablets are expected to comprise nearly 50% of all global devices by 2020, with more than half of all traffic from

these platforms being offloaded to fixed networks by Wi-Fi. OEMs are hence seeking high-performance solutions that can manage this amount of data and deliver a seamless consumer experience.

The new SKY85312-11 and SKY85720-11 contain integrated power amplifiers and low-noise amplifiers, enhancing transmit power and improving system-on-a-chip receiver sensitivity, respectively. Integrated switches and power detectors also eliminate the need for external components and enable power setting without external couplers.

"Skyworks' next-generation Wi-Fi front-end modules provide a highly integrated, turnkey solution for smartphones and Internet of Things applications," says Bill Vaillancourt, VP & general manager of Mobile Connectivity for Skyworks. "Given our systems expertise, we simplify increasingly complex front-end requirements for our customers and, in turn, enable unprecedented connectivity with gains in speed and range."

www.skyworksinc.com/Product/3160/SKY85312-11

www.skyworksinc.com/Product/3161/SKY85720-11

TowerJazz begins mass production of integrated SiGe-based ‘front-end module on a chip’ RF platform tailored for Internet of Things

Specialty foundry TowerJazz (which has fabrication plants at Tower Semiconductor Ltd in Migdal Haemek, Israel, and at its subsidiaries Jazz Semiconductor Inc in Newport Beach, CA, USA and TowerJazz Japan Ltd) has announced volume production of a new RF technology capable of integrating a wireless front-end module (FEM) on a single chip, tailored to meet Internet of Things (IoT) applications. Analysts estimate that the number of IoT connected devices will grow at 15–20% annually, reaching up to 30 billion units by 2020. McKinsey Global Institute recently estimated that IoT could generate up to \$11 trillion by 2025.

The TowerJazz process enables integration of power amplifiers (PAs), switches, and low-noise amplifiers as well as CMOS digital and power control on a single die. TowerJazz is delivering this product now for smartphones, tablets and wearables, and the technology also meets the more universal requirements of IoT applications by providing what are claimed to be cost, power, perform-

ance and form-factor benefits versus competing solutions.

As an example, TowerJazz has partnered with Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) to deliver a first-of-its-kind integrated wireless FEM using this technology. “We are pleased that our long partnership with TowerJazz on SiGe BiCMOS for PA-based products is now in volume production for key customers of Skyworks,” says Bill Vaillancourt, general manager & VP Skyworks Connectivity Solutions.

TowerJazz’s new RF technology includes a 0.18 μ m silicon germanium (SiGe) PA device with what is claimed to be best-in-class silicon-based performance, a low $R_{on}-C_{off}$ switch device, a SiGe low-noise amplifier (LNA), 5V CMOS for power control, 0.18 μ m CMOS for integrating MIPI or other digital content as well as thick copper (Cu) metal layers for low-loss inductors and matching components. By offering all active components typically required for a

wireless FEM, the technology enables a new family of products that can integrate multiple communication standards (WiFi, Bluetooth, 802.15.4 or NFC) that form the backbone of the IoT fabric today onto the same chip.

“This new technology complements our existing suite of SiGe PA and RF SOI [silicon-on-insulator] switch technology offerings and provides customers new architectural options by enabling the combination of these elements on a single die while offering best-in-class silicon-based PA performance,” says Marco Racanelli, senior VP & general manager of RF/High Performance Analog and US Aerospace & Defense Business Groups, and Newport Beach Site Manager, TowerJazz.

TowerJazz exhibited and demonstrated its process technologies for specialty IC manufacturing at IEEE’s International Microwave Symposium (IMS 2016) in San Francisco (22–27 May).

www.ims2016.org

www.towerjazz.com

www.skyworksinc.com

Analog Devices’ silicon SPDT switch cuts size and power consumption in cellular radio RF front ends

Analog Devices Inc (ADI) of Norwood, MA, USA (which provides ICs for analog and digital signal processing applications) has launched a high-power (44W peak) single-pole, double-throw (SPDT) silicon switch that enables designers to reduce hardware size and bias power consumption in cellular radio systems.

As the next generation of communications infrastructure trends toward higher data capacity, cellular radio front-ends must scale down in size and provide faster speeds to meet the demands of increased data usage, notes the firm.

Housed in a small 4mm x 4mm LFCSP SMT package, the new ADRF5130 switch meets these requirements through a high level of integration that eliminates the need for external components, says ADI. The switch also reduces power consumption to more efficient levels by operating on a single low-voltage supply with low current consumption compared with existing pin-diode-based solutions, it is claimed.

The ADRF5130 is specified at 0.7–3.5GHz frequency band with typical 0.6dB insertion-loss, high isolation of 50dB, linearity of +68dBm and peak power handling of 44W

during continuous operation mode. The device features robust 2000V electro-static-discharge protection on all device pins. It also incorporates a fast CMOS-compatible control interface with switching time of less than 1 μ s. Also, a symmetrical circuit architecture allows the RF inputs to be used interchangeably in high-power applications.

The ADRF5130BCPZ is available as samples now, and will be in full production in July, priced at \$10.04 each in 1000-unit quantities. The ADRF5130-EVAL-Z evaluation board will be priced at \$99.

www.analog.com

Mouser to distribute Guerrilla RF's products globally

Mouser Electronics Inc has signed an exclusive global distribution deal with Guerrilla RF Inc of Greensboro, NC, USA, which provides monolithic microwave integrated circuits (MMICs) to wireless infrastructure original equipment manufacturers.

Guerrilla's RF product line comprises four series of low-noise amplifiers.

The GRF205x series ultra-LNAs claim exceptional noise figure, gain and linearity, and support a wide range of LNA applications. The devices' flexible application circuits result in simple, low-cost implementations that allow for optimal efficiency and reuse, says Guerrilla RF.

The GRF2501 high-gain ultra-LNA is designed for IEEE 802.11a/n/ac/p applications in the 5GHz band (4.9–6.0GHz). The device exhibits de-embedded noise figures (NFs) as low as 0.80dB across the band. It uses a single supply voltage of 2.7–5.0V, with typical bias condition of 3.3V and 12mA. The GRF2505 is

a broadband ultra-low-noise linear amplifier for demanding 802.11ac and wireless backhaul LNA and power amplifier (PA) driver applications. It exhibits what is claimed to be outstanding broadband NF, linearity and return losses over 4.0–6.0GHz with a single match. The GRF2505 operates from a single positive supply of 1.8–5.0V with a selectable I_{DDQ} range of 20–70mA for optimal efficiency and linearity. It is internally matched to 50Ω at the input and output ports, requiring only seven external resistor, inductor and capacitor (RLC) components.

The GRF400x series of broadband low-noise gain blocks is designed for small-cell, wireless infrastructures. The devices exhibit what is claimed to be outstanding RF performance over multiple GHz bandwidths with little or no external RF matching, with supply voltages of 1.8–5.0V. Bias currents can be set independently from V_{dd} , allowing a linear

solution with optimal efficiency. The amplifiers suit applications requiring first- or second-stage LNA, or can be used as linear transmit drivers. The GRF4042 is a high-performance amplifier that offers bypass functionality and incorporates Guerrilla Armor technology, which provides high off-state isolation even in the presence of high-RF input powers. This isolation is especially useful in TDD systems in which significant transmitter RF power can leak into the transceiver receive path.

The GRF50x0 Power LNA series consists of high-power, low-noise devices that, with simple matching, can be tuned to cover 100MHz up to 6.0GHz (100MHz to 3.8GHz for the GRF5040) with fractional bandwidths greater than 20%. Devices are suitable for multi-stage LNA applications, microwave backhaul, and distributed antenna systems.

<http://guerrilla-rf.com>

www.mouser.com/guerrilla-rf

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www.WaferWorld.com

MACOM samples new E-band Tx and Rx modules to accelerate evolution to higher-capacity backhaul

MACOM Technology Solutions Holdings Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) has begun sample shipments of its MAMF-011057 and the MADC-011014 highly integrated E-band transceiver (Tx) and receiver (Rx) modules, which are designed to meet the needs of the emerging wideband cellular backhaul and 5G millimeter-wave market.

Helping to accelerate the evolution to higher-capacity backhaul, MACOM says that its surface-mountable E-band Tx and Rx modules simplify the design and manufacturing of low-cost E-band point-to-point radios. The firm's E-band module solution was featured in a 5G millimeter-wave product demonstration at the IEEE International Microwave Symposium (IMS 2016) in San Francisco (24–27 May).

The MAMF-011057 is a transceiver featuring a balanced IR mixer, x8 LO multiplier, envelope detector, RF buffer amplifier, RF power amplifier and output power detector in a small-form-factor surface-mount

module. The module operates at 71–86GHz and is designed to be used in direct conversion applications. The output of the Tx module is a WR12 interface for ease of use.

The MADC-011014 is a receiver module integrating a balanced IR mixer with a x8 LO multiplier and low-noise amplifier (LNA) into a small-form-factor surface-mount module. The device operates at 71–86GHz and is designed to be used in direct down-conversion applications. The RF input to the Rx module is a WR12 interface for ease of use.

MACOM complements these E-band modules with what it claims are best-in-class phase-noise voltage-controlled oscillators (VCOs)

Helping to accelerate the evolution to higher-capacity backhaul, MACOM says that its surface-mountable E-band Tx and Rx modules simplify the design and manufacturing of low-cost E-band point-to-point radios

matched to the module requirements for a total solution.

MACOM reckons that these modules simplify the design of wireless backhaul E-band radios and that their high integration levels help to reduce overall E-band radio bill-of-materials (BOM) costs. The firm hence anticipates that the modules will play a key role in lowering E-band cost of ownership and growing the footprint of E-band radios within the network operator wireless backhaul space.

"Market and customer feedback on our initial samples of the E-band Tx and Rx modules has been very positive, as evidenced by multiple design wins at tier-1 OEMs," says Preet Virk, senior VP & general manager, Carrier Networks, MACOM. "The E-band market is primed for explosive growth and our innovative modules, offering best-in-class performance, are seen as a key component enabling the viable establishment of E-band as a high-capacity solution for cellular backhaul," he adds. "We look forward to several production ramps expected to commence in late 2016."

www.macom.com/wirelessinfra

MACOM adds 3GHz two-stage, 1W driver amplifier to MMIC portfolio

MACOM Technology Solutions Holdings Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) has launched the MAAP-011232, a two-stage, 1W driver amplifier featuring gain shut off and operating from 100MHz to 3GHz. The device is suited to both driver and power requirements across a broad range of applications, including land-mobile-radio, military communications, sensors, telemetry, test & measurement and satellite communications.

The MAAP-011232 features a

typical gain of 23dB and up 40% power-added efficiency. The device can be operated at a drain supply voltage between 5V and 9V and consumes less than 300mA at a maximum output power of 1W. The MAAP-011232 is fully matched while operating in the 100MHz to 1GHz frequency range and can be tuned with input matched to perform up to 3GHz. The device is offered in a 3mm 16-lead PQFN plastic package.

"The MAAP-011232 was designed to offer customers excellent power and drive performance over a broad frequency range," says Paul Beasley, product manager,

RF & Microwave. "The high gain and enable function can replace the need for additional gain blocks and/or attenuators in customers' systems, which makes the device an ideal candidate for applications that require a small footprint and surface-mount solution," Beasley adds.

Production quantities and samples of MAAP-011232 are available from stock. MACOM featured its MMIC portfolio at IEEE's International Microwave Symposium (IMS) 2016 in San Francisco (22–27 May).

www.macom.com/products/product-detail/MAAP-011232

X-Microwave adds Peregrine's RF products to online simulation and prototype system

In a newly announced collaboration, the RF products of Peregrine Semiconductor Corp of San Diego, CA, USA — a fabless provider of radio-frequency integrated circuits (RFICs) based on silicon-on-insulator (SOI) — will be added to the online simulation tool and hardware prototyping system of modular system design firm X-Microwave LLC of Round Rock, TX, USA.

X-Microwave's modular building-block system X-MWsystem simplifies the modular design process and enables RF engineers to easily simulate and prototype RF and microwave circuits. To kick off the new collaboration, 16 Peregrine products are being added to the X-Microwave system as drop-in X-MWblock components.

At the heart of X-Microwave's system is an X-MWblock portfolio of hundreds of physically compatible, drop-in or drop-on components,

which are highly characterized and modeled with X-parameters and S-parameters at the system block level. To create a modular design, X-Microwave provides a free, non-linear online simulation tool that leverages Keysight's Genesys Spectrasys engine. After simulation, X-MWblock drop-in components are used to prototype systems through X-Microwave's prototype station for testing, aligning and configuring integrated microwave assemblies up to 50GHz. Finally, the same X-MWblock components can be moved from the prototype station directly to machined housings for production hardware, eliminating the need for custom layouts.

"From a concept to final production hardware, X-Microwave streamlines the complete design process," says X-Microwave's president & CEO John Richardson. "Peregrine's impressive RF product portfolio is an

important addition to the X-Microwave building-block system," he adds. "Our users will benefit from the ability to drop in Peregrine's products into their X-Microwave-based modular designs."

The Peregrine products now available in the X-Microwave system include RF switches, digital step attenuators (DSAs), tuning control switches, power limiters, and monolithic phase and amplitude controllers (MPACs).

"X-Microwave offers a solution for RF engineers who need a sophisticated evaluation platform for system design simulations and quick prototyping," comments Peregrine's director of marketing Kinana Hussain. "X-Microwave's innovative system provides another avenue for our customers to evaluate our industry-leading RF products, especially in higher frequencies."

www.psemi.com

Anokiwave extends SATCOM Core IC family to Ka-band Tx in quad or octal element configuration

Anokiwave Inc of San Diego, CA, USA, which provides highly integrated silicon core chips and III-V front-end integrated circuits for millimeter-wave (mmW) markets and active electronically scanned array (AESA)-based terminals, has launched the Ka-band Tx Core IC family for earth terminal SATCOM applications. Coupled with Anokiwave's K-band SATCOM Rx ICs, the Tx IC family provide a complete K/Ka-band earth terminal solution enabling auto-alignment of fixed earth terminals and auto pointing for SATCOM-on-the-move applications using GEO satellite space assets.

Operating at 27.5–30.0GHz, the AWMF-0109 supports four dual-polarization elements with full programmable polarization flexibility and 5-bit phase and gain control,

while the AWMF-0113 supports eight single-polarization elements. Each device provides 22dB of gain per channel with +12dBm output power per polarization. Additional features include system-controlled gain compensation over temperature and temperature reporting via the serial control interface bus. Anokiwave's patent-pending IP blocks implemented in silicon technology enable planar antenna design at K- and Ka-band with reduced system size, weight and cost.

"The Ka-band Tx IC family is an important addition to our product offering for SATCOM and we believe this solution will set a new standard in the industry for AESA multi-element beam-forming SATCOM ICs," says CEO Robert Donahue. "Affordable AESAs are critical to enable rapidly emerging SATCOM-on-the-

move terminals that leverage the ever increasing capacity of GEO satellites."

The AWMF-0109 is a highly integrated transmit IC in a commercial QFN-style surface-mount plastic package with dimensions of 6mm x 6mm x 0.9mm, easily fitting within the typical 5mm lattice spacing at 30GHz. The IC is controlled through a 5-wire serial-to-parallel interface (SPI) bus and has ESD protection on all pins.

Anokiwave offers innovator kits and evaluation kits for early access to the technology. Kits include boards with the Ka-band IC, a USB-SPI interface module with drivers, and all required cables. Pilot production deliveries are available in June, with full production quantities available in fourth-quarter 2016.

www.anokiwave.com

Purdue develops high-efficiency SOI CMOS power amplifier for 5G cell phones and next-generation radar

Efficiency of 40% comparable to GaAs-based amplifiers

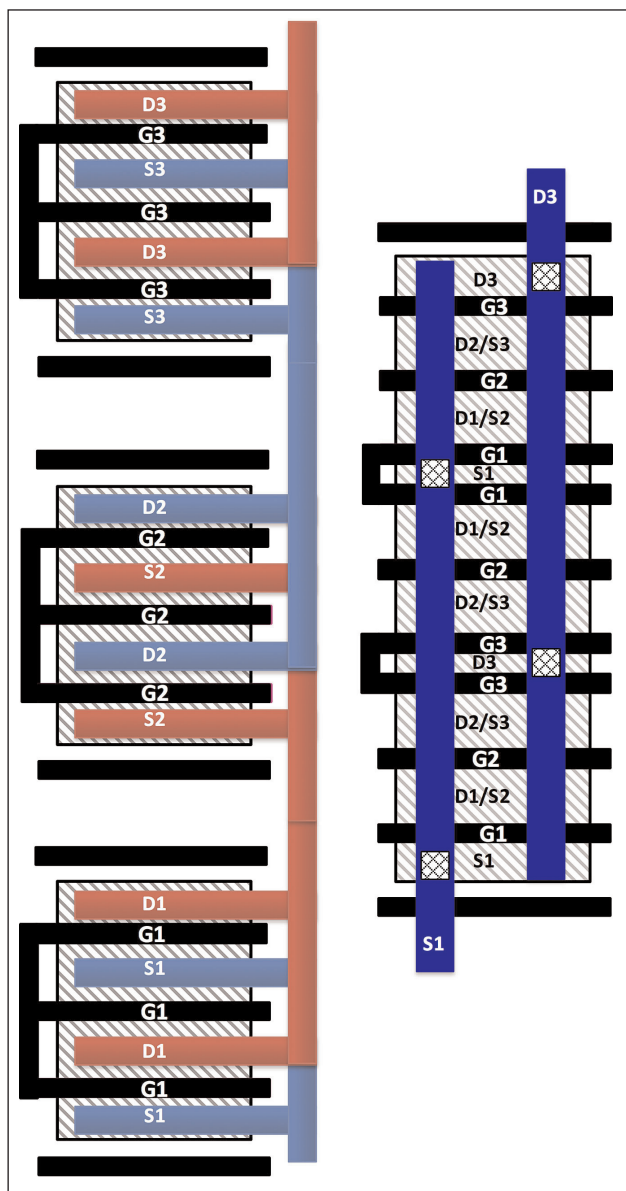
A new highly efficient power amplifier (PA) based on silicon-on-insulator (SOI) CMOS could help to make possible next-generation cell phones, low-cost collision-avoidance radar for cars and lightweight micro-satellites for communications, say researchers at Purdue University.

Fifth-generation (5G) mobile devices (expected around 2019) will require improved power amplifiers operating at very high frequencies. The new phones will be designed to download and transmit data and videos faster than existing phones, provide better coverage, consume less power and meet the needs of an emerging Internet of Things in which everyday objects have network connectivity, allowing them to send and receive data.

Because existing cell-phone power amplifiers for transmitting signals are made of gallium arsenide (GaAs), they cannot be integrated into the phone's silicon-based complementary metal-oxide-semiconductor (CMOS) technology. Since the new amplifier design is CMOS-based, it could allow researchers to integrate the power amplifier with the phone's electronic chip, reducing manufacturing costs and power consumption while boosting performance.

"Silicon is much less expensive than gallium arsenide, more reliable and has a longer lifespan, and if you have everything on one chip it's also easier to test and maintain," says Saeed Mohammadi, associate professor of electrical and computer engineering at Purdue University. "We have developed the highest-efficiency CMOS power amplifier in the frequency range needed for 5G cell phones and next-generation radars." The amplifier achieves an efficiency of 40%, comparable to amplifiers made of gallium arsenide, it is reckoned.

Findings are detailed in two papers presented on 24 May at the IEEE International Microwave Symposium



Standard layout of transistors in cell-phone power amplifiers (left) and new highly efficient amplifier design (right). The new design could help to make possible next-generation cell phones, low-cost collision-avoidance radar for cars, and lightweight microsatellites for communications.

(IMS2016) in San Francisco, authored by former doctoral student Sultan R. Helmi together with Mohammadi. They also authored another paper with former doctoral student Jing-Hwa Chen, to appear in an issue of IEEE Transactions on Microwave Theory and Techniques.

The researchers created the new type of amplifier using silicon-on-

insulator (SOI) CMOS technology. The new amplifier design has several silicon transistors stacked together and reduces the number of metal interconnections normally needed between transistors, reducing parasitic capacitance (which hinders performance and can lead to damage to electronic circuits). "We have merged transistors, so we are using less metallization around the device, and that way we have reduced the capacitance and can achieve higher efficiencies," says Mohammadi. "We are trying to eliminate metallization between transistors."

The new amplifiers could also bring about low-cost collision-avoidance radars for cars and electronics for lightweight communications microsatellites. Specifically, the CMOS amplifiers could allow researchers to design microsatellites that are one-hundredth the weight of existing technology.

The research was funded partially by the US Defense Advanced Research Projects Agency (DARPA), and three US patents related to the amplifier have been issued.

The researchers are currently working on a new version of the amplifier that is twice as powerful. Further work will be needed to integrate the amplifier into a cell-phone chip.

www.purdue.edu

Custom MMIC moves to new corporate HQ, including expanded engineering and manufacturing Labs

To support its rapid growth, Custom MMIC has moved its offices from Westford, MA to 300 Apollo Drive, Chelmsford, MA 01824. All other contact information, including phone numbers, remains the same.

The new headquarters provides a threefold increase in office space for the firm's growing staff as well as increasing lab space. "Our separate engineering and manufacturing labs, along with our new automated equipment,



Custom MMIC's new headquarters in Chelmsford, which provides a threefold increase in office space as well as increased lab space.

will allow for efficient development and production of our growing portfolio of high performance MMICs," says president Paul Blount.

www.custommmic.com

Custom MMIC launches BroadRange distributed amplifier family

Monolithic microwave integrated circuit developer Custom MMIC of Westford, MA, USA has developed the BroadRange Distributed Amplifier family, with bandwidths from DC to 50GHz.

The product line consists of over ten released products, together with five more unveiled at IEEE's International Microwave Symposium (IMS) in San Francisco (22-27 May).

The amplifiers are provided in low-profile die or QFN packaged and offer single positive supply operation, positive gain slope over frequency, and 50Ω matching for ease of design, smaller and lower-power systems.

The amplifiers have low bias voltage requirements down to 3V and bias currents as low as 32mA. With DC to 50GHz bandwidth,

output third-order intercept point (OIP3) of 22-32dBm, output power at 1dB gain compression (P1dB) of 12-29dBm, and saturated output power (Psat) of 12-29dBm, the BroadRange Distributed Amplifier family is suitable for electronic warfare (EW), wideband communication, and instrumentation applications.

www.ims2016.org

DC-18GHz switches and DC-22GHz and 26-35GHz amplifiers

At the IEEE International Microwave Symposium (IMS) in San Francisco (24-27 May), Custom MMIC featured a range of new high-performance microwave amplifiers and switches with ultra-wideband operation.

DC-18GHz SP3T and SP5T non-reflective switches

Leveraging a non-reflective design, the SP3T CMD234C4 switch provides high isolation of 40dB at 10GHz and low insertion loss of 2dB. It includes an on-board binary decoder circuit, requiring only two complimentary control voltage logic lines of 0/-5V. Similar to the SP3T design, the SP5T CMD235C4 features a low-power integrated 3:8 TTL decoder for enhanced digital control. The switch provides an insertion loss of 2.5dB and high isolation of 40dB at 10GHz.

The CMD235C4 and CMD234C4

have small-size and Pb-free RoHS-compliant 4x4 SMT QFN packages, and a switching speed of only 66ns. The GaAs switches are suited to test & measurement, military and telecoms applications.

DC-22GHz and 2-22GHz distributed amplifiers

Offering ultra-wideband performance from DC to 22GHz, the CMD240 is a GaAs MMIC amplifier with a noise figure down to 2.2dB and gain of 15dB. Also highly linear, the CMD240 demonstrates a P1dB (output power at 1dB gain compression) of 19dBm at 10GHz and an OIP3 (output third-order intercept point) of 28dBm with only 80mA supply current. With slightly less current draw and a gain of 13.5dB at 2-22GHz, the CMD241 has a noise figure of 2.3dB and features enhanced linearity

performance with an output P1dB of 21dBm.

Both the CMD240 and CMD241 eliminate the need for an external DC block and are matched to 50Ω. The low-noise distributed amplifiers are suitable for military, aerospace and microwave/millimetre-wave telecoms applications.

26-35GHz balanced driver amplifier

In applications with small size and high-linearity requirements, the CMD243 wideband balanced driver amplifier offers 15.5dB of gain and operates at 26-35GHz. Providing a P1dB of 21dBm, a low noise figure of 4.4dB, and 50Ω matched, it is suitable for communications, military and space applications.

www.ims2016.org

www.custommmic.com

GlobalFoundries releases 130nm SiGe 8XP performance-enhanced RF technology, optimized for 5G wireless networks

GlobalFoundries of Santa Clara, CA, USA (one of the world's largest semiconductor foundries, with more than 250 customers and operations in Singapore, Germany and the USA) has announced a next-generation radio-frequency (RF) silicon solution for its silicon germanium (SiGe) high-performance technology portfolio. The technology is optimized for customers who need improved performance solutions for automotive radar, satellite communications, 5G millimeter-wave (mmWave) base-stations and other wireless and wireline communication network applications.

The SiGe 8XP technology is the latest extension to the firm's 130nm high-performance SiGe family and enables customers to develop RF solutions that deliver faster data throughput, over greater distances, while consuming less power. The technology offers improved heterojunction bipolar transistor (HBT) performance with lower noise figure, higher signal integrity, and up to a 25% increase in maximum oscillation frequency (f_{MAX}) to 340GHz compared to its predecessor SiGe 8HP.

The complexity and performance demands of high-bandwidth communication systems operating in the mmWave frequency bands have created the need for higher-performance silicon solutions, says GlobalFoundries. This creates opportunities for SiGe solutions in

the RF front end of 5G smartphones and other mmWave phased-array consumer applications in addition to the existing applications that depend on SiGe for high performance such as communications infrastructure base-stations, backhaul, satellite and fiber optic networks.

"5G networks promise to bring a new level of innovation to RF SOC [system-on-chip] design to support high-bandwidth data delivery and meet the demands for increased data rates and low-latency applications," says Dr Bami Bastani, senior VP of the RF business unit. "SiGe 8HP and 8XP technologies offer an outstanding balance of performance, power and efficiency that enable customers to develop differentiated RF solutions in next-generation mobile and infrastructure hardware," he claims.

"GlobalFoundries' SiGe technology leadership and comprehensive PDKs [process design kits] enable our designers to develop performance-optimized, differentiated millimetre-wave solutions quickly," comments Anokiwave's CEO Robert Donahue. "Utilizing SiGe 8XP allows us to take performance to even higher levels in future-ready mmWave solutions designed to help providers stay ahead of the demands for reliable connectivity, from anywhere, while handling exploding volumes of mobile data traffic."

With future 5G deployments poised to drive a proliferation of

base-stations with smaller cell areas, SiGe 8HP and 8XP are designed to help offer a balance of value, power output, efficiency, low noise, and linearity at microwave and millimeter-wave frequencies for differentiated RF solutions in next-generation mobile infrastructure hardware and smartphone RF front ends. The SiGe 8HP and 8XP high-performance offerings enable chip designers to integrate significant digital and RF functionality while exploiting a more economical silicon technology base compared to gallium arsenide (GaAs) and higher performance than CMOS, says GlobalFoundries.

In addition to high-performance transistors for efficient operation at mmWave frequencies, SiGe 8HP and 8XP introduce technology innovations that can reduce the die size and enable area-efficient solutions. A new copper (Cu) metallization feature provides improved current-carrying capabilities with five times the current density at 100°C, or up to 25°C higher operating temperature at the same current density compared to standard Cu lines. In addition, GlobalFoundries' production-proven through-silicon via (TSV) interconnect technology is available. SiGe 8XP design kits are available now.

GlobalFoundries exhibited its 130nm SiGe technology solutions at the IEEE's International Microwave Symposium (IMS 2016) in San Francisco (22-27 May).

www.globalfoundries.com/SiGe

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www.semiconductor-today.com

IDT launches silicon-based 50–8000MHz 50Ω SPDT RF switches, drop-in compatible with GaAs

Integrated Device Technology Inc (IDT) of San Jose, CA, USA has launched two high-isolation, low-loss, high-linearity broadband RF switches for a wide variety of applications. Operating at 50–8000MHz, the F2932 and F2933 are silicon-based, low-distortion 50Ω absorptive single-pole, double-throw (SPDT) switches. With industry-standard 4mm x 4mm 16-pin QFN packages and drop-in compatible footprints and control, their combination of specs make the devices suitable for communications and public safety systems, radar and general purpose switching.

At 4GHz the F2932 and F2933 deliver: high isolation of 66dB; low distortion of 64dBm IIP3 (third-order intercept point) @ 15dBm tones, 1MHz channel spacing; insertion loss of 0.93dB; and P1dB (output power at 1dB gain compression point) of >35dBm.

IDT claims that the inherent benefits over most competitive products — particularly compared to typical gallium arsenide (GaAs)-based switches — are: better RF performance; greater reliability; easier integration; and lower total solution cost.

“These two new devices offer one

of the industry’s highest isolation values and, when combined with their low distortion and low insertion loss, they provide superior performance for many different high-isolation applications,” says Chris Stephens, general manager of IDT’s RF division.

The F2932 and F2933 offer similar RF performance, pin-out and control, but the F2932 has an additional enable/disable feature, allowing all RF paths to be put into an off-state and disabling the VCTL feature.

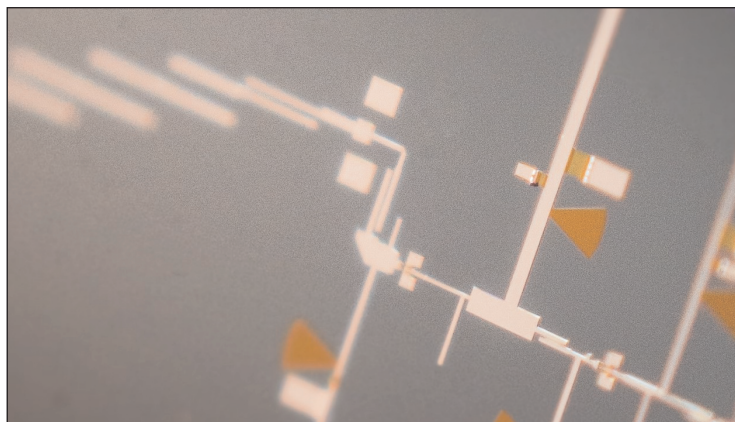
www.idt.com/products/rf-products/rf-switches

Arralis launches first 94GHz transmit & receive core chips

At the IEEE’s International Microwave Symposium (IMS 2016) in San Francisco (22–27 May), Arralis Ltd of Limerick, Ireland, a developer of RF, microwave and millimetre-wave technology (focusing on the W-band), launched what are claimed to be the first fully integrated transmit and receive 94GHz core chips.

Fabricated from gallium arsenide pseudomorphic high-electron-mobility transistors (pHEMTs) and measuring just 5.2mm x 2.2mm, the monolithic integrated circuits (MMICs) make the highly desirable attenuation window of 94GHz available for commercial applications such as fully autonomous radar for drones and self-driving vehicles as well as ‘wireless fiber’ communication speeds for 5G backhaul.

The new MMICs function as an up-converter and a down-converter, greatly simplifying system integration and widening market access at the center frequency of 94GHz. The up-converter consists of a mixer with integrated medium-power amplifier. It offers conversion gain, high image rejection and an output power of more than 13dBm. The down-converter consists of a



Arralis 94GHz transmit & receive core chip.

low-noise amplifier (LNA) and a mixer, giving a noise figure of less than 5dB and a gain of more than 10dB.

“Our focus at Arralis is scale and integration, which for our customers means easier system development and lower cost. These transmit and receive chips deliver both,” says chief technology officer Mike Gleaves. “This delivers on our promise to our customers that we would make our aerospace technology integrated and available for commercial applications,” he adds.

The new devices are currently in the hands of Arralis’ lead customers, in advance of full commercial roll-

out in the coming months.

The launch adds to Arralis’ family of W-band millimeter-wave MMICs. Traditionally, due to high cost and the difficulty of integration, 94GHz has been used almost exclusively in the military

radar market. The 90–100GHz frequency range is attractive due to its ultra-small system size, high resolution and unique propagation (long-range) features.

Arralis says that its developments in technology and scale enable this frequency range to be used in a wide range of commercial applications including 5G, mega constellations, drones, driverless vehicles and the Internet of Things (IoT). In addition, the company manufactures complementary electronic beam-forming and scanning antennas, including the use of meta-materials.

www.arralis.com

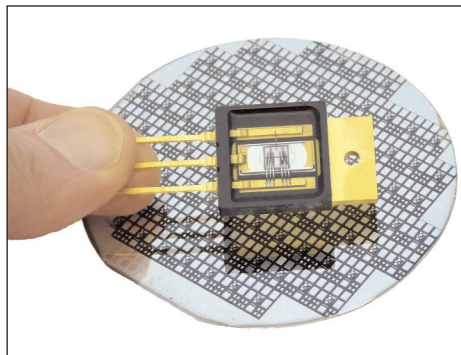
Ascatron raises €4m in A-round funding for final development of its first SiC products

Material technology implemented in SiC epi production equipment; next step to optimize device design and outsource chip fabrication to foundry

Silicon carbide (SiC) power semiconductor device developer Ascatron AB of Kista, Stockholm, Sweden (which was spun out of research institute Acreo in 2011, and supplies SiC epitaxial material) has completed A-round financing intended for the final development of its first own SiC products. The total of €4m consists of €3m in equity capital and €1m in an innovation grant.

Ascatron says that SiC-based power semiconductors can radically reduce losses in electrical transformers. With conventional technology, losses can be up to 20% when electricity is converted to adjust voltage and frequency. The firm therefore focuses on high-voltage applications, where the use of SiC can yield very large energy savings.

"We have started to implement our advanced material technology



Ascatron's 1200V SiC power diode.

in production equipment for SiC epitaxy," says chief technology officer Adolf Schöner. "The next step is to optimize our device design and outsource the remaining manufacturing of the chip to a foundry with capacity for volume production," he adds.

The investors include four Italy- and China-based venture capital investors Quadrivio (through its

venture capital fund TTventure) and Como Venture (which together took a 16.7% stake in Ascatron last October) as well as Rise Leader Investment and InteBridge Technology, together LPE SpA (which designs and makes epitaxial reactors for power electronics). The grant comes from the European Institute of Innovation and Technology (EIT) through KIC InnoEnergy (which supports innovation projects in sustainable energy).

"Our investors have a good mix of understanding both the advanced material technology needed for high-performance SiC power devices, and how to address volume markets for semiconductors," says CEO Christian Vieider. "40% of the market for power electronic components is in China, and there is a lot of interest in SiC for energy saving."

www.ascatron.com

Global Power Technologies signs franchise agreement with Richardson Electronics

Richardson Electronics Ltd of LaFox, IL, USA (a global channel partner for electron devices, power electronics, and RF & microwave components) has signed a new franchise agreement with Global Power Technologies Group (GPTG), a full-service manufacturer of silicon carbide (SiC) semiconductors for the commercial power market. The agreement aligns with Global Power Technologies Group's efforts to identify new opportunities using SiC technology, as market demand continues to expand for power electronics and green energy technologies. Richardson has this extensive portfolio of components in stock and ready for distribution.

Global Power Technologies Group

is a portfolio company of the Global Opportunities Fund (GOF), which is a venture fund uniquely focused on the application of wide-bandgap materials technology for the development of high-frequency, high-temperature and efficient power semiconductor devices. GPTG produces 100mm and 150mm epitaxial wafers, SiC discrete diodes, SiC discrete MOSFETs, SiC modules and sub-systems for multiple market sectors.

"We are pleased to align with a key innovator of SiC discrete power devices and SiC-based power modules and subsystems for the electric vehicle/hybrid electric vehicle, server, solar inverter, lighting, and power industries," says Greg Peloquin,

executive VP of Richardson Electronics' Power & Microwave Technologies group. "Global Power Technologies Group's focus on highly efficient and compact products with high integration and performance at a low cost results in game-changing power electronics for our customers."

"Richardson Electronics performs a unique service to the power semiconductor industry and is an ideal fit, with a highly technical sales force that concentrates on achieving design-wins," comments Michael Digangi, executive VP & chief business development officer of Global Power Technologies Group.

www.gptechgroup.com

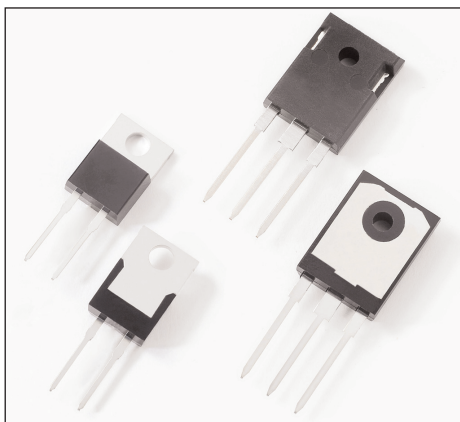
www.rellpower.com

Littelfuse launches SiC Schottky diodes

At PCIM (Power Conversion and Intelligent Motion) Europe 2016 in Nuremberg, Germany (10–12 May), Littelfuse Inc of Chicago, IL, USA (which provides circuit protection technologies) introduced the LFUSCD Series of silicon carbide (SiC) Schottky diodes as the latest addition to its growing line of power semiconductor products.

Compared to standard silicon bipolar power diodes, LFUSCD Series SiC Schottky diodes allow designers to reduce switching losses, accommodate large surge currents without thermal runaway, and operate at higher junction temperatures, all of which enable substantial increases in system efficiency and robustness.

The merged p-n Schottky (MPS) device architecture of the LFUSCD Series ensures enhanced surge capability and reduced leakage current, says Littelfuse. Available in voltage ratings of 650V and 1200V at current ratings ranging from 4A to 30A, they are suitable for a broad range of markets including industrial power supplies, solar inverters, industrial drives, welding and plasma cutting, and electric vehicle/hybrid electric vehicle



(EV/HEV) charging stations.

LFUSCD Series SiC Schottky diodes are said to improve the efficiency, reliability and thermal management of applications, such as:

- power factor correction (PFC);
- buck or boost stages in DC-DC converters;
- free-wheeling diodes in inverter stages (switch-mode power supplies, solar, UPS, industrial drives); and
- high-frequency output rectification.

“With best-in-class forward voltage drop and stored capacitive charge, Littelfuse SiC diodes will enable our customers to optimize the efficiency of their designs while increasing system robustness and reliability,” claims Dr Kevin Speer, business

development manager for the Power Semiconductor technology line.

LFUS Series SiC Schottky diodes are said to offer the following benefits:

- best-in-class capacitive stored charge and near-zero reverse recovery make the devices suitable for high-frequency power switching, ensure negligible switching losses, and reduce stress on the opposing switch;
- best-in-class forward voltage drop ensures low conduction losses;
- maximum junction temperature of 175°C provides for a larger design margin and relaxed thermal management requirements; and
- a merged p-n Schottky (MPS) device architecture enhances surge capability and provides extremely low leakage.

LFUS Series SiC Schottky diodes are available in tubes in TO-220 two-lead and TO-247 three-lead packages. Sample requests can be placed through authorized Littelfuse distributors worldwide.

www.mesago.de/en/PCIM/main.htm
www.littelfuse.com/products/power-semiconductors/silicon-carbide/sic-schottky-diode-discretes
www.monolithsemi.com

Toshiba's second-gen SiC Schottkys deliver 50% greater current density and improved surge current ratings

At PCIM (Power Conversion and Intelligent Motion) Europe 2016 in Nuremberg, Germany (10–12 May), Toshiba Electronics Europe of Düsseldorf, Germany (TEE, the European electronic components business of Japan's Toshiba Corp) unveiled new Schottky barrier diodes (SBDs) based on the firm's second-generation silicon carbide (SiC) technology. The SBDs deliver current densities up to 50% higher than first-generation devices and can handle significantly higher forward surge currents.

With its second-generation SiC process, Toshiba has been able to reduce die thickness to develop



SBDs with current densities about 1.5x higher than first-generation devices. In addition, they also offer higher non-repetitive forward surge current (IFSM) ratings.

The first products in the second-generation line-up will be 650V

devices with current ratings of 4A (TRS4E65F), 6A (TRS6E65F), 8A (TRS8E65F), and 10A (TRS10E65F) in TO-220 2-pin and TO-220 isolated 2-pin packages. These TRS...A65F diodes are suitable for high-speed switching power conversion designs including power factor correction (PFC) schemes, photovoltaic inverters and uninterruptible power supplies (UPS). Toshiba's SiC SBDs can also be used to improve the efficiency of switching power supplies through the replacement of conventional silicon diodes.

www.mesago.de/en/PCIM/main.htm
www.toshiba.co.jp

Rohm showcases third-generation 650V SiC Schottkys and 1200V/180A full-SiC modules at PCIM

At PCIM (Power Conversion Intelligent Motion) Europe 2016 in Nuremberg, Germany (10–12 May), Japan's Rohm Semiconductor showcased its latest power products for high-speed switching and high-power performance, while meeting the need for greater energy savings and higher efficiency.

3rd-gen SiC Schottky barrier diodes (SBDs) for enhanced performance and reliability

Continuing to develop its portfolio, Rohm introduced its new third-generation silicon carbide (SiC) Schottky barrier diode (SBD) for enhanced performance. The first products are rated at 650V/6A, 8A and 10A (supplied in a TO220AC package), and realize the lowest VF and lowest IR within the entire

temperature range among all SiC SBDs available on the market, it is claimed. They also feature high surge current capability, which is suitable for power supply applications. As this 3rd-Gen product contains a PN junction structure along with a Schottky barrier, durability in bipolar operation is ensured, says the firm. These features contribute to the ongoing trend of high efficiency, high power density and highly robust designs. **3rd-gen 1200V/180A full-SiC module for efficient high-frequency operation**

After pioneering commercial power modules equipped with SiC-MOSFETs and SiC-SBDs, Rohm presented its new BSM180D12P3C007 SiC power module, which is rated at

1200V/180A. The half-bridge SiC module integrates mass-produced trench-type SiC MOSFETs and embedded SiC SBDs in the same footprint as previous modules. Based on the U MOS structure, the new module achieves 77% lower switching loss than conventional silicon-based IGBT (insulated-gate bipolar transistor) modules and 42% lower switching loss than SiC modules utilizing SiC-DMOS structures. This not only enables high-frequency operation but also contributes to smaller cooling systems and peripheral components, which in turn results in greater energy savings and end-product miniaturization, says Rohm.

www.rohm.com/web/global/sic-mosfet

STMicroelectronics' SiC MOSFETs used in Zaptec's portable electric-car charger

STMicroelectronics of Geneva, Switzerland says its silicon carbide (SiC) metal-oxide-semiconductor field-effect transistor (MOSFET) devices have enabled the ZapCharger Portable (claimed to be the world's smallest electric-car charging station) to be created by Zaptec of Stavanger, Norway, which was founded in 2012 to commercialize 10 years of R&D in super-compact power electronics.

ST says that its SiC MOSFETs' power-conversion capabilities have enabled Zaptec to design an electric-car charger with energy efficiency of 97% that weighs 3kg and measures 45cm x 10cm x 10cm (ten times smaller and lighter than products with comparable performance).

With a built-in electronic transformer that allows it to work with any electric car on any grid, ZapCharger is fully galvanically insulated and continuously monitors the grid it is connected to. It dynamically

adjusts the amount of power it delivers and can shut down immediately if it detects a fault, in order to protect the car. The charger offers GPRS connectivity and operates over an extended temperature range from -40°C to +55°C.

The ZapCharger contains 32 high-voltage SiC power MOSFETs from ST. Compared with traditional (silicon) solutions, these components can sustain much higher voltages, currents, and temperatures, and their power-conversion circuits operate faster, enabling smaller, lighter designs, higher system efficiency, and reduced cooling requirements, says ST.

"The key for us was to find a power technology with a very high efficiency so we could reduce the overall size of the charger without compromising performance," says Zaptec's chief operating officer Jonas Helmikstøl. "The support of ST as a strong and reliable partner helped us transform our invention

into a product that dramatically changes the user experience and, by allowing consumers to take their chargers anywhere, eliminates 'range anxiety' and can accelerate the adoption of electric vehicles worldwide," he adds.

"Solutions like ZapCharger that can enable drivers to safely charge their vehicles anywhere are set to catalyze the growth of the e-car market and the smart-energy ecosystem as a whole," believes Philip Lories, EMEA VP, marketing & application, STMicroelectronics.

In addition to electric-car charging, Zaptec's patented electronic-transformer technology targets new applications in industrial, marine, and space.

After successful field tests, ZapCharger is starting pilot production now, with volume ramp-up scheduled at the end of third-quarter 2016.

www.zaptec.com/zapcharger
www.st.com/sicmos

ST unveils 650V and 1200V SiC power devices for EVs MOSFET & diode production to scale from 4" to 6" wafers by end-2016

STMicroelectronics of Geneva, Switzerland has announced high-efficiency silicon carbide (SiC) power semiconductors for hybrid and electric vehicles (EVs), with a timetable for qualification to the automotive quality standard AEC-Q101.

ST says that, in EVs and hybrids (where better electrical efficiency means greater mileage), its latest SiC technology enables auto makers to create vehicles that travel further, recharge faster, and fit better into owners' lives. The firm is among the first to present new-generation rectifiers and MOSFETs for high-voltage power modules and discrete solutions addressing all the vehicle's main electrical blocks. These include the traction inverter, on-board battery charger, and auxiliary DC-DC converter.

Existing power modules typically rely on standard silicon diodes and insulated-gate bipolar transistors (IGBTs). As a wide-bandgap technology, SiC allows smaller device geometries capable of operating well above the 400V range of today's electric and hybrid drivetrains. The smaller SiC diode and transistor structures present lower internal resistance and respond more quickly than standard silicon devices, which minimizes energy losses and allows associated components to be smaller, saving even more size and weight.

"Major carmakers and automotive tier-1s are now committing to SiC technology for future product development to leverage its higher aggregate efficiency compared to standard silicon in a wide range of operating scenarios," says Mario Aleo, group VP & general manager, Power Transistor Division. "Our SiC devices have demonstrated superior performance and reached an advanced stage of qualification as we support customers preparing to launch new products in the 2017 timeframe," he adds.

ST has been among the first firms to produce SiC high-voltage MOSFETs, with its first 1200V SiC MOSFET

introduced back in 2014, achieving a 200°C rating for more efficient and simplified designs.

The firm is fabricating SiC MOSFETs and diodes on 4-inch wafers. But, to drive down the manufacturing costs, improve the quality, and deliver the large volumes demanded by the auto industry, ST is scaling up its production of SiC MOSFETs and diodes to 6-inch wafers, and is on schedule to complete both conversions by the end of 2016.

ST has already qualified its 650V SiC diodes to the AEC-Q101 standard, and will complete qualification of the latest 650V SiC MOSFETs and 1200V SiC diodes in early 2017. The qualification of the new-generation 1200V SiC MOSFETs will be completed by the end of 2017.

The STPSC20065WY 650V SiC diode is in full production now in DO-247. The range also includes lower current ratings and smaller-form-factor TO-220 package options. The STPSC10H12D 1200V SiC diode is sampling now to lead customers in the TO-220AC package and goes into production in May, with volume production of the automotive-grade version planned for fourth-quarter 2016. Multiple current ratings from 6A to 20A and packaging options will also be available.

The SCTW100N65G2AG 650V SiC MOSFET is sampling now to lead customers in the HiP247 package, and will ramp up in volumes in first-half 2017. To enable more compact designs, a 650V SiC MOSFET in the surface-mount H2PAK will also be qualified to AEC-Q101 in first-half 2017.

Using the 650V SCTW100N65G2AG SiC MOSFET in the EV/HEV main inverter (typical frequencies up to 20kHz) increases the efficiency compared with an equivalent IGBT solution by up to 3%, the firm claims. This improvement translates into longer battery life and autonomy, and a smaller and lighter power unit with lower cooling requirements.

The SiC MOSFET reduces power losses in the inverter (up to 80% lower at light/medium load), enabling designers to use higher switching frequencies for more compact designs. Additionally, a SiC-based solution offers highly robust intrinsic-body diodes, eliminating the need for the freewheeling diodes necessary with IGBTs, further saving cost, size, and weight, adds ST.

In other EV/HEV applications like the OBC (on-board charger) and DC-DC converter, the inherently faster switching performance of SiC, compared with standard silicon devices, allows much higher switching frequencies, reducing the size of passive components. Furthermore, the SiC MOSFET increases design flexibility as it can be used in diverse topologies, says the firm.

Such advances are helping to propel the state of the art in hybrid and electric vehicles, says ST. The firm claims that its manufacturing processes deliver advantages over competing SiC devices, such as superior stability over a wide operating temperature range, translating to more dependable vehicle performance and range.

Housed in a proprietary high-thermal-efficiency HiP247 package, ST's SiC MOSFETs also feature what is claimed to be the industry's highest junction temperature rating of 200°C and show very small variation in on-state resistance even at high temperatures. This leads to higher system efficiency, which reduces cooling requirements and PCB form factors, simplifying thermal management, says the firm.

The new 650V and 1200V SiC diodes have what is claimed to be the best-in-class forward voltage drop (V_f) of all devices on the market, minimizing the energy dissipated as heat by EV/HEV power converters. These thermal properties help to further improve overall vehicle reliability, the firm adds.

www.st.com/auto-sic-diodes

Infineon unveils CoolSiC MOSFET technology

Infineon Technologies AG of Munich, Germany has unveiled a silicon carbide (SiC) MOSFET technology allowing product designs to achieve what are claimed to be previously unattainable levels of power density and performance. CoolSiC MOSFETs are targeted at helping developers of power conversion schemes to save space and weight, reduce cooling requirements, improve reliability and lower system costs.

The new MOSFETs are based on a state-of-the-art trench semiconductor process and represent the latest evolution of Infineon's comprehensive family of CoolSiC technologies. This family includes Schottky diodes and 1200V J-FETs and a range of hybrid solutions integrating a silicon insulated-gate bipolar transistor (IGBT) and SiC diode in a module.

"For more than 20 years, Infineon has been at the forefront of developing SiC solutions which address demands for energy savings, size reduction, system integration and improved reliability," says Dr Helmut Gassel, president of Infineon's Industrial Power Control Division. "Infineon has manufactured millions of products containing SiC devices, while our Schottky diode and J-FET technologies have allowed designers to achieve power density and performance not possible with conventional silicon," he adds.

"The strategy has now taken a significant step forward encompassing power MOSFETs that raise the ben-

efits available from SiC technology to a new level, which has never before been possible."

SiC MOSFET functionality allows power conversion schemes that can operate at triple or more the switching frequency in use currently. This leads to benefits such as reducing the copper and aluminium materials used in magnetics and system housing, facilitating smaller and lighter systems for less transportation effort and easier installation. New solutions supporting energy savings can be realized by the designers of power conversion applications, which can hence harness performance, efficiency and system flexibility in a completely new dimension, says Infineon.

The new 1200V SiC MOSFETs have been optimized to combine reliability with performance. They operate with 'benchmark' dynamic losses that are an order of magnitude lower than 1200V silicon IGBTs. This initially supports system improvements in applications such as photovoltaic inverters, uninterruptible power supplies (UPS) or charger/storage systems, while later configurations will also extend support to industrial drives.

The MOSFETs are fully compatible with the +15V/-5V voltages typically used to drive IGBTs. They combine a benchmark threshold voltage rating (V_{th}) of 4V with short-circuit robustness required by the target applications and fully

controllable dv/dt characteristics. Key benefits over silicon IGBT alternatives include temperature-independent switching losses and threshold-voltage-free on-state characteristics.

The first discrete 1200V CoolSiC MOSFETs feature on-resistance ($R_{DS(ON)}$) ratings of just 45m Ω . They will be available in 3-pin and 4-pin TO-247 packages targeted at photovoltaic inverters, UPS, battery charging and energy storage applications. Both devices are ready for use in synchronous rectification schemes due to the integration of a commutation robust body diode operating with nearly zero reverse recovery losses. The 4-pin package incorporates an additional (Kelvin) connection to the source, which is used as a reference potential for the gate driving voltage. By eliminating the effect of voltage drops due to source inductance, this further reduces switching losses, especially at higher switching frequencies.

Infineon has also announced 1200V 'Easy1B' half-bridge and booster modules based on the SiC MOSFET technology. Combining PressFIT connections with a good thermal interface, low stray inductance and robust design, each module is available with $R_{DS(ON)}$ rating options of 11m Ω and 23m Ω .

Infineon will sample for target applications in second-half 2016, with volume production in 2017.

www.infineon.com/coolSiC

Advantech launches 50W Ku-band airborne-grade SSPB/BUC

Advantech Wireless Inc of Montreal, Canada (which makes satellite, RF equipment and microwave systems) has launched the 2500-G Series 50W Ku-band gallium nitride (GaN)-based airborne-grade solid-state power block/block up-converter (SSPB/BUC) designed to meet stringent commercial airborne requirements and specifications.

The new SSPBs/BUCs provide high power density in a compact size and

are suitable for use in the rapidly growing market for in-flight connectivity and satellite mobility services.

"Advantech Wireless' solid expertise in earth station SSPBs has now been combined with the specific features and operational requirements of airborne operation," says VP business development Cristi Damian. "These new advanced GaN-based units are ideal for the next-generation airborne SatCom terminals. They

provide high power with extremely high linearity and efficiency, while maintaining very high reliability."

With a design based on the firm's industry-proven solid-state high-power amplifiers, the 2500-G Series' rugged and conservative thermal design allows operation over an extreme temperature range. The new Ku-band BUCs are designed to meet DO-160G specifications.

www.advantechwireless.com

TI launches 600V driver-integrated GaN 70mΩ FET power stage for power conversion

Texas Instruments Inc has made available 600V gallium nitride (GaN) 70mΩ field-effect transistor (FET) power-stage engineering samples, making TI the first semiconductor manufacturer to publicly offer a high-voltage driver-integrated GaN solution, it is claimed.

Coupled with the firm's analog and digital power-conversion controllers, the new 12A LMG3410 power stage enables designers to create smaller, more efficient and higher-performing designs compared to silicon FET-based solutions, TI says. These benefits are especially important in isolated high-voltage industrial, telecom, enterprise computing and renewable energy applications.

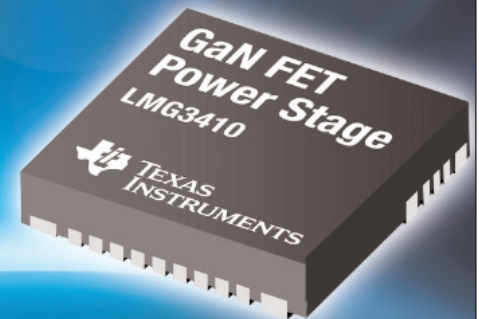
"With over 3 million hours of reliability testing, the LMG3410 gives power designers the confidence to realize the potential of GaN and to rethink their power architecture and systems in ways not feasible before," says Steve Lambouses, VP of high-voltage power solutions. "Expanding on TI's reputation for manufacturing capability and extensive system-design expertise, the new power stage is a significant step," he adds.

With its integrated driver and features such as zero reverse-recovery current, the LMG3410 provides reliable performance, especially in hard-switching applications where it can reduce switching losses by as much as 80%, it is reckoned. Unlike stand-alone GaN FETs, the easy-to-use LMG3410 integrates built-in intelligence for temperature, current and under-voltage lockout (UVLO) fault protection.

The LMG3410 is the first integrated circuit to include GaN FETs manufactured by TI. Building on years of experience in manufacturing and process technologies, TI creates its GaN devices in a silicon-compatible factory and qualifies them with practices that are beyond the typical Joint Electron Device Engineering Council (JEDEC) standards to ensure

Integrated 600-V GaN FET power stage

- Easy-to-design
- Twice the power density, half the power loss
- Enables new topologies



the reliability and robustness of GaN for demanding applications, TI says. Easy-to-use packaging can help to increase the adoption of GaN power designs in applications such as power factor controller (PFC) AC/DC converters, high-voltage DC bus converters and photovoltaic (PV) inverters, the firm adds.

Features of the LMG3410 include:

- **Double the power density.** The 600V power stage delivers 50% lower power losses in a totem-pole PFC compared with state-of-the-art silicon-based boost power-factor converters. The reduced bill of materials (BOM) count and higher efficiency enable a reduction in power-supply size of as much as 50%, it is reckoned.
- **Reduced packaging parasitic inductance.** The new device's 8mm x 8mm quad flat no-lead (QFN) package decreases power loss, component voltage stress and electromagnetic interference (EMI) compared to discrete GaN solutions.
- **New topologies.** GaN's zero reverse-recovery charge benefits new switching topologies, including totem-pole PFC and LLC topologies to increase power density and efficiency.

Expanding the GaN ecosystem

To support designers who are taking advantage of GaN technology in their power designs, TI is also introducing new products to expand its GaN ecosystem. The LMG5200POLEVM-10, a 48V to 1V point-of-load (POL) evaluation module, will include the new TPS53632G GaN FET controller, paired with the 80V LMG5200 GaN FET power stage. The solution allows for efficiency as high as 92% in industrial, telecom and datacom applications, the firm reckons.

The LMG3410 is the first integrated circuit to include GaN FETs manufactured by TI

TI will offer a development kit that includes a half-bridge daughtercard and four LMG3410 IC samples. A second kit contains a system-level evaluation motherboard. Used together, these two kits enable immediate bench testing and design. The two development kits are available now, priced at \$299 and \$199, respectively.

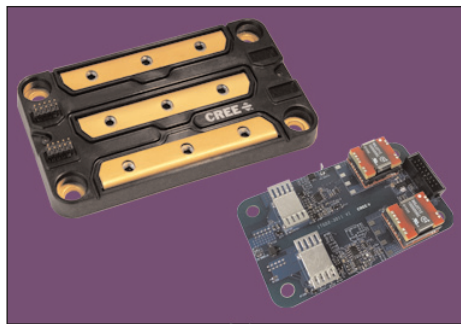
www.ti.com/lmg3410-pr

Wolfspeed launches all-SiC half-bridge power module & gate driver combination

At PCIM (Power Conversion Intelligent Motion) Europe 2016 in Nuremberg, Germany (10–12 May), Wolfspeed of Research Triangle Park, NC, USA introduced the first fully qualified commercial power module from its operation in Fayetteville, AR.

The 62mm module represents a new generation of all-SiC power modules that enable unprecedented efficiency and power density for high-current power electronics, such as converters/inverters, motor drives, industrial electronics, and high-performance electric vehicle (EV) systems. The module allows systems designers to realize lighter-weight systems that are up to 67% smaller by achieving efficiencies of over 98% and improvements in power density of up to 10 times versus systems built with silicon-based technologies, it is reckoned.

“Wolfspeed’s launch of this fully qualified, next-generation SiC power module represents the culmination of an engineering development program that began with the firm’s early SiC MOSFET module designs,” says chief technology officer John Palmour. “Our 2015 acquisition of Arkansas Power Electronics International (APEI) [a provider of SiC power modules and power electron-



The CAS325M12HM2 power module.

ics applications] enabled our team to deliver this advanced power module design on an aggressive timeline by combining leading-edge SiC device technology with the industry’s most advanced wide-bandgap packaging innovation,” he adds. “The resulting module is the first of many products that promise an accelerated disruption of the power electronics market.”

Compared to conventional silicon insulated-gate bipolar transistor (IGBT) power modules, or even previous-generations of SiC MOSFET modules, the new module can offer much higher power density for applications in which volume and weight are critical limitations, says Wolfspeed. Operating at a higher switching frequency without any compromise in system efficiency

means a reduction in the number and size of magnetic and passive components required for the balance of the system. The thermal characteristics of SiC devices, along with the packaging design and materials, enable the module to operate at 175°C, which is a key advantage for many industrial, aerospace and automotive applications.

The newly commercialized Wolfspeed module design achieves a 66% reduction in module inductance to 5.5nH, compared with competitive power products at 15nH, it is reckoned, enabling faster switching speeds, higher-frequency operation, and ultra-low losses.

Available as CAS325M12HM2, the power module is configured in a half-bridge topology consisting of seven 1.2kV 25mΩ C2M SiC MOSFETs and six 1.2kV 50A Z-Rec Schottky diodes. The companion gate driver (CGD15HB62LP) is specifically designed for integration with the module to fit within the 62mm mounting footprint. An engineering evaluation kit that includes both the module and the gate driver is also available so design engineers can quickly and easily test the performance of the new device in their systems.

Wolfspeed presents SiC power device portfolio at PCIM

Participating with its distribution partner MeV, at PCIM Europe 2016 Wolfspeed highlighted examples of the smaller, cooler, more efficient 20kW DC–DC converters made possible through the design, circuit and performance improvements and overall system savings of SiC power devices and modules. It also showcased the expansion of its 900V SiC MOSFET platform.

“As the wide-bandgap power semiconductor market continues to expand, we’re going to be launching more devices that are designed and developed specifi-

cally to optimize SiC’s inherent performance advantages,” says Guy Moxey, senior director of power products.

During PCIM, Wolfspeed gave the following presentations:

- business development & program manager Jeffrey Casady presented a paper ‘Ultra-low (1.25μΩ) On-Resistance 900V SiC 62mm Half-Bridge Power Modules Using New 10mΩ SiC MOSFETs’;
- director of business development Dr Ty McNutt took part in a Power Electronics Market Briefing hosted by Yolé Développement;

- chief technology officer Dr John Palmour presented ‘SiC Volume, Production & Cost’ as part of the Bodo’s Power System Forum;

- technical marketing manager Dr Marcelo Schupbach presented ‘A Digital Predictive Constant Frequency Controller For High Frequency 3-Phase Silicon Carbide PFC Rectifier’;

- product marketing engineer Edgar Ayerbe presented ‘Wolfspeed 900V MOSFETs for Fast Battery Charger Applications’.

www.mesago.de/en/PCIM/main.htm
www.wolfspeed.com/power/products

Wolfspeed launches SpeedFit online circuit simulation tool to speed SiC device evaluation and adoption

Wolfspeed has introduced a free online circuit simulation tool that allows power electronics design engineers to simulate and evaluate the performance of SiC-based power circuits, and to aid in the selection of the optimum SiC devices for each application.

"The SpeedFit simulation tool allows designers to determine the right SiC device for their power system in mere seconds, a process that previously required hours examining datasheets and making calculations," says Guy Moxey, senior director of power marketing. "This tool will increase the rate and ease of SiC-device adoption worldwide," he believes.

Developed using the proven PLECS web-based simulation platform from Plexim, the SpeedFit circuit simulation tool features a simple, intuitive interface that power electronics design engineers

can use to simulate any SiC-based power converter circuit topology: DC/DC, AC/DC, or DC/AC. Users simply input their specific application parameters, and the SpeedFit tool generates a comprehensive analysis of SiC device performance, including: voltage and current waveforms, average switching and conduction losses, and maximum junction temperature for specific operating conditions.

Engineers have the ability to select a topology, specify their recommended SiC power device or choose one from the library, define their thermal interface parameters and cooling method, and see the results immediately. Speedfit also allows users to specify external gate resistance, as well as major passive component values present in the circuit, allowing them to compare performance results for several different circuit configura-

tions and devices. The tool quickly, easily and accurately summarizes system parameters, device part numbers and simulation results in a single, concise report.

"Since the SpeedFit simulation tool was successfully developed using our widely adopted simulation engine, Wolfspeed has made files containing loss and thermal impedance information for their SiC devices available on their website so current PLECS platform users can download and access models for Wolfspeed SiC power devices," says Plexim's business development manager Kristofer Eberle. "Our PLECS Standalone tool features a free demo mode that provides access to a collection of pre-built designs, and can be accessed — along with free PLECS trial licenses for custom model development — on the Plexim website."

www.wolfspeed.com/speedfit

Wolfspeed highlights GaN-on-SiC RF HEMTs at IMS 2016

At the IEEE International Microwave Symposium (IMS 2016) in San Francisco (May 22–27), Wolfspeed of Research Triangle Park, NC, USA — a Cree Company that makes GaN-on-SiC high-electron-mobility transistors (HEMTs) and monolithic microwave integrated circuits (MMICs) — highlighted its latest RF and microwave devices and foundry services. The firm also supported the IMS 2016 STEM (Science, Technology Engineering & Math) program, and several on-site student design competitions.

Live product demonstrations of the latest Wolfspeed RF technology included the new CGHV14800, for L-band radar applications and reckoned to be the highest output power 50V GaN HEMT demonstrated to date (providing a minimum of 800W of pulsed power at 1.2–1.4GHz with better than 65% drain efficiency).

Another was the new CGHV59070 GaN HEMT for C-band radar systems, which delivers 50% drain efficiency at high gain, making it a suitable driver for the 350W, 5.2–5.9GHz CGHV59350 device released last year.

Wolfspeed also showcased a wide-band LTE Doherty power amplifier, developed using the firm's high-performance 0.4µm 50V GaN RF foundry process. The amplifier operates from 1.8–2.2GHz instantaneously, with 55% power-added efficiency at 7.5dB backed off to improve linearity.

Wolfspeed says that, compared to conventional silicon and gallium arsenide devices, its GaN-on-SiC devices deliver higher breakdown voltage, higher-temperature operation, higher efficiency, higher thermal conductivity, higher power density, and wider bandwidths. These qualities allow the firm's

GaN devices to enable smaller, lighter and more efficient microwave and RF products, including: radar, broadband, public safety, and ISM (industrial, scientific & medical) amplifiers; broadcast, satellite and tactical communications amplifiers; unmanned aerial vehicle (UAV) data links; cellular infrastructure; test instrumentation; and two-way private radios.

In addition to supporting the IMS 2016 STEM program, Wolfspeed supported two of the on-site student design competitions — one for High Efficiency Power Amplifier Design, and another that focuses on Power Amplifier Linearization Through Digital Pre-Distortion (DPD) — by both speaking with participating students and donating GaN HEMTs, large-signal models, and Doherty amplifiers built with Wolfspeed GaN HEMTs.

www.wolfspeed.com/RF

Qorvo launches GaN-on-SiC PAs for military radar, communications and electronic warfare applications

Qorvo Inc of Greensboro, NC and Hillsboro, OR, USA (which provides core technologies and RF solutions for mobile, infrastructure and aerospace/defense applications) has launched three gallium nitride on silicon carbide (GaN-on-SiC) power amplifiers (PAs) optimized for use in military radar, communications and electronic warfare (EW) systems:

- TGM2635-CP — an X-band 100W MMIC amplifier operating at 7.9–11GHz for satellite communications, data links and radar applications that provides 50dBm of saturated output power, with 22.5dB of large signal gain and 35% power-added efficiency (PAE). Available in a pure copper-base bolt-down package, the TGM2635-CP offers superior thermal management

for added system flexibility.

- TGA2307-SM — a C-band 50W MMIC amplifier operating at 5–6GHz that produces more than 47dBm of saturated output power with a PAE greater than 44% and a large-signal gain greater than 20dB. Packaged in a small low-cost 6mm x 6mm plastic overmold QFN package, the TGA2307-SM provides size, weight and power (SWAP) benefits for C-band radar applications.

- TGA2963 — a 20W wideband MMIC amplifier (in die form) operating at 6–18GHz for wideband communication platforms, radar systems, electronic warfare and test instrumentation that provides more than 43dBm saturated output power with PAE of more than 20% and a large-signal gain greater

than 20dB.

“Qorvo’s newest GaN PAs improve performance and reduce size and cost for defense radar, communications and EW systems by offering a combination of power, PAE and gain that is unmatched over their respective frequency bands,” claims Roger Hall, general manager of Qorvo’s Defense & Aerospace Products business unit.

Qorvo is a Defense Manufacturing Electronics Agency accredited 1A Trusted Source, having completed the Defense Production Act Title III GaN-on-SiC program in 2014. The firm remains the only GaN supplier to have achieved Manufacturing Readiness Level (MRL) 9.

www.ims2016.org

www.qorvo.com

Qorvo and NanoSemi demonstrate ultra-wideband linearization for massive multi-input multi-output transceivers

In conjunction with NanoSemi Inc of Waltham, MA, USA (a developer of digital linearization and compensation algorithms), Qorvo has demonstrated industry-leading ultra-wideband linearization results with its gallium nitride (GaN) power amplifiers for wireless infrastructure.

Qorvo’s QPA2705 is an integrated GaN driver and GaN Doherty power amplifier with 30dB gain, P3dB output power of 44dBm, power-added efficiency (PAE) of 35% at 37dBm average output power in a compact 6mm x 10mm surface-mount package for next-generation massive MIMO applications. Using the QPA2705 integrated GaN driver and GaN Doherty power amplifier with NanoSemi’s proprietary digital compensation algorithms, the two firms have achieved adjacent channel power ratio (ACPR) of –58dBc for a 60MHz signal bandwidth and 3x20MHz LTE carrier configuration, and –55dBc for a

100MHz signal bandwidth and 5x20MHz LTE carrier configuration.

Leading cellular operators are enhancing wireless spectrum efficiency and boosting network capacity by more than 500% by adopting technologies including massive multi-input multi-output (MIMO), active antenna systems (AAS) and LTE-Pro. Qorvo says that, by combining its ultra-compact power amplifier (PA) modules with NanoSemi’s digital pre-distortion (DPD) intellectual property, operators are able to implement highly efficient, small-form-factor massive MIMO transceivers for next-generation base-stations.

“Active antenna systems with 64 transceivers pose significant challenges to design power amplifiers with the small form factors, high efficiency and linearity needed for multi-carrier configurations,” says Sumit Tomar, general manager of Qorvo’s Wireless Infrastructure business unit. “The combination of Qorvo’s ultra-compact advanced

PA modules and NanoSemi’s DPD IP enables customers to implement high-efficiency, smaller-form-factor massive MIMO transceivers suitable for next-generation base-stations,” he adds.

“We are excited to collaborate with Qorvo and demonstrate best-in-class results with our digital compensation technology,” says NanoSemi’s CEO Helen Kim. “NanoSemi’s unique approach to digital pre-distortion (DPD) and CFR [crest factor reduction] enables our customers to tune their products to the sweet-spot of performance, resource needs, power and targeted bandwidth.”

NanoSemi and Qorvo have also demonstrated linearization of the QPA2705 cascaded Doherty driver amplifier and QPD2730 dual-channel GaN Doherty PA final stage with –58dBc for 60MHz LTE signals, and –55dBc for 100MHz LTE signals.

www.nanosemitech.com

www.ims2016.org

www.qorvo.com

Qorvo's GaN transistor passes stringent environmental tests, proving readiness for public safety and defense applications

Qorvo Inc of Greensboro, NC and Hillsboro, OR, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) says that its 15W gallium nitride on silicon carbide (GaN-on-SiC) wideband input-matched transistor has completed stringent environmental testing, demonstrating its reliability for use in defense and emergency response communications equipment.

"Qorvo has experience applying GaN technology to handheld communications equipment, like wideband handheld radios for first responders, with products that must operate reliably in challenging environmental conditions," says Roger Hall, general manager of the Defense & Aerospace Products business unit. "Qorvo's QPD1000 recently passed JEDEC's JESD22-A110D Highly Accelerated

Temperature/Humidity Stress Test (HAST), proving its reliability in harsh environmental conditions, including severe temperature, humidity and bias."

HAST measures a device at 130°C, 85% relative humidity and high atmospheric pressure for a minimum of 96 hours. Additional testing is ongoing, demonstrating the QDP1000's ability to exceed the industry standard test.

The QPD1000 wideband input-matched GaN transistor is offered in a low-cost, space-saving surface-mount plastic DFN package and operates at 30–1215MHz. With an integrated wideband input-matching network, the QPD1000 enables wideband gain and power performance along with high efficiency. The output can be matched on the board to optimize power and efficiency for any region within the band. The QDP1000 can be used in

continuous wave and pulsed signals for defense and public safety communications applications.

Qorvo is the leading GaN RF supplier for the defense and cable industries, according to market research firm Strategy Analytics. Since 1999, Qorvo has been offering proven GaN circuit reliability and compact, highly efficient products. Qorvo is a Defense Manufacturing Electronics Agency accredited 1A Trusted Source, having completed the Defense Production Act Title III GaN on SiC program in 2014. The firm remains the only GaN supplier to have achieved Manufacturing Readiness Level (MRL) 9.

Qorvo's GaN products were showcased at the IEEE MTT-S International Microwave Symposium (IMS 2016) in San Francisco (22–27 May).

www.ims2016.org

www.qorvo.com

Qorvo's new GaN 50V transistors boost power gain and efficiency for wideband defense & commercial radar, communications & avionics

Qorvo Inc of Greensboro, NC and Hillsboro, OR, USA (which provides core technologies and RF solutions for mobile, infrastructure and aerospace/defense applications) has launched six 50V gallium nitride (GaN) transistors designed to optimize power performance for commercial and defense radar, communications systems and avionics.

"This new family of 50V GaN transistors improves system performance by offering more power gain and power-added efficiency," says Roger Hall, general manager of Defense & Aerospace Products. "Qorvo can better enable defense equipment such as phased-array radars, to deliver higher performance while managing size, cost and power."

The new family of 50V GaN transistors is said to offer significant operational and system cost savings from greater system-level efficiency. The small device size and higher impedance input/output leads help to optimize board designs for radar, communications, avionics, wideband amplifiers and test instrumentation.

The new family of GaN transistors operates from 10W up to 125W Psat power levels. The 4GHz 15W QPD1009 and 10W QPD1010 are now available in low-cost 3mm x 3mm plastic QFN packages, while the 3.2GHz, 125W QPD1008(L) and 65W QPD1015(L) are now available in industry-standard, thermally enhanced NI-360 air-cavity ceramic packages, in both eared (L) and earless versions.

Qorvo is the leading GaN RF supplier for the defense and cable industries, according to market research firm Strategy Analytics. Since 1999, Qorvo has been offering proven GaN circuit reliability and compact, highly efficient products. Qorvo is a Defense Manufacturing Electronics Agency accredited 1A Trusted Source, having completed the Defense Production Act Title III GaN on SiC program in 2014. The firm remains the only GaN supplier to have achieved Manufacturing Readiness Level (MRL) 9.

Qorvo's GaN products were showcased at the IEEE International Microwave Symposium (IMS 2016) in San Francisco (22–27 May).

www.ims2016.org

MACOM sues Infineon over Nitronex's GaN technology for 4G/LTE and 5G networks

Infineon tried to renegotiate International Rectifier–Nitronex agreements to reduce MACOM's rights, it is alleged

MACOM Technology Solutions Holdings Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) has initiated legal action against Germany's Infineon Technologies AG and US-based International Rectifier (acquired by Infineon in 2015) to defend its rights to use the patented gallium nitride on silicon (GaN-on-Si) technology developed by Nitronex LLC of Durham, NC, USA (acquired by MACOM for \$26m in February 2014) in MACOM's core markets. GaN technology promises to improve network data service and cell coverage of 4G/LTE and 5G base-stations while reducing their energy consumption and associated carbon footprint, says MACOM.

In the lawsuit filed in the US District Court for the Central District of California in Los Angeles, it is alleged that Infineon has attempted to interfere with and usurp MACOM's rights under certain agreements

between Nitronex and International Rectifier. "Nitronex and IR, and later, MACOM and IR, successfully collaborated for many years. Problems developed only after Infineon acquired IR and began to try to 'renegotiate' the Nitronex–IR agreements to reduce MACOM's rights," says MACOM's president & CEO John Croteau. "When MACOM declined to accede to Infineon's demands, Infineon concocted claims to interfere with our rights under the agreements," he alleges.

"Infineon's behavior is clear validation that MACOM's GaN technology — the product of 15 years and over \$100m in investment — is at the tipping point of market adoption, threatening large incumbents like Infineon," continues Croteau. "This has caused Infineon to engage in strong-arm tactics designed to retard, rather than accelerate, innovation," he believes. "We submit that such business practices are unethical and anti-competitive and will strenuously oppose them as a matter of course."

MACOM's suit against Infineon includes claims for breach of contract, breach of the covenant of good faith and fair dealing, declaratory judgment of contractual rights, and intentional interference with contract. Among other relief, MACOM is asking the court to grant it declaratory and injunctive relief confirming its rights under the Nitronex–IR agreements and ordering Infineon to assign to MACOM several Nitronex GaN patents.

MACOM asserts that it has built a successful business that has benefited both the electronics industry, consumers and the firm's shareholders through the acquisition and integration of companies and intellectual property rights that support its strategic plans. Defending its intellectual property rights is core to MACOM's success and it has previously prevailed against large company infringement of its rights, the firm adds.

www.infineon.com

www.irf.com

MACOM demonstrates Gen4 GaN-on-silicon portfolio at IMS

At IEEE's International Microwave Symposium in late May, MACOM showcased its GaN-on-Si portfolio and other products, optimized for commercial, industrial, scientific and medical RF applications:

- a GaN 60W average-power Doherty module live demonstration with Xilinx DPD (digital pre-distortion) for base-station applications;
- a GaN for RF energy applications;
- new E-band TX and RX SMD modules and portfolio of wideband millimeter-wave products for addressing the emerging 5G access and backhaul markets;
- high-power (120W), broadband PIN diode transmit–receive (T/R) switch demonstrating low TX IL,

low RX IL, high RX isolation, small physical size, plastic SMT package across DC–1GHz for MILCOM and land mobile applications;

- a W-band power amplifier monolithic microwave integrated circuit (MMIC) covering 80–100GHz with what is claimed to be leading gain and power performance; and
- high-reliability and component products for mission-critical space and aerospace applications.

Also, MACOM participated in various sessions at IMS, including:

Workshop

'Use of Nonlinear Vector Network Analyzer Measurements in the Development of GaN on Silicon for BTS Applications' in session

'Large Signal Network Analysis: From Instrumentation Architectures to Software Applications for Your RF Design Flow Improvement';
'Transceivers for Highly Spectral Efficient Multi-Gbps radio links' in session 'E-Band Communications: Market, Technology and IC Design'.

Technical Session WE1B-3

'Soldered Hot-via E- and W-band Power Amplifier MMICs for Millimeter-wave Chip Scale Packaging'.

Microapps pavilion

'GaN on Silicon Power Amplifier Bias and Decoupling Techniques'; and 'GaN on Si Thermal Behavior and Its Impact on PA Performance, Reliability and Cost'.

www.macom.com/gan

MACOM launches 300W plastic-packaged GaN-on-Si power transistor for commercial RF energy applications

MACOM Technology Solutions Holdings Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) has launched the MAGE-102425-300, a 300W gallium nitride on silicon rugged power transistor in cost-effective plastic packaging optimized for commercial-scale solid-state RF energy applications. Based on MACOM's Gen4 GaN technology, it delivers performance that defies the inherent power efficiency and density limitations of LDMOS at an equivalent price profile at scaled volume production levels, says the firm.

The intersection of GaN performance and silicon cost structures opens up an opportunity to leverage solid-state RF energy as a highly efficient and precise heat and power source for a wide range of commercial applications including microwave ovens, automotive

ignition, lighting systems, and industrial, scientific & medical (ISM) applications such as RF plasma lighting, material drying, and blood and tissue heating and ablation. The RF devices that underpin these systems must strike an optimal balance of performance, power efficiency, small size, and reliability, at a price point that promotes mainstream commercial adoption.

Providing 300W output power and 70% efficiency at 2.45GHz, the MAGE-102425-300 meets the core technical requirements for next-generation power amplifiers proposed by the RF Energy Alliance (a non-profit technical association). Meanwhile, the cost structure and volume supply-chain benefits of MACOM's Gen4 GaN technology position the MAGE-102425-300 to meet aggressive cost targets on a par with LDMOS, the firm says.

"Solid-state RF energy technology holds the promise to transform entire

market segments, providing wide-ranging benefits from consumer goods to ISM systems and infrastructure," says senior director of marketing Mark Murphy. "The MAGE-102425-300 sets a new price and performance benchmark for RF power devices, affirms MACOM's GaN technology and application expertise, and signals a clear inflection point in the evolution toward mainstream RF energy adoption," he reckons.

"The RF Energy Alliance recently published the RF Power Amplifier (PA) Roadmap, which sets parameters for future PA module generations that are viable alternatives to magnetron-based solutions," notes the RF Energy Alliance's executive director Klaus Werner. "The MAGE-102425-300's breakthrough in efficiency is in step with our PA Roadmap, enabling new markets for residential solid-state RF energy applications."

www.rfenergy.org

www.macom.com/rfenergy

MACOM's latest 320W and 160W plastic-packaged GaN power transistors achieve 79% efficiency for wireless base-stations

MACOM has launched new entries in its MAGb series of GaN-on-Si power transistors for use in macro wireless base-stations. Based on its Gen4 GaN technology, the MAGb-101822-240B0P and -120B0P power transistors harness the performance benefits of GaN in rugged, low-cost plastic packaging, enabling improved cost efficiencies over legacy LDMOS silicon for base-station applications, says MACOM.

The plastic TO-272-packaged -240B0P and -120B0P provide 320W and 160W output peak power, respectively, in the load-pull system with fundamental tuning only, and cover all cellular bands and power levels in the 1.8–2.2GHz range. The ability to operate over 400MHz of bandwidth precludes the need for multiple LDMOS products, optimizing cost and design efficiencies.

Plastic-packaged MAGb power transistors deliver power efficiency up to 79% — an improvement of up to 10% compared to LDMOS — with only fundamental tuning across the 400MHz RF bandwidth, and with linear gain of up to 20dB. The transistors provide an alternative to ceramic-packaged devices without compromising RF performance or reliability — thermal behavior is improved by 10% versus ceramic-packaged MAGb offerings.

The power transistors enable the implementation of a simple symmetric Doherty amplifier design while maintaining superior RF performance compared to complex asymmetric Doherty topologies imposed by LDMOS transistors. With MAGb series transistors, Doherty amplifiers show the same level of digital pre-distortion (DPD)

friendliness as LDMOS solutions. MACOM hosted joint demonstrations with Xilinx's DPD solution at the International Microwave Symposium.

"DPD is critical to increase the efficiency of power amplifiers for 4G and 5G base-station applications and has a significant impact on network operators' operating expenses and capital expenditures," says Dr Chris Dick, chief DSP architect at Xilinx.

"Our collaboration with Xilinx demonstrates the linearity and ease of correction of our MAGb, especially with signals that are known to be challenging to correct using GaN-based solutions like multi-carrier GSM and TDD-LTE signals," said Preet Virk, senior VP & general manager, Carrier Networks, at MACOM.

www.macom.com/wirelessinfra

NXP launches GaN transistors for EW & communications

NXP Semiconductors N.V. of Eindhoven, The Netherlands has expanded its portfolio of broadband GaN RF power transistors suitable for electronic warfare (EW) and battlefield radio applications, including launching six new driver or final-stage amplifiers with frequency coverage as broad as 1–3000MHz.

The new GaN-on-SiC transistors combine high power density, ruggedness and very flat frequency response over wide bandwidths. All are input matched to optimize operating frequency range, and can withstand a VSWR (voltage standing wave ratio) greater than 20:1 with 3dB overdrive without degradation. They are also part of NXP's Product Longevity Program.

The transistors' broadband frequency coverage from HF to S-band allows them to cover virtually all frequencies used by radios or the lower-frequency sections of electronic systems. This reduces the number of RF power transistors

required to build an amplifier with a specific RF output level, which decreases the amplifier size and bill of materials, says NXP.

The new transistors include:

- MMRF5011N (28V) and MMRF5013N (50V): operating at 1–3000MHz with RF output power up to 12W CW, 15dB gain, and 60% efficiency, housed in an OM-270-8 over-molded plastic package;
- MMRF5015NR5: operating at 1–2700MHz with RF output power up to 125W CW, 16dB gain, and 64% efficiency, housed in an OM-270-2 over-molded plastic package;
- MMRF5019N: operating at 1–3000MHz with RF output power up to 25W CW, 18dB gain, and 40% efficiency, housed in an OM-270-8 over-molded plastic package;
- MMRF5021H: operating at 1–2700MHz with RF output power up to 250W CW, 16dB gain, and 58% efficiency, housed in a NI-780H-4L air-cavity ceramic package;
- MMRF5023N: operating at 1–2700MHz with RF output power

up to 63W CW, 16dB gain, and 60% efficiency, housed in an OM-270-2 over-molded plastic package.

"Our customers want to reduce the size, weight and power of military systems even at the device level," says Paul Hart, executive VP & general manager of NXP's RF Power business unit. "Our new GaN transistors meet these requirements and can provide improved ruggedness, broad operating bandwidth and high efficiency," he adds.

The new transistors join NXP's expanding portfolio of RF power transistors suitable for defense systems that operate in HF, VHF, UHF and L-band radar, IFF transponders and avionics systems. As well as GaN devices, NXP offers over 40 LDMOS transistors covering 1–3000MHz with RF output up to 1500W.

The six new transistors are either sampling or in production. Application circuits are available that support CW operation in frequencies within the range 30–2600MHz.

www.nxp.com/RFmilitary

GaN RF power transistors for Doherty amplifiers in base-stations

NXP has expanded its portfolio of 48V GaN RF power transistors for Doherty power amplifiers for use in cellular base-stations. The four new transistors collectively cover bands from 1805MHz to 3600MHz, meeting the needs of wireless carriers for superior performance at higher frequencies.

With the wireless spectrum shortage, carriers are exploring higher frequencies to accommodate the exponential annual increases in traffic, notes NXP. These networks require RF power transistors and amplifiers that deliver higher performance over wider signal bandwidths, as well as higher efficiency and ruggedness, higher output power and smaller footprints.

Designed to meet these challenges, the new GaN transistors have high efficiency and gain, and are extremely rugged, with the ability to

deliver their rated performance with an impedance mismatch (VSWR) greater than 10:1. Designed for use in Doherty power amplifiers, the transistors are optimized for integration with digital pre-distortion linearization systems.

The new products are:

- A2G22S251-01S: Ultra-wideband symmetrical Doherty two device solution covering 1805–2170MHz (365MHz bandwidth). In a symmetric Doherty, it delivers average RF output of 71W (450W peak), gain of 16.5dB, and drain efficiency of 46% in concurrent multi-band operation at 8dB back-off configured. The device is housed in a NI-400S-2S air-cavity ceramic package.
- A2G26H281-04S: NXP's first in-package Doherty transistor covering 2496–2690MHz, with average RF output power of 50W (288W peak), gain of 15.3dB, and drain efficiency

of 57% configured in a NI-780S-4L air-cavity ceramic package.

- A2G35S160- & A2G35S200-01S: Two-transistor Doherty amplifier solution covering 3400–3600MHz with 53W average RF output power (331W peak), gain of 13.8dB, and drain efficiency of 46%. Each of these transistors is housed in a NI-400S-2S air-cavity ceramic package.

"Cellular customers are actively pursuing GaN technology especially in higher frequency bands," says Paul Hart, general manager of NXP's RF power business unit. "Given its leadership in the cellular base-station market, NXP is committed to being a dominant source of top-quality GaN products," he adds. "Our new transistors fully harness the inherent strengths of GaN enabling broad bandwidth, efficient and compact solutions."

www.nxp.com/products/rf

ACCESS achieves record 6Gb/s terrestrial radio transmission over 37km

GaN power amplifiers and InGaAs LNAs enable 71–76GHz E-band wireless to exceeding state of the art by factor of 10

The collaborative project ACCESS (Advanced E Band Satellite Link Studies) has set a record in terrestrial radio transmission, achieving a data rate of 6Gb/s over a distance of 37km (exceeding the state of the art by a factor of 10).

Comprising a research group headed by professor Ingmar Kallfass from the Institute of Robust Power Semiconductor Systems (ILH) at the University of Stuttgart, the Institut für Hochfrequenztechnik und Elektronik (IHE) at the Karlsruhe Institute of Technology (KIT), industrial partner Radiometer Physics GmbH (A Rohde & Schwarz Company), and the Fraunhofer Institute for Applied Solid State Physics IAF, the ACCESS team realised the record data transmission on a stretch between stations located on the 45-storey Uni-Center in Cologne and the site of the Space Observation Radar TIRA at the Fraunhofer Institute for High Frequency Physics and Radar Techniques FHR in Wachtberg 36.7km away.

The high data rate of 6Gb/s was achieved by using efficient transmitters and receivers at radio frequencies of 71–76GHz in the E-band (regulated for terrestrial and satellite broadcasting). Only in this millimeter-wave frequency range are the required high effective bandwidths available. A further difficulty is the weakening of the signals over larger distances. The transmission must be especially powerful, and the amplifiers must be correspondingly efficient. The key to the unique combination of gigabit data rates and great distance is efficient transmitters and receivers in the form of fully monolithically integrated millimetre-wave circuits (MMICs) based on two different transistor technologies developed and manufactured by project partner Fraunhofer IAF.



E-band transmitters with parabolic antenna.

In the transmitter the broadband signals are amplified to a comparatively high transmission power of up to 1W with the help of power amplifiers based on gallium nitride (GaN). A highly directive parabolic antenna emits the signals. Built into the receiver are low-noise amplifiers (LNAs) based on high-speed transistors using indium gallium arsenide (InGaAs) layers with very high electron mobility, ensuring the detection of the weak signals at great distance.

Radio transmission of high amounts of data over great distance serves many important application areas. For example, the next generation of satellite communication requires an ever-increasing data offload from earth observation satellites down to earth. The trial shows that supplying rural areas and remote regions with fast Internet is possible: 250 Internet connections can be supplied with 24Mb/s ADSL. Terrestrial radio transmissions in the E-band are suitable as a cost-effective replacement for the deployment of optical fiber or as ad-hoc networks in the case of crises and catastrophe, and for connecting base-stations in the backhaul of mobile communication systems.

The ever-increasing demand for higher data rates in fiber-based and wireless communication networks can only be met by technical innovations in network infrastructure. Developments such as the Internet of Things (IoT) and Industry 4.0 are

still in their early stages, and will demand unprecedented aggregated data quantities. Their processing and transmission in cloud-based services is already taking the communication infrastructure to its limits. In satellite communication as well, the progress in earth observation and space research as well as plans for a planet-scale satellite network are leading to as-yet unsolved challenges for the communication infrastructure.

The ACCESS project was completed at the end of April and is being continued in the follow-up project ELIPSE (E-band Link Platform and Test for Satellite Communication), targeting the next generation of communication systems for the fast connection of satellites. However, a further application lies in terrestrial fixed wireless links.

The ACCESS project was funded by the Federal Ministry for Economy and Energy (BMWi) on the basis of a resolution by the German Bundestag.

Support was provided by Fraunhofer FHR, the Uni-Center Cologne and the Südwest-Rundfunk (SWR), who granted access to their buildings.

www.iaf.fraunhofer.de

Richardson to distribute GaN Systems' power devices

Richardson RFPD Inc (an Arrow Electronics company) — which specializes in the RF and wireless communications, power conversion and renewable energy markets — is to sell the gallium nitride in silicon (GaN-on-Si) power devices of GaN Systems Inc of Ottawa, Ontario, Canada, on a global basis, excluding Israel.

GaN Systems is a fabless firm that provides a range of gallium nitride high-power transistors for consumer, enterprise, industrial, solar/wind/smartgrid, and

transportation power-conversion applications.

"GaN Systems adds another innovative technology to our power-conversion linecard," says Richardson RFPD's president Rafael R. Salmi Ph.D. "GaN Systems brings GaN industry leadership to our portfolio, which already includes silicon carbide industry leaders. This ensures we can better support our customers that want to leverage the benefits of wide-bandgap semiconductors," he adds.

"GaN Systems' products have

been adopted globally across consumer, industrial, data-center and transportation markets," says GaN Systems' VP of sales & marketing Larry Spaziani. "To respond to the increased demand for our products and to provide the highest level of service for customers and prospects, we are pleased to partner with Richardson RFPD, a leading global distributor with a strong energy and power focus and dedicated resources in the markets we serve."

www.richardsonrfpd.com

www.gansystems.com

GaN Systems showcases customers' products using its transistors

At PCIM (Power Conversion Intelligent Motion) Europe 2016 in Nuremberg, Germany (10–12 May), GaN Systems showcased a lineup of its customers' systems that are enabled by gallium nitride transistors.

The customer products featured included:

- a 1kW energy storage system that is 50% smaller than prior silicon-based solutions;
- high-current power modules used in the industrial and automotive industries;

- a 1.2kW battery charger delivering 33% more power in the same volume as its silicon predecessor;

- a 12kW stop-start generator showcasing a 5x size reduction;

- a >97% efficient, ultra-compact electric vehicle (EV) charger;

- a multi-voltage, high-speed 1.5kW motor controller; and

- a high-power, high-efficiency traction inverter using GaN power modules.

As well as commercial products, GaN Systems exhibited the inverter

enabled by its transistors which recently won Google's Little Box Challenge. The team Red Electrical Devils from CE+T Power of Wandre, Belgium, won the US\$1m first prize for designing, building, and demonstrating an inverter with the highest power density in the smallest volume: 143W/cubic inch in only 14 cubic inches. Also on show is be a half-bridge evaluation board that simplifies GaN transistor testing.

www.mesago.de/en/PCIM/main.htm

Intersil extending radiation-tolerant portfolio to GaN power conversion ICs for satellite applications

Intersil collaborating with EPC to sample eGaN-based products this summer

Intersil Corp of Milpitas, CA, USA, a provider of power management and precision analog solutions, says that it plans to extend its radiation-tolerant portfolio to include gallium nitride (GaN) power conversion ICs for satellites and other harsh-environment applications.

Intersil intends to couple its radiation-hardened field-effect transistor (FET) drivers with GaN FETs to deliver performance that leapfrogs existing products that rely on traditional high-reliability FET technologies. GaN provides better

conductivity and switching characteristics that enable several system benefits, including a reduction in system power losses.

"Intersil has decades of experience developing state-of-the-art radiation-tolerant devices and a long heritage supplying space flight applications," says Philip Chesley, senior VP of Precision Products at Intersil. "When combined with the demonstrated ability of GaN devices to operate reliably under harsh environmental conditions, we will provide customers with a

far superior alternative to existing FET technology," he reckons.

Intersil is collaborating with Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA — the first firm to introduce enhancement-mode gallium-nitride-on-silicon (eGaN) FETs as a replacement for power MOSFET, and a provider of E-mode GaN power transistors. Intersil's new products based on the eGaN technology will be sampling this summer.

www.intersil.com

www.epc-co.com

Panasonic showcases GaN-based technologies at PCIM

At PCIM (Power Conversion Intelligent Motion) Europe 2016 in Nuremberg, Germany (10–12 May), Panasonic Automotive & Industrial Systems Europe showcased its technology lineup, highlighting innovations including passive components, semiconductors and thermal management solutions that provide increased efficiency and reliability for a range of applications. These included an X-GaN gate driver.

With GaN moving into mainstream production, Panasonic exhibited applications that harness the power of its transistors. Optimized for high-frequency switching, the newly

released X-GaN gate driver unlocks the full performance of the X-GaN transistor while keeping design efforts to a minimum. With fine control possible (0.5–99.5% @ 50kHz), the device benefits from a built-in precise current source optimized for GiT transistors and a built-in negative voltage source.

Panasonic also exhibited example GaN applications: GaN-based compact power supply units and a GaN-based inverter for motors. Also featured were a GaN evaluation environment, GaN power devices, power modules (GaN- and SiC-based) as well as a bi-directional AC/DC

converter for power storage systems (as an example SiC application).

In addition, for the first time in Europe, to showcase one of its applications Panasonic presented its prototype of assist robots that applies X-GaN technologies. Power assist suits for industrial applications have been developed by Activelink Co Ltd (one of Panasonic's in-house venture companies). Panasonic has applied X-GaN inverter technologies to ActiveLink's assist suit (which is equipped with motors that assist human body mechanics).

<https://eu.industrial.panasonic.com/products/semiconductors/gan-power>

Ampleon's 2nd-gen 50V, 0.5µm RF power transistors

Ampleon Netherlands B.V. of Nijmegen, The Netherlands (formerly NXP Semiconductors N.V.'s RF Power business, acquired by China's Jianguang Asset Management Co Ltd last December) has launched its second generation of 50V, 0.5µm gallium nitride on silicon carbide (GaN-on-SiC) RF power transistors, dedicated for mobile broadband applications.

Providing a 5% improvement in power efficiency compared with LDMOS-based silicon devices, and enabling high-power multi-band applications, the new GaN family also offers a size reduction of

30–50% compared with similar LDMOS transistors. Designers of power amplifiers (PAs) can now more easily find a suitable fit for each particular set of requirements (efficiency, size, power and cost) while getting the full benefit of Ampleon's experience in PA and transistor design, and manufacturing, says the firm.

The new portfolio will include transistors with 15–600W of peak power for all major cellular bands between 1.8GHz and 3.8GHz.

The CLF2H27LS-140 is a single-ended transistor providing 140W of peak power in band 41. Other

devices currently sampling include the CLF2H1822LS-160 and CLF2H1822LS-220 suitable for 1.8–2.2GHz multi-band applications and the CLF2H38LS-140 and CLF2H38LS-40 (driver) for 3.4–3.8GHz applications with 140W and 40W outputs at P3dB.

The family is suitable for RF PA designers developing high-efficiency or multi-band Doherty PAs for use in wireless infrastructure networks.

Ampleon also provides application support, including ready-to-go Doherty reference designs optimized for mass-production.

www.ampleon.com

Akoustis presents AlGaIn-on-Si BAW filter technology

Akoustis Technologies Inc of Huntersville, NC, USA (in the Piedmont technology corridor between Charlotte and Raleigh), which manufactures patent-pending BulkONE single-crystal piezoelectric bulk acoustic wave (BAW) RF filters for mobile wireless applications, says that chief device scientist Dr Rama Vetury was a presenter at the IEEE Radio Frequency Integrated Circuits Symposium (RFIC 2016) in San Francisco (22–24 May) as part of Microwave Week 2016.

During the presentation 'Single Crystal AlGaIn Bulk Acoustic Wave Resonators on Silicon Substrates with High Electromechanical Coupling', Vetury highlighted the firm's single-crystal RF resonator technology, recent technical milestones, and its application to wide-bandwidth, high-frequency RF filter applications for mobile communications.

Akoustis is also providing an update on the development of a new class of BAW-based RF filters

based on patented, highly differentiated high-purity single-crystal piezoelectric materials. Targeting the fast-growing multi-billion-dollar market of device OEMs, network providers and consumers, the firm's BulkONE technology aims to reduce front-end phone heat, battery drain and signal loss — which are all considered to be directly related to the limitations of existing RF filter technologies.

<http://rfic-ieee.org>
www.akoustis.com

Exagan partners with TÜV Nord Group's Aerospace and Electronics business unit to establish GaN-on-Si's reliability for power converters

Gallium nitride (GaN) technology start-up Exagan of Grenoble, France has begun a strategic partnership to develop and commercialize GaN-on-silicon products with HIREX Engineering, a company of Alter Technology Group (TÜV Nord Group's Aerospace and Electronics business unit). TÜV NORD is a multi-national technical services provider to aerospace, industrial, mobile communications and IT markets.

Based in Grenoble, France (with a branch office in Toulouse), Exagan was spun off in 2014 from Soitec and micro- and nanotechnology research center CEA-Leti (with financial support from each), and licenses materials and technology from both organizations. Exagan aims to accelerate the power-electronics industry's transition from silicon-based technology to GaN-on-Si technology, enabling smaller and more efficient electrical converters. The firm's GaN power switches are designed for full compatibility with manufacturing in standard 200mm-wafer silicon foundries to deliver high-performance, high-reliability products through a robust supply chain.

The goal of the partnership with HIREX is to establish the reliability of GaN-on-Si while also demonstrating to users the performance improvements to be gained and the low risk of integrating the energy-efficient technology in their own products.

Located near Toulouse, France, HIREX conducts reliability testing and qualification of ICs and discrete semiconductors for aerospace and industrial high-reliability applications. Together, the firms will test and qualify Exagan's G-FET products, which are fabricated using standard 200mm silicon processing and proprietary G-Stack technology. G-FETs can be used in making smaller, more efficient power converters that have a broad range of applications in high-growth markets including plug-in hybrid and full-electric vehicles (HEV/EV), solar energy and industrial applications as well as efficient charging of all mobile electronic devices.

"This dynamic partnership will help to propel GaN market development by pioneering test methodologies and measurement processes that make it easier for makers of electrical

converters to implement GaN in improving their products," says Exagan's president & CEO Frédéric Dupont. "This timing is perfect to combine Exagan's strengths with those of the top European specialist in high-reliability testing. GaN technology has matured to deliver the high performance of silicon carbide (SiC) devices at silicon IC price and quality levels, and our key markets are ready for this next-generation solution," he adds.

"Through its participation, HIREX Engineering will expand its expertise and business portfolio to include advanced power GaN technology and the end products it enables," says Alter Technology Group's CEO Luis Gomez. "We hope to establish robust and easy-to-reference product parameters for GaN that will allow fast integration in electrical converters," he adds.

"We are confident that GaN's bulletproof reliability will present remarkable advantages in the fast-growing power electronics market," comments TÜV Nord Group's CEO Dr Guido Rettig.

www.altertechnology.com/atn/en/hirex-engineering/about-hirex-438.htm
www.tuev-nord-group.com

Exagan showcases GaN-on-silicon technology and announces strategic partnership at PCIM Europe

At the PCIM (Power Conversion Intelligent Motion) Europe 2016 trade show in Nuremberg, Germany (on 10 May), Exagan of Grenoble, France, a gallium nitride (GaN) technology start-up that enables smaller and more efficient electrical converters, announced its latest strategic partnership to develop and commercialize GaN-on-silicon products.

The new partnership will be the third major alliance to be announced by Exagan in the past

12 months. In the span of two weeks last May, the firm entered a strategic partnership with CEA-Leti to accelerate the GaN-on-Si technology integration roadmap and a joint development agreement with X-FAB Silicon Foundries AG of Erfurt, Germany to develop a high-volume production process for GaN-on-Si devices using 200mm wafers.

GaN-on-Si technology's capabilities in power integration and energy efficiency can increase the

performance and decrease the size of power converters, says Exagan, making these systems suitable for a wide range of applications — from electric vehicles and solar energy to industrial electronics and re-charging consumers' mobile devices.

Also at PCIM Europe, Exagan showcased its latest innovations in GaN-on-Si technology and its G-FET fast-switching, high-efficiency power transistors.

www.exagan.com

IQE joins imec's GaN-on-Si Industrial Affiliation Program

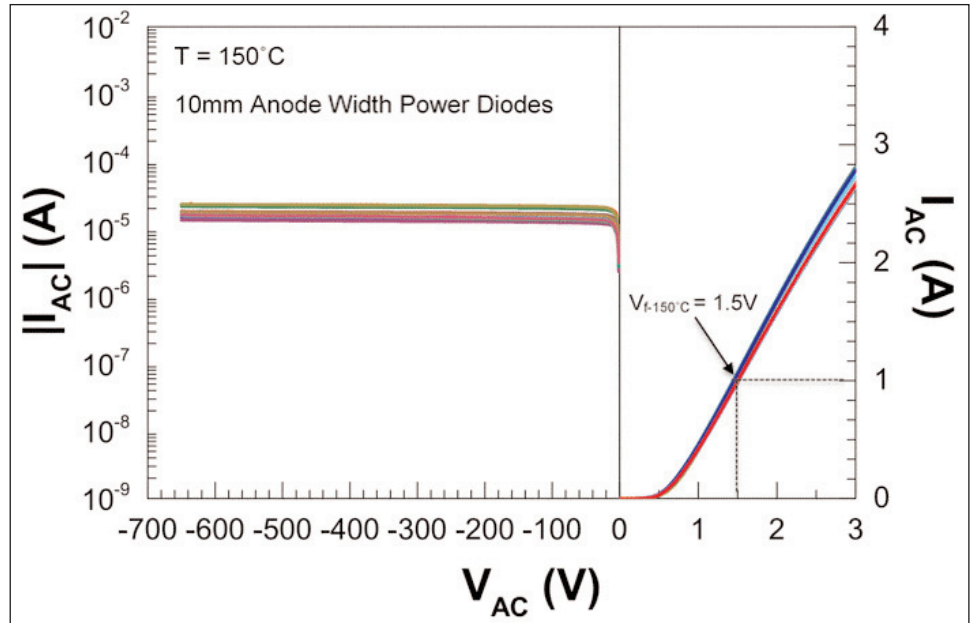
IQE and imec demonstrate 650V power diodes on 200mm wafers

Epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK has announced a strategic partnership on gallium nitride-on-silicon (GaN-on-Si) technology with nanoelectronics research centre imec of Leuven, Belgium.

GaN technology offers faster power-switching devices with higher breakdown voltage and lower on-resistance than silicon, suiting advanced power electronic components. The partnership builds on promising results achieved in a recent project, in which imec and IQE collaborated to fabricate GaN power diodes using imec's proprietary diode architecture and IQE's high-voltage epiwafers.

imec's GaN-on-Si Industrial Affiliation Program offers joint R&D on GaN-on-Si 200mm epitaxy and enhancement-mode device technology to companies including integrated device manufacturers (IDMs), equipment and material suppliers, fabless design houses and packaging companies. The program includes research on novel substrates to improve the quality of epitaxial layers, new isolation modules to enhance integration levels, and advanced vertical device development. As a GaN-on-Si Program partner, IQE gains access to next-generation epitaxy, devices and power electronics processes, including imec's complete 200mm CMOS-compatible GaN process line.

"The importance of GaN-on-Si for power devices cannot be understated, particularly as we enter an era of electrically propelled transportation and increasing demands for energy-efficient power control systems that require high-voltage and high-power capabilities," says Wayne Johnson, head of IQE's Power business unit. "IQE's proven track record in developing and manufacturing GaN-based epiwafers, coupled with imec's unquestionable reputation for world-leading research in nanoelectronics, makes for a powerful collaboration in this rapidly



Forward and reverse diode current at high temperature (150°C). The diodes have 10mm anode width and an anode-to-cathode distance of 10µm.

growing technology space," he adds.

In its earlier collaborative project, imec worked with IQE to create state-of-the-art GaN power diodes.

Imec has applied its proprietary gated edge terminated (GET) Schottky diode device architecture to IQE's high-voltage GaN buffers on 200mm silicon substrates. The main challenge on power diodes is to obtain devices that simultaneously show low leakage current and low turn-on voltage. Due to the GET

The main challenge on power diodes is to obtain devices that simultaneously show low leakage current and low turn-on voltage. Due to the GET diode architecture and to the low buffer leakage current of IQE wafers, the large GaN power diodes showed a low leakage current (up to 650V) and low turn-on voltage

diode device architecture and to the low buffer leakage current of IQE wafers, the large GaN power diodes (10mm), which were fabricated in imec's 200mm silicon pilot line, showed a low leakage current (up to 650V) and low turn-on voltage. The power Schottky diodes reaches forward and reverse specifications across the full temperature range, spanning from 25°C to 150°C with a tight distribution.

"Our joint results show that the IQE epiwafers are of excellent quality and are well aligned to meet the specifications for power Schottky diodes," comments Rudi Cartuyvels, executive VP smart systems and energy technology at imec. We look forward to collaborating with IQE to advance our promising results, which demonstrate that our proprietary GET Schottky diode device architecture and process technology can be transferred to external wafers like those provided by IQE," he adds. "Our 200mm GaN-on-Si process is available to our program partners and is engineered to fit partner specific product needs."

www.iqep.com

www.imec.be

IQE transfers Translucent's cREO growth capability to North Carolina facility

Interface charge tuning demonstrated using cREO for GaN-on-Si

At the International Conference on Compound Semiconductor Manufacturing Technology (CS MANTECH 2016) in Miami, FL, USA (16–18 May), epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK has announced two key developments.

Transfer of cREO growth technology to North Carolina facility

IQE has successfully transferred the cREO (rare earth oxide) molecular beam epitaxy (MBE) deposition equipment and associated process of Translucent Inc of Palo Alto, CA, USA to its facility in Greensboro, North Carolina. Translucent (a subsidiary of Australian-listed company Silex Systems Ltd) provides cREO engineered silicon substrates for low-cost epitaxy.

Following the exclusive license of cREO technology from Translucent last September and the initial license fee payment of \$1.4m (in IQE shares) this March, IQE has transferred two of Translucent's reactors to Greensboro. The first (production) system has been installed and is now producing cREO templates on silicon. The template structural and morphological characteristics are said to be an excellent match to results previously achieved by Translucent. The second (R&D) system is due to be online in about a month.

The production tool will produce standard templates for the IQE group and select commercial partners, with an initial focus on III-N materials for RF (wireless) communications and power electronics applications.

Demonstration of interface charge tuning using cREO for GaN products

Using cREO templates, IQE has demonstrated that it can tune the interfacial characteristics for gallium nitride on silicon (GaN-on-Si).

For RF applications, GaN-on-Si typically exhibits an undesirable p-type channel at the GaN/Si interface (a parasitic channel) that detrimentally affects RF efficiency. Using its patented technology, IQE has demonstrated that the parasitic channel can be completely eliminated. In addition, the firm has shown that growth conditions can be tuned to generate and rationally engineer an n-type layer between the GaN and silicon. This enables applications that require buried conductors for III-N on Si applications.

"We have demonstrated that we are able to rationally manipulate the cREO characteristics to tune the conductivity of the III-N/Si interface," says Dr Rodney Pelzel, vice president, IQE Group Technology. "This is a significant enabler for GaN HEMT [high-electron-mobility

transistor] technology on silicon for RF applications. In addition, it is an enabler for other III-N technology on Si such as RF filter technology," he adds.

"IQE is committed to fully exploiting cREO technology for GaN as well as other III-V and group IV materials. This technology offers exciting opportunities for fully realizing III-V growth on Si, thereby eliminating the cost-prohibitive issue with native substrates such as InP," Pelzel continues. "Furthermore, it enables hetero-integration at the epi level, allowing previously incompatible materials systems to be successfully combined. cREO is an excellent complement to IQE's well-established wireless, photonics, power, and CMOS products and will enable novel solutions for our customers."

Under the terms of the license and assignment agreement signed last September, IQE has 30 months in which to decide to acquire Translucent's technology with the payment of a further \$5m. Upon commercialization of the technology, a perpetual royalty of 3–6% of IQE's revenues generated from the technology would be payable to Translucent.

www.translucentinc.com

www.csmantech.org

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AXT's greater-than-expected growth in Q1 driven by InP Higher-margin product mix drives firm into profit

For first-quarter 2016, 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 \$18.7m, down 7% on \$20.1m a year ago but 3.3% up on \$18.1m last quarter and above the expected \$17.5–18.5m.

Of total revenue, 64% came from Asia Pacific, 23% from Europe, and 13% from North America. Only one customer generated more than 10% of revenue, and the top five generated 41% of total revenue (down from 45% two quarters ago), reflecting diversification of both products and customers.

InP was again the largest product category (AXT's strongest InP revenue in recent years) — greater than semi-insulating GaAs, semi-conducting GaAs and germanium products — contributing more than 30% of total revenue (up from under 30% last quarter).

"InP is still an emerging material — the drivers for its demand are significant and are becoming clearer as activity steadily increases," says CEO Dr Morris Young. "InP sales continued to be driven by lasers and detectors for fiber-optic communications and passive optical network applications such as EPON and GPON," says Young. "These short-haul networks are used for Internet access, voice-over-Internet protocol (VoIP), digital TV delivery in metropolitan areas, and backhaul connections for 4G cellular base-stations," he adds.

"In addition, silicon photonics continue to grow rapidly as a driver for indium phosphide. A number of leading companies including Cisco, HP, IBM and Intel are developing their technology for next-generation data-centers to improve connectivity both within and between that," says Young. "Here again, InP is a material of choice for the transmitter and receiver at each end of the data stream," he adds.

"Finally, we are seeing increasing

evidence that high-performance substrates will be a key element for 5G wireless technology. In order to support ultra-high-definition and 3G video, video frequency front-ends are moving towards multi-mode, multi-band power amplifiers that can operate at significant higher frequencies. These will be challenging for silicon or even gallium arsenide. As a result, RF suppliers are actively evaluating indium phosphide for its performance capabilities in meeting the more stringent requirement of 5G wireless," continues Young. "We are now receiving request from multiple customers for several quantities of 6-inch InP substrates. InP-based derivatives for all of these applications at time specification requirements, limiting the field of competitors that can address them.

As we have noted, opto-electronics devices require very low etch-pit density (EPD) material, a specification in which AXT's VGF [vertical gradient freeze] technology strongly excels," he adds.

"In addition, performance is a much larger factor than price. These contribute to a much more stable margin profile and pricing stability

than we see total today in gallium arsenide," Young notes. "AXT's superior performance has allowed us to take a market-leading position and enjoy healthy growth as customer demand continues to increase," he claims.

Semi-insulating gallium arsenide revenue was down, but AXT did achieve some yield improvements in manufacturing. "This area of our business has reached a relatively stable level, having weathered a major technology transition in previous years," says Young. "For semiconducting gallium arsenide, we continue to play modestly because of the serious competitive landscape and corresponding pricing environment in the general market. However, we continue to pursue higher-end applications such as backlighting, signage and automotive, where title specification allows us to come in at better margins."

In addition, AXT is seeing increasing interest in sample wafers for vertical-cavity surface-emitting lasers (VCSELs), driven by applications such as gesture recognition and 3D sensing. "VCSELs bring together the advantage of low cost and optical efficiency within a small footprint," says Young. "Unlike other optoelectronic devices, VCSELs have highly stringent EPD requirements. We believe that the VCSEL markets could become a significant driver for semiconducting gallium arsenide, sometime next year."

For raw materials, the overall market remains challenging. Revenue fell in Q1, due largely to pricing pressures. In particular, the market for gallium has experienced the greatest decline in both sales volume and pricing in recent quarters as a result of oversupply. "However, we believe that several suppliers are now considering cutting their production in an effort to balance demand. We are hopeful that this will result in greater pricing stability in the coming quarters," says Young. "Overall, raw material pricing

Front-ends are moving towards multi-mode, multi-band power amplifiers that can operate at significant higher frequencies. These will be challenging for silicon or even GaAs. RF suppliers are actively evaluating InP for its performance capabilities in meeting the more stringent requirement of 5G wireless. We are now receiving request from multiple customers for several quantities of 6-inch InP

► remains reflective of the continued general weakness worldwide in commodities. However, these joint ventures had been a positive contributor to our business for the last 15 years, and we believe they continue to represent an important part of our value proposition and competitive differentiation," he adds.

"Q1 was a strong quarter for AXT in which we exceeded our revenue and profitability guidance, and posted a strong increase in both our gross and operating margins from the prior quarter," notes Young.

"Our manufacturing team continues to work on efficiency and yield improvement, and these efforts — along with our product mix [favoring InP] — helped improve our gross margin." Gross margin was 28.1%, rebounding strongly from 17.1% last quarter (when AXT took a lower cost of market inventory write-down charge from one of its gallium raw material subsidiaries, reducing margin by about 3 percentage points). "If you look at our gross margin over the four quarters

before Q4/2015, gallium write-down has been averaging close to 24% and then in Q4 it dropped," notes chief financial officer Gary Fischer. "Q1 is a good rebound, driven by more indium phosphide sales and more efficient manufacturing."

Operating expenses were \$4.8m, level with last quarter but cut from \$6.5m a year ago, due mainly to selling, general & administrative (SG&A) expenses falling from \$5.3m to \$3.4m.

Net profit was \$42,000 (\$0.00 per share), compared with a net loss of \$1.2m (\$0.04 per share) last quarter and \$1m (\$0.03 per share) a year ago (and better than the expected loss of \$0.03–0.05 per share) due to the increased InP in the product mix, increased revenue, and improved gross margin.

Capital expenditure (CapEx) was \$0.8m (up from \$0.5m last quarter). During the quarter, cash and investments fell from \$44m to \$43.3m.

For Q2/2016, AXT expects further growth in revenue to \$19.5–20.5m (led by InP) and between breakeven

and a profit of \$0.02 per share.

"The Beijing city government has announced that it will expand its offices into the area where our manufacturing facility is located. They want to upgrade this area and they're applying pressure on manufacturing companies to relocate," notes Fischer. "We're cooperating with them and have reached a verbal understanding to reduce our usage of arsenic at the current site by 31 March 2017, and we have agreed to stop production of gallium arsenide wafers at this site by 31 December 2017," he adds. "There is no similar agreement addressing InP or germanium, but internally we believe that they will insist that we also stop manufacturing InP and germanium at this location sometime in 2018. We're in the process of looking at alternative sites and looking for a plant for an orderly phased relocation," Fischer continues. "Eventually, if we do totally vacate our current site, we will probably put it up for sale."

www.axt.com

Riber's Q1 revenue almost halves year-on-year ...but orders almost treble, driven by recovery in MBE systems

Riber S.A. of Bezons, France, which manufactures molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells, says that its quarterly revenue had almost halved year-on-year from €2.7m in first-quarter 2015, down 52% to €1.4m in first-quarter 2016 (30% from Asia, 33% from Europe, 37% from the USA).

While no revenue was recorded for MBE systems (compared with €1.5m a year ago), this reflects a delivery schedule for system orders that is focused on second-half 2016 and is not indicative of the firm's performance over the full year.

Sales of services, accessories and cells show 17% growth year-on-year from €1.2m in Q1/2015 to €1.4m in Q1/2016, driven by sustained demand in the USA and the good commercial performance achieved

following the acquisition at the end of March 2015 of MBE Control Solutions of Santa Barbara, CA, USA (which provides MBE system maintenance and refurbishment services). Specifically, revenue for services & accessories has risen by 11% from €0.9m to €1m, while revenue for cells & sources has risen by 33% from €0.3m to €0.4m.

The total order book has almost trebled, rising by 176% from just €4.5m at the end of Q1/2015 to €12.4m at the end of Q1/2016.

Following the high level of orders recorded in second-half 2015, in Q1/2016 Riber received orders for a production system in Asia and a research system in Europe, highlighting the gradual upturn in MBE business. The system order book hence comprises two production machines for delivery in 2016

(worth €5m) compared with none in 2015, and five research systems for delivery in 2016 (worth €4.5m) compared with just two in 2015. The system order book specifically has hence almost quadrupled, rising by 265% from €2.6m at the end of Q1/2015 to €9.5m at the end of Q1/2016.

In addition, the order book for services, cells and sources has risen by 45% from €2m to €2.9m. Specifically, the order book for services & accessories has almost doubled, rising by 85% from €1.3m to €2.4m, while the order book for cells & sources has fallen by 28% from €0.7m to €0.5m.

● Riber noted in early May that, to "stream line it's treasury position", it is undertaking a bargain agreement regarding selling part of its facility.

www.riber.com

Veeco's revenue falls 21% in Q1 to \$78m

Cost reduction plans to lower EBITDA breakeven to \$75–80m revenue

For first-quarter 2016, epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA has reported revenue of \$78m, near the high end of the \$70–80m guidance range. However, this is down 21% on \$98.3m a year ago and down 27% on \$106.5m last quarter, driven largely by the decline from Lighting & Display markets (where LED chip makers continued to work through industry oversupply conditions).

Of total revenue, the Lighting, Display & Power Electronics segment — primarily metal-organic chemical vapor deposition (MOCVD) systems — has hence fallen further, from 67% in Q3/2015 and 47% in Q4/2015 to 29% in Q1/2016, most of which came from the EMEA (Europe, the Middle East & Africa) region.

The Advanced Packaging, MEMS & RF segment has risen further, from 10% in Q3/2015 and 20% in Q4 to 30% of total revenue in Q1/2016, driven by strong growth in shipments to the RF (mobile device) market and capacity ramps for fan-out wafer-level packaging, which has been boosted by the Precision Surface Processing (PSP) business — formerly Solid State Equipment Holdings LLC (SSEC) of Horsham, PA, USA until its acquisition in Q4/2015.

The Scientific & Industrial segment has risen to 19% of revenue (from 17% in Q4/2015 and 10% in Q3).

The Data Storage segment has risen to 22% of revenue (from 16% in Q4/2015 and 13% in Q3).

Correspondingly, on a geographic basis (compared with last quarter), China fell from 48% to 11% of total revenue, while the USA and EMEA represented 35% each (rising from 18% and 12%, respectively), with the rest of the world comprising the remaining 19% (down from 22%). "Many countries outside of the USA are experiencing slow growth impacted by weak currencies, high unemployment rates and geopolitical tensions," comments chairman & CEO John R. Peeler. "These factors continue to weigh on consumer spending and, in turn, the end markets in which we participate."

On a non-GAAP basis, gross margin was 41.7%, up from 36.8% last quarter and 37.7% a year ago, and above the 37–39% guidance (and well above the target of 40%) due to a favorable product mix as well as margin expansion in MOCVD and PSP products.

Operating expenses have risen from \$37.1m a year ago but were steady quarter-over-quarter at \$38m (at the low end of the guidance \$38–40m range). "We are maintaining tight controls over expenses while continuing to make strategic R&D investments," says chief financial officer & executive VP-finance Sam Maheshwari.

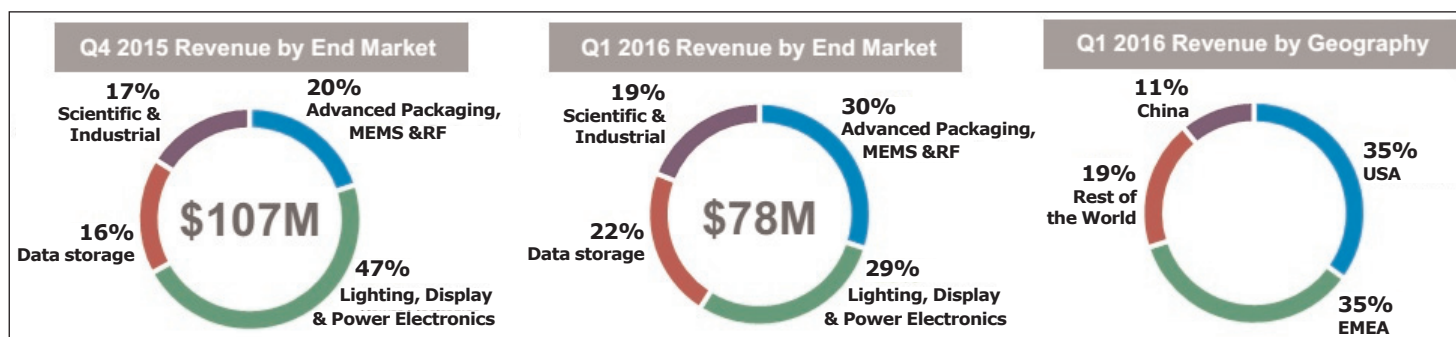
"LED industry conditions remain weak. As we navigate this challenging environment, we are assessing our cost structure to align with the current business outlook while positioning the company for future growth," notes Peeler. "We are prioritizing investments in areas that

offer meaningful growth. We're focused on qualifying our Precision Surface Processing (PSP) systems for additional Advanced Packaging applications and have made progress in our customer engagements for through-silicon via (TSV) applications. We are also leveraging our expertise in MOCVD to capture emerging opportunities for gallium nitride (GaN)-based power devices and to strengthen our position for arsenic/phosphide applications including automotive lighting. These efforts support our strategy to enhance growth and improve the stability of our revenue stream," Peeler concludes.

Net loss was \$5.7m (\$0.15 per share), versus net income of \$0.6m (\$0.01 per share) last quarter, but better than the expected \$14–10m (\$0.35–0.25 per share). Adjusted earnings before interest, taxes, depreciation and amortization (EBITDA) was cut to -\$2.1m, compared with +\$4.4m last quarter, but better than the expected loss of \$9–5m due to the strong gross margin performance.

"Although business conditions remain challenging, Veeco executed well in the first quarter. We achieved revenue at the high end of our guided range, expanded non-GAAP gross margin to nearly 42%, as well as exceeded expectations for adjusted EBITDA and earnings per share," summarizes Peeler.

Cash flow used by operations was \$19m (up from \$6m last quarter). Capital expenditure rose slightly to \$4m. "We remain committed to



▶ investing in next-generation engineering programs, and these investments are made to enhance our ability to develop products for the Power Electronics and Advanced Packaging markets," says Maheshwari. Veeco also repurchased \$13m of common stock. Cash and short-term investments hence fell from \$385m to \$349m.

After more than doubling sequentially to \$107m last quarter, order bookings fell back to \$62m (down from \$102m a year ago), reflecting the ongoing impacts of global economic uncertainty, a slowdown in consumer spending and the weak LED industry environment.

Lighting, Display & Power Electronics rose from 30% of total orders to 39% (although still down on 59% a year ago). "While EPIK makes up the bulk of our MOCVD orders, we are beginning to generate customer interest for our recently launched K475i tool for red, orange and yellow (R/O/Y) LEDs, where we booked orders with a second customer in Q1," says Maheshwari.

Advanced Packaging, MEMS & RF fell sharply from a spike to 37% of orders in a record Q4/2015 to just 11% in Q1. "We are working with device manufacturers and OSAT

[outsourced semiconductor assembly & test provider] customers to expand our PSP position and remain encouraged by the progress we are making in Advanced Packaging," says Maheshwari. "In RF and MEMS markets, we have seen a slowdown in the pace of new capacity orders which coincides with weaker-than-expected demand for high-end smartphones," he adds.

Scientific & Industrial rebounded from just 17% of total orders to 36%, supported by strong demand for MBE products. "We continue to win the lion's share of MBE opportunities for advanced materials research, and recently booked our 20th GENxplor Advanced Research System," says Maheshwari. "Roughly half of MBE orders were for production applications, where Veeco's technology is enabling high-power fiber lasers and high-end RF devices for mobile applications... We have a healthy pipeline of opportunities for MBE and optical tools."

We are beginning to generate customer interest for our recently launched K475i tool for R/O/Y LEDs

Data Storage fell further, from 16% of total orders to 14%, impacted by declining PC demand and the ongoing transition to flash drives (so customers are limiting investments to critical technology buys).

During the quarter, total order backlog fell by \$17m from \$186m to \$169m (down from \$289m a year ago). "Business conditions remain challenging," notes Peeler.

For second-quarter 2016, Veeco expects revenue to be steady at \$70–83m. Due to product mix, gross margin is expected to fall to 39–41% (although this is still ahead of the previous gross margin target at these low business volumes). Operating expenses should be steady at \$37–39m. Veeco also expects net loss to worsen to \$11–5m (\$0.29–0.14 per share), and adjusted EBITDA loss of between –\$6m and breakeven.

Based on current visibility, third-quarter revenue is trending to be in the same range as Q2/2016, concludes Veeco. "We are planning expense reduction initiatives in the near future which target lowering our EBITDA breakeven by year-end to quarterly revenue levels of \$75–80m," notes Maheshwari.

www.veeco.com

Israel's SemiConductor Devices chooses Veeco GEN200 MBE system for infrared detector production expansion

Infrared detector and laser diode maker SemiConductor Devices (SCD) of Haifa, Israel has bought a Veeco GEN200 molecular beam epitaxy system to meet the growing demand for the production of IR detectors.

SCD has a vertical R&D, integration and production structure that allows close control of products, throughout the various processes, from crystal growth to device packaging and testing. In-house capabilities include semiconductor processing, LPE and MBE growth, VLSI design, dewar and vacuum technology, assembly and radio-metric modeling and testing.

"The addition of another Veeco GEN200 MBE system is attributed

to our great experience with Veeco production MBE systems and their clear, demonstrated expertise in epitaxial deposition," says Dr Eli Weiss, VP of SCD Epitaxial Materials. "Our capacity expansion using Veeco's superior technology enables us to meet the growing demand for IR detectors based on our patented XBn and T2SL technologies."

The worldwide market for commercial and dual-use IR systems is expected to rise at a compound annual growth rate (CAGR) of 10% from \$3.2bn in 2015 to \$5.6bn in 2021, according to market research firm Maxtech International Inc, which also reports that newer IR detectors are increasingly being

produced using MBE technology.

"We are pleased that SCD, an industry innovator, has selected another Veeco GEN200 MBE system to ramp their production of IR detectors," says Gerry Blumenstock, VP of Veeco MBE Operations.

"Compared to other MBE systems, the novel design of the GEN200 provides excellent productivity with superior material quality in growing III/V antimonide-based wafers for IR sensors and laser diodes," he adds. "In addition, the GEN200 has Veeco's patented source technology for difficult-to-evaporate corrosive materials such as antimony."

www.scd.co.il

Aixtron agrees €670m takeover by Fujian Grand Chip Investment Fund

Offer of €6 per share targets second-half 2016 close

Deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany has entered into an agreement for Grand Chip Investment GmbH (CGI), an indirect subsidiary of Fujian Grand Chip Investment Fund LP (FGC), to take it over.

Fujian Grand Chip Investment Fund LP is a Chinese investment fund, 51% of which is held by Chinese businessman and private investor Zhendong Liu and 49% by Xiamen Bohao Investment Ltd (an investment entity indirectly controlled by Chinese private investors Zhongyao Wang and Wanming Huang).

Grand Chip Investment is hence to launch a voluntary public takeover offer to acquire all of the outstanding ordinary shares of Aixtron SE, including all ordinary shares represented by Aixtron ADS. Under the terms of the agreement, Aixtron shareholders will be offered €6 per ordinary share. The transaction values Aixtron's equity (including net cash) at about €670m and reflects a 50.7% premium to the three-month volume weighted average share price prior to announcement. About RMB1.7bn (€231m, at €1 = RMB 7.3456) of equity financing will be provided by FGC, and the remainder will be financed by debt facilities.

The agreement sets out the purpose and the principal terms of the transaction with FGC and the future strategy. FGC says that it intends to support Aixtron's strategy going forward.

Aixtron and FGC add that they view the transaction as an opportunity to grow and to expand the company and its workforce — the transaction is not directed towards cost or staff reductions. The transaction aims to support Aixtron's long-term R&D activities to bring new products and technologies to market, support the execution of the firm's current

strategy and technology roadmaps, and improve its ability to compete and grow in China.

Specifically, R&D competency and Aixtron's existing technology will be maintained at the existing technology centers. FGC has also agreed that Aixtron will further strengthen its technology and IP portfolio, which will remain vested with Aixtron, including in Germany. In addition, Aixtron's existing global set up will be maintained and expanded at its three technology hubs in Herzogenrath (Germany), Cambridge (UK) and Sunnyvale, CA (USA). Further international technology hubs may be established. Aixtron's legal domicile and headquarters will remain in Herzogenrath, Germany.

Executive and Supervisory Boards support the transaction. "It provides immediate value to our shareholders while also enabling Aixtron to bring their new products to market,"

comments Supervisory Board chairman Kim Schindelhauer. "With FGC we have found a partner that will provide local market insights to support our business objectives in Asia," he adds.

"The transaction allows us to address our short-term challenges, and to strengthen our long-

term future prospects by enabling us to execute on our roadmaps across all our technology areas," says CEO Martin Goetzeler. "It will provide us with a long-term horizon to promote the further development of new products," he adds. "In addition, our customers will benefit from stronger support and execution of their roadmaps."

"Through this transaction we will support Aixtron in gaining stronger access to the Chinese market and establishing Aixtron as a local provider amongst Chinese partners," says Mr Liu, managing partner at FGC. "We are committed to support the necessary investments for Aixtron and to enhance its product portfolio... Aixtron is a cornerstone in our overall investment strategy," he adds. "Enabling future growth for Aixtron will lead to a strengthening of the employee base. Customers will continue to be provided with the excellent standard in quality that Aixtron is known for as well as state-of-the art new technologies and products."

GCI expects the offer to commence in July after approval of the offer document by the German Federal Financial Supervisory Authority (Bundesanstalt für Finanzdienstleistungsaufsicht/BaFin). The offer will be subject to certain closing conditions, including regulatory approvals and a minimum acceptance threshold of 60% of Aixtron's issued shares, including shares represented by ADS. Closing is expected in second-half 2016.

In the event that the takeover is successful, Martin Goetzeler will remain chief executive officer of Aixtron and Dr Bernd Schulte will remain chief operating officer. Following closing of the transaction it is anticipated that Grand Chip Investment will nominate four candidates to Aixtron's six-member Supervisory Board.

www.aixtron.com

With FGC we have found a partner that will provide local market insights to support our business objectives in Asia.

The transaction allows us to address our short-term challenges, and to strengthen our long-term future prospects by enabling us to execute on our roadmaps across all our technology areas

Aixtron's Q1 revenue hit by ongoing weak LED-related demand

...but 42% rebound in orders in Q1 to drive revenue growth in second-half 2016

For first-quarter 2016, deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany has reported revenue of €21.4m, almost halving (down 47%) from €40.3m a year ago and down by almost two-thirds (62.5%) from last quarter's €62.5m. This was due in particular to the ongoing weak demand for production systems for gallium nitride (GaN)-based LED applications and the corresponding low order intake in Q3/2015 and Q4/2015.

Of total revenue, 56% came from equipment sales and 44% (€9.5m) from sales of spare parts & services (much higher than normal due to the very low product sales). On a regional basis, over 70% of revenue came from Asia, 13% from Europe, and 17% from the USA.

"We continue to diversify our revenue base, which can be seen in our revenue mix," notes president & CEO Martin Goetzeler. Aixtron's largest market was optoelectronic components (including lasers, transmitters, etc) at 36% of sales (up from 5% a year ago), followed by silicon at 26%, LEDs at just 15% (down from 26% last year), and power electronics at 15%.

Despite a favorable product mix, gross margin of 15% is down on 31% last quarter and 22% a year ago due to the low utilization.

"Based on the order backlog as of 31 December 2015, Q1/2016 developed on a modest scale. As a result it has been more important than ever to increase productivity as well as to control costs," says Goetzeler. Although roughly level with €17.6m a year ago, operating expenses of €17.8m are lower than €21.1m last quarter, as the

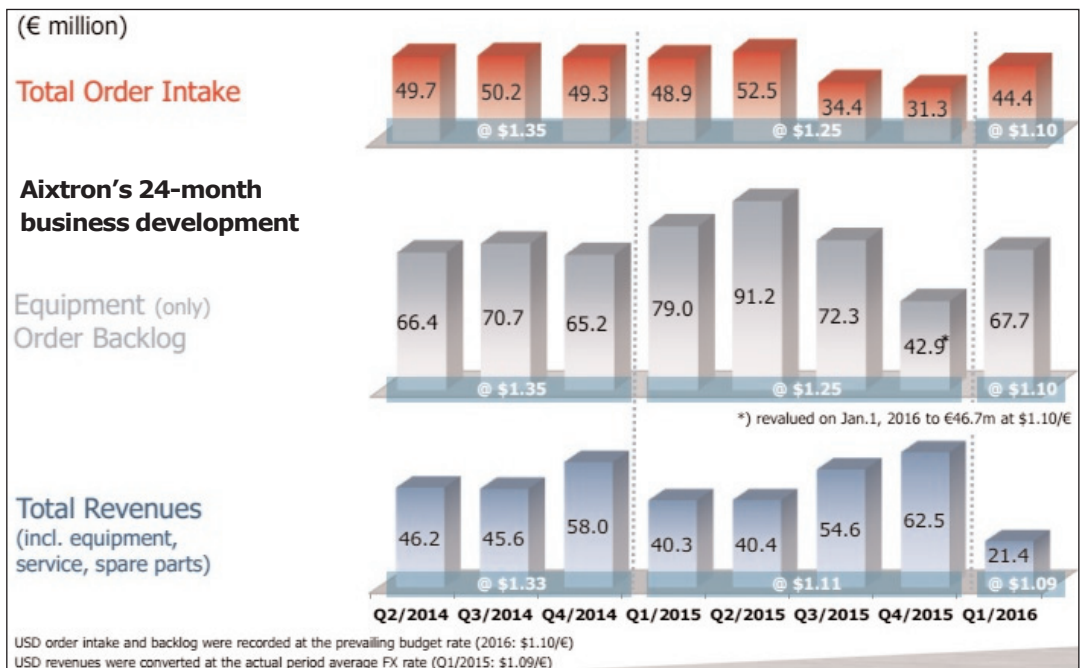
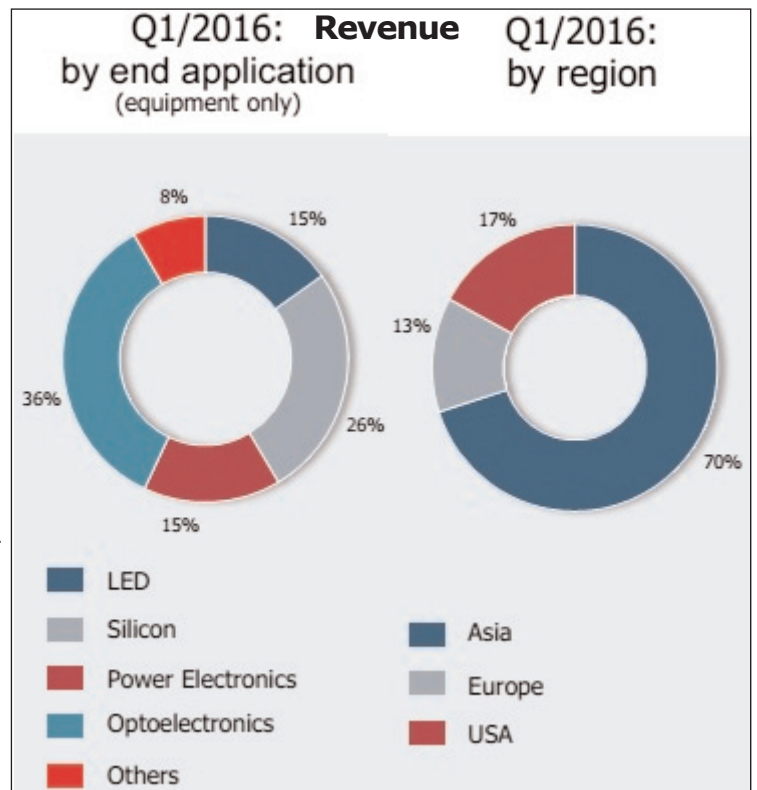
additional €1.3m quarterly operating costs of PlasmaSi of Fremont, CA, USA (acquired in Q2/2015) — which provides low-temperature silicon nitride plasma-enhanced chemical vapor deposition (PECVD) systems for the encapsulation of organic thin films — plus €4.7m in comparative negative currency-related translational and valuation

effects were offset by higher productivity, better cost control, and a contractual settlement.

EBITDA (earnings before interest, tax, depreciation and amortization) has hence fallen from €1.3m last

quarter to -€11.7m (compared with -€6.4m a year ago).

Operating cash flow was -€19.4m (below -€10.1m a year ago, but an improvement on -€32.1m last quarter), due mainly to paying the

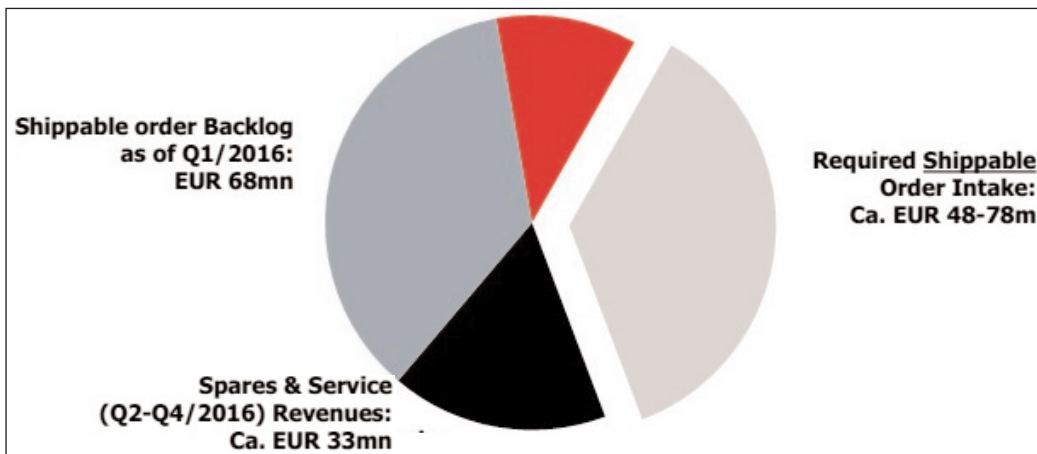


► second installment in returning the advanced payment from San'an Optoelectronics Co Ltd (China's largest LED maker), which did not qualify Aixtron's new AIX R6 metal-organic chemical vapor deposition (MOCVD) system. Capital expenditure (CapEx) was just €0.9m (down from €2.9m last quarter and €3.5m a year ago). Hence, despite still being down on –€12.1m a year ago, free cash flow improved from –€35m last quarter to –€20.3m. However, free cash flow would have been close to break-even without repaying the second installment to San'an.

Due partly to the repayment to San'an and an agreed milestone payment of €4.1m for the acquisition of PlasmaSi in 2015, cash and cash equivalents were €181.9m at the end of March, down on €209.4m at the end of December and €263.2m a year ago. Aixtron has no financial debt.

Although still down by 9% on €48.9m a year ago, total order intake rose by 42% from €31.3m last quarter to €44.4m, due mainly to stronger demand for Aixtron's planetary reactor technology across a variety of applications.

Aixtron says that there were positive developments in the business, particularly related to optoelectronics and power electronics, caused by growing demand for high-performance and energy-efficient components for markets such as communications, data storage and electric mobility. In addition, in Q1/2016 Aixtron saw increased demand for AIX 2800G4 Planetary Reactor production MOCVD systems for gallium arsenide/indium phosphide material in red-orange-yellow (ROY) LEDs. Also, the G4 system has been transferred to Aixtron's latest controls platform IC 2, giving compatibility to the firm's latest auto-mation features. Demand for systems in silicon-related applications was slow, but the firm expects a recovery in the coming quarters.



In March, Aixtron said that its AIX R6 MOCVD system had been qualified by Epistar Corp of Hsinchu Science-based Industrial Park, Taiwan (the world's largest manufacturer of LED epiwafers and chips). "We expect the tool to be qualified in other LED manufacturers, and we believe that we will consequently see orders for the AIX R6, depending on market conditions," says chief operating officer Bernd Schulte. "With our G5 Planetary Reactor, our customers have made significant progress in developing gallium LEDs on large silicon wafers, enabling the potential to reduce LED costs significantly," he adds.

"The significant increase in our order intake in the first three months of 2016 demonstrates that we were able to convince our customers with our system technologies for the production of future-oriented materials such as gallium nitride-on-silicon, silicon carbide or graphene in particular," says Goetzeler. "In the area of opto and power electronics, we have performed well with our planetary systems, especially with our AIX G5+ C cluster tool and our revised AIX G4-TM system," he adds. "Furthermore, we put great emphasis on cooperation projects with leading research institutions such as imec and Institut Lafayette. Thus, we support our goal to achieve a diversified technology and product portfolio."

During the quarter, equipment order backlog hence rose significantly, by 58% from €42.9m to €67.7m (although still down on €79m a year ago).

This development supports the expectation of revenue growth for the remainder of 2016, reckons Aixtron. Consequently, despite a slow start to the year, based on its current order situation Aixtron reiterates the full-year 2016 guidance given in February for revenue of €170–200m (compared with 2015's €197.8m), with significantly stronger revenue generation in second-half 2016 compared to first-half 2016. Currency adjusted, order intake (in Euros) is expected to be at the same level as in 2015.

Aixtron forecasts that it can generate Spares & Services revenue of €11m per quarter over Q2–Q4/2016, i.e. €33m for the remainder of 2016. So, in addition to shippable order backlog of €68m by end-Q1, Aixtron needs to secure additional shippable orders of €48–78m for 2016. "These orders we expect primarily from application areas like silicon, opto, power electronics and from LEDs," says Goetzeler.

Based on the internal budget rate of US\$/€1.10 and depending on the successful completion of qualification processes, market-entry efforts as well as the achievement of revenues at the high end of the revenue guidance range, Aixtron expects EBITDA, EBIT, net result and free cash flow to improve slightly compared to 2015 but to remain negative for full-year 2016. EBITDA should be positive for full-year 2017. "We expect 2017 to be a stronger year, driven by growing demand across all the markets we are addressing," concludes Goetzeler.

www.aixtron.com

Sandia qualifies and accepts Nippon Sanso's SR-4000HT commercial MOCVD system

Matheson Tri-Gas Inc of Basking Ridge, NJ, USA, together with its parent company industrial gas supplier Taiyo Nippon Sanso Corp (TNSC) of Tokyo, Japan, says that Sandia National Laboratories has qualified and accepted the SR-4000HT commercial-grade gallium nitride (GaN) metal-organic chemical vapor deposition (MOCVD) system for its continued compound semiconductor

device developmental work with aluminium gallium nitride (AlGaIn) and aluminium nitride (AlN).

"As a prominent leading national institution, this customer's qualification and acceptance of the SR-4000HT MOCVD system is a significant step forward for the entire MOCVD market focused on AlGaIn and AlN technology," says TNSC executive corporate officer

Koh Matsumoto.

Matheson and TNSC expect the SR-4000HT MOCVD system to be the platform for AlGaIn and AlN applications. The two firms aim to continue developing its MOCVD system for the deep ultraviolet light-emitting diode (UVC-LED) and power electronics applications.

www.mathesongas.com

www.tn-sanso.co.jp/en

MRSI providing die bonding assembly work cell for Fabrinet's Silicon Valley optical packaging center

MRSI Systems of North Billerica, MA, USA, which manufactures fully automated, ultra-precision die bonding and epoxy dispensing systems, is supplying its flagship MRSI-M3 precision die bonding assembly work cell to the Fabrinet West facility in Santa Clara, CA, USA.

Thailand-based Fabrinet Co Ltd (which also has engineering and manufacturing resources and facilities in China) is a provider of optical packaging and precision optical, electro-mechanical and electronic manufacturing services to original equipment manufacturers of products such as optical communication components, modules and subsystems, industrial lasers and sensors.

MRSI notes that optoelectronic and microelectronic component and module products are experiencing record volumes driven by the rapid growth in cloud computing, data transfer and storage, and the adoption of the Internet of Things. This high volume and high growth trend has challenged component and module providers to produce prototypes quickly during product development and subsequently to scale to high-volume manufacturing, fast and risk free, adds the firm.

To respond to these challenges, Fabrinet is setting up an optical packaging center in its Santa Clara facility to provide fast prototyping

and process-development capability for customers of both Fabrinet and MRSI. Equipped with the MRSI-M3 die bonder (along with other capabilities such as active optical alignment, wire bond, epoxy underfill, laser dicing, and various metrology tools), MRSI says that the application center will further assist its customers in advanced product development and fast ramping to volume manufacturing. Fabrinet and MRSI have agreed to form a partnership to provide support to West Coast customers, with both easy access to a state-of-the-art packaging facility and the ability to accelerate new product development and risk-free scaling to volume production.

The MRSI-M3 is said to deliver a combination of accuracy, speed and reliability for complex eutectic bonding with scrubbing and/or force, integrated epoxy dispensing and stamping, thermal and UV epoxy bonding, and flip-chip bonding. MRSI says that the system provides flexibility, handling multiple die sizes and carrier geometries for complex multi-die packaging or fabrication of multiple products. Real-time closed-loop force control enables placement of delicate components either mechanically fragile or structurally complex for photonics, RF and microwave, sensor, MEMS and other applications.

Die can be picked from waffle pack, Gel-Pak, wafer, and tape & reel. The MRSI-M3 can be configured for flexible applications during prototyping or more dedicated processes during volume manufacturing.

"MRSI Systems has been serving optoelectronic and microelectronic customers for the past 32 years," says MRSI Systems' president Michael Chalsen. "Fabrinet is the industry leader in contract manufacturing for advanced packaging of complex products and has been a great customer to us. Both companies also serve the same customer base and market segments," he adds.

"MRSI Systems is the industry leader in providing equipment and solutions for one of the most critical processes in advanced packaging — ultra-precision and high-speed die bonding," comments Dr Hong Hou, executive VP & chief technology officer at Fabrinet. "Fabrinet and its customers have been working with MRSI Systems for many years because of their product's performance, reliability and field service, particularly their platform design in meeting unique needs from prototyping to high-volume manufacturing," he adds. "We are looking forward to further our collaboration in this application center."

www.fabrinet.com

www.mrsisystems.com

Plasma-Therm tops Customer Satisfaction Survey for 'Etch and Clean Equipment' and 'Fab Equipment'

Plasma process equipment maker Plasma-Therm LLC of St Petersburg, FL, USA has earned two first-place awards in the 2016 Customer Satisfaction Survey conducted by market research firm VLSIresearch, scoring higher than in any previous year and the 17th consecutive year that the firm has earned a top ranking (after participating in the independent survey since 1998).

Plasma-Therm was 'RANKED 1st' among equipment suppliers in both the 'Etch and Clean Equipment' and 'Fab Equipment' categories. In addition, the firm placed second overall in the '10 BEST Focused Suppliers of ChipMaking Equipment' rankings.

"As we expand our product and application portfolio, we are grateful to see that our customers, from

small labs to high-volume manufacturing, continue to praise Plasma-Therm's overall performance year after year," says CEO Abdul Lateef.

"The higher scores that Plasma-Therm earned in the Customer Satisfaction Survey show that their customers appreciate both the reliability of Plasma-Therm's tools and the responsiveness of its customer service team," comments VLSIresearch's chairman & CEO G. Dan Hutcheson. "The company's focus on technology innovation and customer service is widely recognized."

The '10 BEST' awards recognize the top-rated suppliers of all types of equipment used in semiconductor device manufacturing, including fabrication, testing and assembly

equipment. The awards are presented in two categories based on company size: 'Large' suppliers and 'Focused' suppliers, based on a three-year average of revenues.

'THE BEST' awards recognize top-rated equipment suppliers across a range of equipment types, including Fab (chip fabrication), Test, and Assembly.

Survey participants worldwide were asked to rate equipment suppliers in 15 categories based on three key factors: supplier performance, customer service, and product performance. In 2016, VLSIresearch received feedback from more than 95% of the chip market, with a total of 3619 surveys returned, resulting in 54,282 total responses.

www.plasmatherm.com

Liangdongxin orders first Temescal UEFC series evaporator in China for new GaAs foundry

Materials, component and precision system supplier Ferrotec Corp of Santa Clara, CA, USA (whose Temescal division of Livermore, CA, USA makes electron-beam-based evaporative coating systems) says that a Temescal UEFC series evaporator — the first Auratus Enhanced system to be installed in China — will be delivered to the new GaAs foundry Hangzhou Liangdongxin Microelectronics, which has been established by China-based power semiconductor firm Hangzhou Li-On Microelectronics Corp (founded in 2002 with processing, quality and management technology transferred from On Semiconductor). With the addition of the Temescal UEFC system to the Liangdongxin foundry, customers can benefit from near-perfect uniformity and reduced material consumption, says Ferrotec.

"With the growth of mobile devices in China and the expansion of IoT (Internet of Things), the demand for

the next generation of semiconductor devices based on GaAs material is growing," says Liangdongxin's chief operating officer Dr William Wang. "We need a tool that could deliver high production throughput, consistent process uniformity, and operational efficiency to minimize our total cost of ownership. After a rigorous evaluation process, we concluded that Ferrotec's Temescal UEFC system is the best evaporator in meeting our specifications for thickness, composition and particulate control," he adds.

"The Chinese government has committed to becoming more self-sufficient in the manufacturing of semiconductor devices, and Hangzhou Liangdongxin

The Chinese government has committed to becoming more self-sufficient in the manufacturing of semiconductor devices

Microelectronics' new GaAs-based foundry will enable the production of leading-edge devices that power mobile and IoT," says Gregg Wallace, managing director of Temescal Systems at Ferrotec.

"Ferrotec's Temescal UEFC evaporator is a workhorse in the production of compound semiconductor devices, and our Auratus Deposition Process Enhancement Methodology delivers unmatched product quality and operating efficiency," he claims. "We look forward to strong growth from Hangzhou Liangdongxin Microelectronics and this tool will be an exceptional fit with their expanding GaAs foundry business."

In China, Temescal evaporators are supported by long-term representative MPS (Micro-Power Scientific Corp).

www.Li-On.com
www.temescal.net
www.ferrotec.com

CORIAL releases process control software for atomic layer processing using conventional dry process tools

Plasma etch and deposition equipment maker CORIAL of Bernin, France, a provider of plasma etching and deposition equipment has launched COSMA Pulse as new software enabling pulsed or time-multiplexed processing on conventional dry process tools.

The firm has found a way to add new capabilities (pulsing of process parameters) to conventional dry etching and plasma-enhanced chemical vapor deposition (PECVD) systems to realize deep reactive ion etching (DRIE)-Bosch processing, atomic layer etching (ALE) and/or atomic layer deposition (ALD).

Developed with the R&D market in mind, COSMA Pulse can control and pulse simultaneously and independently from all other process parameters, including gas flow rate, working pressure, RF power, LF power or virtual process parameters.

"We are proud to announce the first successful demonstration of COSMA Pulse on a 200mm ICP-RIE system", says R&D manager Jean-Pierre Roch. For this demo, CORIAL chose the DRIE-Bosch — a classical process that alternates repeatedly etching and passivation steps to achieve deep anisotropic etching of silicon structures. DRIE-Bosch is the cornerstone of MEMS, advanced packaging and power

The firm has found a way to add new capabilities (pulsing of process parameters) to conventional dry etching and PECVD systems to realize DRIE-Bosch processing, ALE and/or ALD

devices manufacturing flows. "COSMA Pulse, with adequate electronic controller, will deliver very fast process step switching from 10ms for a single process step up to 1 minute," says Roch.

The software ensures that the wide range of dry etching and deposition techniques — from continuous wave plasma to pulsed processing — can be realized in conventional ICP-RIE and PECVD tools.

"COSMA Pulse expands CORIAL's available market, giving customers alternative options for their etching processes," says marketing manager Elsa Bernard-Moulin. "This demonstration is just a taste of the capabilities of COSMA Pulse. Soon, we will be letting you see true atomic layer processing on our conventional ICP-RIE tool."

www.corial.net

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ITO GLASS	500			
LINBO3				
NITRIDE ON SILICON				
SAPPHIRE				
SILICON				

Rubicon's revenue rebounds, driven by 6-inch patterned sapphire substrates

Flat Q2 to be followed by significant PSS growth in Q3

For first-quarter 2016, Rubicon Technology Inc of Bensenville, IL, USA (which makes monocrystalline sapphire substrates and products for the LED, semiconductor and optical industries) has reported revenue of \$4.3m, down on \$8.9m a year ago but up on \$2.45m last quarter.

The rise was due primarily to wafer revenue rising by \$1.5m from \$0.86m to \$2.35m, mostly from 6-inch diameter patterned sapphire substrates (PSS) for the LED market rising by \$1.1m from \$0.4m to \$1.5m, while polished wafers rose from \$0.45m to \$0.83m (though down on \$1.4m a year ago).

R&D revenue was steady at about \$0.1m (down slightly on \$0.14m a year ago). Although it is still down on \$1.8m a year ago, optical revenue rose from \$1m to \$1.4m.

Revenue from core sales has fallen further from \$5.1m a year ago and \$0.48m last quarter to \$0.44m. Apart from just \$2000 of 2-inch cores (down from \$10,000 last quarter and \$4m a year ago), nearly all of this was from 4-inch cores for the LED market (down slightly from \$0.47m last quarter and \$1m a year ago). Despite the fact that the LED market continues to grow and some competitors have left the market, excess sapphire capacity continues to keep pricing at historically low levels, especially for 2- and 4-inch cores. Hence, in recent quarters, Rubicon has been limiting the amount of 2- and 4-inch core sold.

Crystal growth production is operating at 30% capacity, "a level at which we can retain our key crystal growth talent [and a certain number of furnaces running]. This talent is important for us to keep if we are to be able to respond to the new application opportunities we are working on," notes chief financial officer Mardel Graffy. "The crystals produced are primarily used for

6-inch wafers, optical parts and some relatively small-volume 4-inch core sold to a couple of key customers in that market to maintain the relationships," she adds. "If they ramp quickly we want to be able to respond to them accordingly," notes president & CEO Bill Weissman.

With the low crystal-growth utilization and under-utilized polishing operation in Malaysia, idle plant cost remained high at \$2.3m, similar to both last quarter and a year ago.

However, operating expenses have been cut from \$3.3m last quarter to \$2.7m, due mainly to general & administrative expenses being cut from \$2.3m last quarter to \$1.8m including reduced professional fees and lower bad debt expense, as sales & marketing expenses remain about \$0.4m and R&D expenses remain about \$0.6m.

GAAP net loss was \$7.3m (\$0.28 per share), cut from \$12.7m (\$0.49 per share) last quarter, and \$8.3m (\$0.32 per share) a year ago.

Cash use remained relatively high at \$5.7m, because it included the initial payment on the SapphirEX tool and a \$900,000 payment for settlement of securities litigation that was previously expensed. During the quarter, cash and short-term investments hence fell further, from \$30m to \$25m.

Capital expenditure was kept under \$1m for the whole of 2015.

For second-quarter 2016, Rubicon expects revenue and loss per share to be similar to the first quarter.

However, based on current customer projections, revenue growth is expected to resume in third-quarter 2016, driven by a significant rise in PSS wafer sales.

"While the organic light-emitting diode (OLED) is taking market share from sapphire-based LEDs in the backlighting segment, the general lighting market continues to grow," says Weissman. "There remains opportunity within that segment of the market for revenue and margin growth. Specifically, we believe that demand for 6-inch diameter PSS wafers will continue to grow, as the competitive landscape for providing that product is more limited," he adds.

"While PSS pricing is impacted by the macro sapphire pricing environment, it tends to be less volatile. We have a competitive advantage in being able to produce high-quality large-diameter PSS wafers in a vertically integrated process starting from powder aluminum oxide... few competitors have that capability. For customers that are very sensitive to potential disruptions in the supply chain and consistency of quality, that vertical integration is very important," Weissman believes. "We expect meaningful increases in 6-inch PSS sales over the course of this year because of our large-diameter capability and vertical integration," he adds.

"The customer qualification process of these wafers can be quite lengthy, which we believe can lead to greater customer loyalty... However, despite the limited number of capable competitors for 6-inch PSS wafers, current pricing is also weak because the demand for these 6-inch wafers today is fairly limited. Therefore, it is essential that we continue to expedite cost reductions in our polishing operation, so that we can optimize the potential of our vertical integration model particularly as it relates to

One challenge in reducing wafer cost has been the limited volumes processed in our Malaysian facility. The expected increase in volumes in the third quarter should also help to reduce wafer costs

► PSS opportunities," says Weissman. "We made progress in the first quarter and we are continuing to implement improvements. One challenge in reducing wafer cost has been the limited volumes processed in our Malaysian facility. The expected increase in volumes in the third quarter, which is based on customer projections, should also help to reduce wafer costs," he adds.

"In addition to pursuing our PSS potential, we are targeting high-margin optical applications [that fit particularly well with Rubicon's unique set of sapphire knowledge and capabilities] and developing

new products. We are making significant strides in building a valuable optical business like cultivating new customers, expanding our product offerings and completing the development of two new technologies, our LANCE and our SapphirEX technologies," says Weissman. Both the LANCE large window growth and SapphirEX coating technologies (patents pending) met additional key milestones during Q1, and both should move into production this year. "Over the next several months, we expect to see meaningful developments in some of these new

market opportunities, as well as developments in our new technologies and further progress in product cost reductions," he adds.

"We continue our efforts to reduce both wafer and crystal growth costs and keep support cost as low as possible," says Weissman. "While we will have the remaining balance of the SapphirEX tool to pay in the second quarter [\$700,000], we expect cash used for capital expenditures to be minimal for the remainder of the year and expect to see a reduction in cash used in operations as we further reduce cost."

www.rubicon-es2.com

Rubicon appoints new independent director

Rubicon has appointed a new independent director, Timothy E. Brog, president of Locksmith Capital, to its board, expanding it to six members (five of whom are independent).

"He is an accomplished executive, with extensive investment, legal, management and financial experience — as well as a strong track record of driving change as a member of public company boards, serving on director slates of both

management and activist shareholders," says chairman Don N. Aquilano. "We welcome his insights as we pursue the appropriate path forward to drive long-term stockholder value. Timothy brings valuable new perspectives to our board, and his appointment is consistent with our commitment to maintaining a highly qualified board with the necessary skills and expertise to navigate the current environment."

"I look forward to leveraging my experiences to work with the board and management team to implement necessary change and maximize stockholder value as I have in previous situations with an array of public and private companies," says Brog. "I am excited to work with Rubicon as we continue to strengthen the company's existing platform, capitalize on new market opportunities, and position Rubicon for the future."

SPTS wins RoSPA Gold Award for occupational health & safety for fourth consecutive year

SPTS Technologies Ltd of Newport, Wales, UK (an Orbotech company that manufactures etch, PVD and CVD wafer processing solutions for the MEMS, advanced packaging, LED, high-speed RF on GaAs, and power management device markets) has won a Gold Award in the Royal Society of Prevention of Accidents (RoSPA) Occupational Health and Safety Awards for the fourth consecutive year. The award will be presented during a ceremony at the Hilton Birmingham Metropole Hotel on 14 July.

"It recognizes their commitment to maintaining an excellent health and safety record and raises the

bar for other organisations to aspire to," says Julia Small, RoSPA's head of awards and events.

"We have a strong culture of continuous improvement throughout our organization, which has been instrumental in sustaining our business growth," says Kevin Crofton, president of SPTS Technologies and corporate VP at Orbotech. "It takes commitment and support of all the staff to maintain this high level of health and safety best practices in the work place."

RoSPA is a safety charity that recognizes companies that have demonstrated a commitment to occupational safety and health for

their employees. Celebrating its diamond anniversary, the RoSPA Awards scheme is the largest and longest-running programme of its kind in the UK. It is open to businesses and organizations of all types and sizes from across the UK and overseas. Most of the awards are non-competitive and mark achievement at merit, bronze, silver and gold levels. Gold medals, president's awards and orders of distinction are presented to organizations sustaining the high standards of the gold level over consecutive years.

www.spts.com

www.rospace.com/awards

Crystal IS expands range to high-powered UVC LEDs for disinfection of water, air and surfaces

At Analytica 2016 (the 25th International Trade Fair for Laboratory Technology, Analysis and Biotechnology), Crystal IS Inc of Green Island, NY, USA, an Asahi Kasei company that makes proprietary ultraviolet light-emitting diodes (UVC LEDs), launched a commercial product line targeting higher-power applications for UVC disinfection of water, air and surfaces.

Building on the firm's commercialized Optan product line, Klaran is the firm's first-generation disinfection product line (available now in both sample and production quantities). Offering germicidal output powers from 15mW to 30mW, it is uniquely suited to use in healthcare, lab water and consumer product applications where health and human safety is of primary importance.

Applications demonstrating the need for high-powered UVC LEDs include healthcare, lab water and consumer products:

- According to the Centers for Disease and Control (CDC), hospital-

acquired infections (HAIs) impact one in 25 patients in the USA each year. The Affordable Care Act (ACA) and the Centers for Medicare and Medicaid Services (CMS) report improved patient outcomes, shorter stays and fewer repeat visits linked to healthier environments that incorporate UVC technology in addition to approved standard surface wipe protocols.

- Point-of-use (PoU) lab water purifiers now make up 75% of an approximately \$480m global market. UVC LEDs can be integrated into these systems for Type I, II and III water purification, as defined by the American Society for Testing and Materials (ASTM).

- Global headlines highlight the need for safe and reliable drinking water, and the UVC water purifier market is hence expected to almost double in size over the next five years from \$9.16bn to \$17.85bn in 2020. In addition to the USA, this growth is attributed to China and India, where industrialization and a

rising urban population is putting a strain on drinking water resources.

Crystal IS says that the new Klaran can benefit manufacturers who need:

- optimized, high-output germicidal power for maximum disinfection rates;
- smaller footprint that affords design flexibility and product innovation;
- a rugged design for mobile applications; and
- non-hazardous, mercury-free solution with no fragile quartz tubes.

"For Crystal IS, developing a reliable disinfection product has been one of the company's primary strategic goals," says CEO Larry Felton.

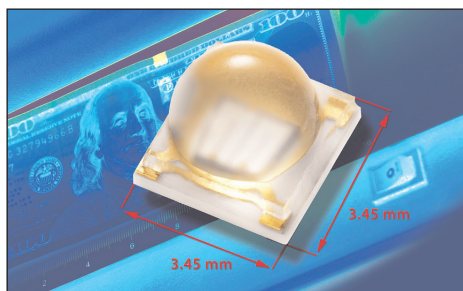
In addition, Crystal IS offers technical assistance via application engineering support, software modeling or onsite training to assist innovation teams in developing disinfection solutions.

www.cisuvc.com/products/klaran
www.analytica.de/index-2.html

Vishay launches ceramic-based, high-power 365nm UV LED with silicone lens delivering long lifetime

Vishay Intertechnology Inc of Malvern, PA, USA has launched a new device in its VLMU35xx series of ceramic-based, high-power UV LEDs with silicone lenses that features a wavelength in the 365nm range for medical, industrial and printing applications. Designed to provide a reliable, energy-saving replacement for mercury lamps, the silicone lens of the Vishay Semiconductors VLMU3510-365-130 enables lifetimes up to 25,000hr, versus the typical mercury lamp lifetime of 10,000hr.

Supplied in a compact 3.45mm by 3.45mm surface-mount package, the environmentally friendly UV LED is free of heavy metals and provides increased reliability through its shock resistance and immunity to



degradation from frequent on/off switching. While mercury lamps require complex drive circuits and need 2–15 minutes to warm up, the VLMU3510-365-130 allows the use of simple low-voltage circuitry and requires no warm-up period.

Fabricated from indium gallium nitride (InGaN) technology, the new UV LED features typical radiant power of 690mW at 500mA and

945mW at 700mA in a wavelength range of 362.5–370nm. The VLMU3510-365-130 has an emission angle of 130° and radiant intensity of 315mW/sr at 700mA.

The LED's specifications make it suitable for UV curing in nail salon, dental and poster printing applications; blood and counterfeit money detection; and photocatalytic purification. RoHS-compliant, halogen-free and Vishay Green, the VLMU3510-365-130 is compatible with reflow soldering processes and features a Moisture Sensitivity Level of 3 in accordance with J-STD-020.

Samples and production quantities are available now, with lead times of 6–8 weeks.

www.vishay.com/ppg?84363

RayVio launches surface-mount UV LEDs for compact, portable disinfection of water and environments

RayVio Corp of Haywood, CA, USA, which is commercializing deep-ultraviolet (UV) LEDs and consumer disinfection solutions, has launched a new series of UV LEDs with what is claimed to be the highest power output available from a small surface-mount device (SMD) footprint. RayVio's technology enables the UV disinfection of water and environments via a new generation of powerful and portable health and hygiene devices.

The new series of UV LEDs is reckoned to be among the smallest commercially available (at a width of 6.5mm), enabling the flexibility for incorporation into a range of products from self-disinfecting water bottles to hospital surface cleaners. The technology provides up to 40mW at 100mA continuous current operation in a single package (the most power available in that size on the market, it is claimed). With its wavelength range 280–290nm and its high power density, the LEDs can deactivate

the DNA of bacteria, viruses and other pathogens, preventing disease.

"RayVio's innovative new form factor brings the protective power of ultraviolet light to a galaxy of innovative new products," says RayVio's CEO Dr Robert C. Walker. "We're facing serious global challenges around hospital-acquired infections and contamination of the food and water supply. This new technology marks an important step in providing peace of mind to billions of consumers," he adds.

UV light is widely used to protect against germs in water, surfaces and air, and can also aid in treating skin diseases including psoriasis, eczema, rickets and jaundice. However, traditional UV light sources are bulky, fragile and contain toxic mercury. RayVio's UV LEDs are portable and compact and can be used safely across a range of applications, from cleaning water tanks in home humidifiers to disinfecting water at the faucet.

The firm is working with partners worldwide to incorporate its line of UV LEDs into a new generation of products and applications.

Coupled with a hemispherical quartz lens, RayVio's new UV LEDs provide precise beam shape, enabling uniform light distribution over a large area. The UV LED emitters are offered in a range of wavelengths, power levels and mounting designs. They also offer thermal resistance of 6°C per watt, are RoHS (Restriction of Hazardous Substances) compliant, and are manufactured in a facility in Silicon Valley, with additional high-volume manufacturing partners around the world to meet global demand.

RayVio is exhibiting its technology at the Association for Professionals in Infection Control and Epidemiology Annual Conference (APIC 2016) in Charlotte, NC, USA (11–13 June). Product samples and a wide range of application support are available.

<http://ac2016.site.apic.org>
www.rayvio.com

Excelitas features new UV LED curing solutions at RadTech UV+EB 2016

At the RadTech UV+EB 2016 trade show in Chicago, IL, USA (16–18 May), Excelitas Technologies Corp of Waltham, MA, USA, which provides customized photonic solutions to OEMs, highlighted its new UV LED curing products.

Excelitas says that its solutions meet the lighting, detection, optics and other technology needs of OEMs across a wide range of industries. Products on display include:

- **OmniCure LX500 UV LED Spot Curing System:** Available in either two or four LED head system configurations with up to 16W/cm² peak irradiance, the LX500 provides optical stability via Intelli-Lamp LED technology for repeatable device assembly and reduced costs.

OmniCure LX500 is suitable for use in medical devices such as catheters, cannulas, endoscopes and syringes; electronics such as OPU, smartphones and tablets; and general-purpose small component applications such as bonding and coatings.

- **OmniCure AC5 Series UV LED systems:** Designed for small-area curing with a unique combination of high-output LEDs and custom optics, the AC550/P and AC575/P air-cooled UV LED curing systems provide high irradiance (14W/cm²), enabling manufacturers to achieve high productivity, it is claimed. Additionally, the LEDs deliver long lifetime and lower electrical consumption to reduce running costs. OmniCure AC5 Series Systems are

designed to cure inks, adhesives and coatings in print, industrial and electronics manufacturing applications. The systems' high irradiance allows adhesive curing at a low temperature for sensitive components used in medical device and electronics manufacturing.

In addition, Mike Kay, Excelitas' director of product management, UV Curing, presented 'Improving Cure with UVC LEDs' in RadTech's Deep UV LED session, which addresses the use of UV LED-curable adhesives, inks and coatings for commercial applications (including the feasibility and requirements of adding deep-UVC LEDs into a commercial LED curing system).

www.excelitas.com/OmniCure

Everlight launches AEC-Q101-qualified high-power LEDs in highly reflective packages for exterior automotive

Taiwan-based Everlight Electronics Co Ltd has launched four new ceramic high-reflective-packaged high-power automotive LEDs with a golden lead frame in four different colors — white, PC-amber, red, and super-red — according to the preferred exterior applications.

The 3030CLU-NP (white) features a cool color temperature of 5180–6680K, making it especially suitable for daytime running lamps (DRLs). The 3030CLU-UY (PC-amber) is recommended for turn indicators and tail lights. As for center high-mount stop lamps (CHMSLs), brake lamps and rear combination lamps, Everlight is introducing red and super red color options. Both 3030CLU-URR (red) and 3030CLU-USR (super-red), with wavelengths of 612–624nm and 627–639nm respectively, provide high luminous flux at a drive current of 350mA.



The 3030CLU-USR (super-red) is based on European OE's preference and provides a more vivid and hence easier-to-recognize red color, which is expected to help to reduce car accidents.

With compact size (3.0mm x 3.0mm x 0.8mm) and a wide viewing angle of 120°, the 3030CLU(AM) Series of LEDs is offered in a golden high-reflective package. Using a ceramic substrate results in lower costs and a low thermal resistance of less than 7°C/W for optimized heat management. A further benefit is a junction

temperature (T_j) of up to 150°C while maintaining good performance. Typical 3030 packages are destroyed at this temperature, but the 3030CLU(AM) is more suitable for demanding exterior automotive applications. A golden lead frame also

improves sulphur resistance.

The 3030CLU(AM) LED packages have passed qualification according to AEC-Q101 and comply with the highest moisture sensitivity level standard MSL1 (an electronic standard for the time period during which a moisture-sensitive device can be exposed to ambient room conditions). The devices are also ESD protected for voltages up to 8kV.

Samples of 3030CLU(AM) LEDs. Mass production is starting in second-quarter 2016.

www.everlight.com

Plessey signs UK & Ireland distribution deal with Freeway

Plessey of Plymouth, UK has entered into a distribution agreement for the UK and Ireland with Newbury-based Freeway Lighting, an electronics distributor and provider of advanced lighting solutions.

"We specialize in the distribution of solid-state lighting components and have been developing our LED EcoSystem over recent years to

include many solutions for our customers," says Freeway Lighting's technical director Ian Wood. "The Plessey products will be an excellent addition to the Freeway Lighting Linecard, complementing the existing product portfolio," he adds.

"We have been immensely impressed with the skills within Freeway for finding lighting solutions

for difficult applications," comments Plessey sales director Giuliano Cassataro. "We are keenly looking forward to working with them and bringing to Freeway some of the innovative lighting technologies and solutions Plessey has built up using our MaGIC gallium nitride on silicon technology."

www.freeway-lighting.com

Plessey wins Manufacturing Business of the Year Award

Plessey has won the Plymouth Herald's Manufacturing Business Award 2016 for large businesses.

Now in their sixth year, the awards celebrate the city's most dynamic companies. Presented on 14 April, the event was attended by over 600 guests, including some of the leaders of Plymouth's business community.

"We are grateful to the sponsors, City College Plymouth, Plymouth

University and BD (Becton, Dickenson and Company), for their support," said Plessey's operations director Mike Snaith. "GaN-on-Si LED lighting manufacturing expansion plans are well on track," he adds.

"We are entering a very exciting period for the company, with our new technology and products now gaining traction in one of the fastest-growing technology markets — solid-state lighting," said

Neil Harper, Plessey's director LED Product Line. "Our recent wins in horticultural and human-centric lighting are proof of the long-term viability for Plessey and its LED manufacturing strategy."

Plessey recently signed a license agreement for the manufacture and supply of PhytoLux LED grow light fixtures.

www.plesseysemiconductors.com/led-plessey-semiconductors.php

Samsung Electronics' LED test lab approved for UL Total Certification Program

Samsung Electronics Co Ltd of Seoul, South Korea says that its test lab for LED packages and modules has been qualified by global safety science organization UL (Underwriters Laboratories) to operate the UL Total Certification Program (TCP), one of the highest levels of testing and qualification under the UL Data Acceptance Program (DAP).

UL's standards and certification are recognized as indicators of product safety and reliability, says Samsung. To better handle increasing requests for testing and certification, UL has been running DAP, which allows approved manufacturers to test products using their own labs, equipment and engineers, and then submit the test data to UL for review. Samsung's test lab for LED packages and modules is now recognized for the UL TCP. Within UL-specified parameters, Samsung can manage the full TCP process from examining a product's structure, to selecting and conducting appropriate UL testing, and obtaining UL certification.

As a UL-approved TCP lab from

May, Samsung is performing tests to measure the safety of its LED components under varying environmental settings including electrical, temperature and humidity variation.

"By fully embracing the UL TCP, we will be able to speed up the UL testing and certification process for our LED products and strengthen the foundation for our LED business around the world," says SungKwan Lim, VP of the LED Quality team, Samsung Electronics.

"UL TCP will support Samsung's LED business with more flexibility for timely UL certifications," notes Todd Denison, VP & general manager of UL's Appliances, HVAC and Lighting division. "UL will continue to work closely with manufacturers to support improvements in the overall safety of LED components."

Samsung says that, by managing its own UL-approved test lab, it can reduce the testing period for its LED components by 50–75%, aiding its ability to rapidly supply UL-certified LED components to customers.

As a part of the criteria for its TCP qualification, Samsung satisfied quality management system

requirements, stipulated by ISO 17025. The ISO 17025 standard is used by testing and calibration laboratories for accreditation that allows them to be recognized as technically competent. To maintain its product examination system, Samsung will maintain a close relationship with UL through testing validation processes including regular assessment of the Samsung LED test lab as required by the TCP program.

A few years ago Samsung's LED test lab was also qualified as an international test lab from the Korea Laboratory Accreditation Scheme (KOLAS), a governmental accreditation organization that evaluates quality and technical capabilities of testing and inspection laboratories. The Samsung lab has also been recognized by the VDE Institute, the testing and certification branch of VDE Association for Electrical, Electronic & Information Technologies (one of the largest technical and scientific associations in Europe).

www.samsung.com

www.ul.com

Phoseon launches UV LED curing solutions with 16W/cm² peak irradiance

UV LED curing firm Phoseon Technology of Hillsboro, OR, USA has introduced the next-generation FireJet FJ200, its highest UV power air-cooled light array (with peak irradiance of up to 16W/cm²), designed for the most demanding printing, coatings and area curing applications. The FireJet family of products comes in a scalable form factor to accommodate various curing lengths for ease of installation and low maintenance.

Available in May, FireJet FJ200 will come equipped with Phoseon's new TargetCure and WhisperCool patented technologies. TargetCure



Phoseon's FireJet FJ200 UV LED curing system.

delivers precise, stable and consistent curing (and hence less maintenance), and WhisperCool offers a low-noise solution with increased UV output. These are the first of several new technologies that Phoseon is bringing to the market in 2016 to improve the capabilities of customers.

"The new FireJet brings customers a high-performance, reliable solution that translates directly to increased productivity and improved profitability," says Stacy Fender, VP of worldwide sales.

www.phoseon.com/products/uv-curing-systems/firejet

Lumileds launches second-generation LUXEON CoB Compact Range LED arrays

LED maker Lumileds of San Jose, CA, USA has launched its second-generation LUXEON CoB Compact Range of LEDs, which feature an efficacy and output boost of up to 16% over its previous-generation arrays. Lumileds says that the new product line reinforces its position in chip-on-board technology by enabling cost-effective solid-state PAR, GU-10 and MR-16 lamps for retail, hospitality and home lighting applications.

Due to the common light-emitting surface (LES) of 6.5mm across the LUXEON CoB Compact Range Gen 2 LEDs, different power range directional lamps such as a 35W-equivalent and a 50W-equivalent MR-16 lamp can use the same optic, minimizing design and system cost. The upgraded arrays also achieve what is claimed to be unsurpassed center-beam candlepower (CBCP) or 'punch'. At 1500 lumens, the LUXEON CoB 209 reaches 76,000 candelas at a 10° beam angle.

"Customers currently using



Lumileds' second-generation LUXEON CoB Compact Range.

first-generation LUXEON CoB Compact Range can replace a Gen 1 Compact Range 109 with a Gen 2 Compact Range 205 to attain the same performance at a significantly lower cost, or they can replace a Gen 1 Compact Range 105 with a Gen 2 Compact Range 205 and boost output by 16% in efficacy," says Ivan Tsoi, product manager for the LUXEON CoB Compact Range.

The performance boost, combined with what is claimed to be the industry's lowest thermal resistance, leads to smaller heat-sinks and more cost-efficient lamps.

LUXEON CoB Compact Range LEDs are offered in what is claimed to be the industry's widest range of color temperatures (CCT of 2200–5700K) and color rendering indexes (CRI of 80 and 90). The range is also available with Lumileds' CrispWhite Technology (designed to be used in fashion retail lighting to reveal the richest whites, most vibrant reds and to make all colors pop). All LUXEON CoB Compact Range arrays are hot tested at 85°C to ensure performance in real-world operating conditions and to minimize additional testing.

Also, with the wide availability of compatible holders, optics and drivers, the time to market of spotlights and directional lamps is now faster, says the firm.

www.lumileds.com/LUXEONCoBCompact

Arrow to distribute Lumileds' LEDs, arrays, light engines and automotive products globally

LED maker Lumileds of San Jose, CA, USA and Arrow Electronics announced a strategic agreement for the global distribution of Lumileds comprehensive portfolio of application-optimized LEDs including high-power, mid-power, low-power, chip-on-board (CoB), color and ultraviolet (UV) LEDs as well as the infinitely configurable Matrix Platform. The agreement aligns with both companies' dedication to providing customers with responsive, accelerated service and reliable, high-performance solutions.

"Lighting is an extremely dynamic market and today's lighting producers expect timely delivery of the right LEDs where and when they are needed," says

Emmanuel Dieppedalle, Lumileds' senior VP of marketing & sales. "Arrow is a technology leader that is known for connecting customers with the right comprehensive solutions, quickly... This agreement will expand our market coverage and, with Arrow, customers can count on the consistently high level of service that they have come to expect from Lumileds," he adds.

"Building upon our already strong Lighting infrastructure, we are

Lighting is an extremely dynamic market... lighting producers expect timely delivery of the right LEDs where and when they are needed

pleased to now offer Lumileds comprehensive portfolio of LEDs to our growing customer base," says David West, senior VP of global marketing at Arrow. "With this partnership, Arrow is well positioned to support all LED-based lighting applications."

Arrow is a supply chain partner to industrial and commercial users of electronic components including over 100,000 OEMs and customers worldwide. With this new engagement, Lumileds expects to broaden its availability to the lighting market by accessing Arrow's customer base and service model, enabling faster global adoption of Lumileds portfolio of LEDs, arrays, light engines and automotive products.

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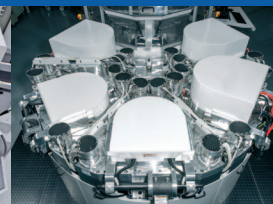
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MORE INFO

Cree files patent infringement counterclaims in US District Court against Feit Electric

LED chip, lamp and lighting fixture maker Cree Inc of Durham, NC, USA has filed counterclaims in the US District Court for the Middle District of North Carolina against Feit Electric Company Inc of Pico Rivera, CA, USA to stop infringement of Cree's patented technologies. The suit alleges infringement of two patents related to LED bulbs:

- US Patent No. 8,998,444 'Solid State Lighting Devices Including Light Mixtures', addressing color mixing in an LED lighting product; and

- US Patent No. 9,052,067 'LED Lamp with High Color Rendering Index', addressing color mixing and a globe that improves omnidirectional light.

"Cree was the first to develop LED bulb technology that achieved both omnidirectionality of light and high-CRI (color rendering index) light," says John Edmond, Cree's co-founder & director of advanced

optoelectronics. "Cree's groundbreaking color mixing technology took years to develop and perfect. It is unfair for others to improperly use our patented technology," he adds.

"Cree is committed to continuing innovation and protecting shareholder value. These court actions protect our inventions from misuse," says Brad Kohn Cree's VP legal & general counsel. "We have more than 4000 issued patents, and we will continue to vigorously defend Cree's patented technology to protect our investments in R&D."

In July 2015, Feit filed a complaint in the US District Court for the Middle District of North Carolina alleging that Cree's 4Flow line of LED light bulbs infringes US Patent Nos. 8,408,748 and 9,016,901, seeking an injunction against sales of 4Flow LED light bulbs as well as damages for past infringing sales. Previously, in January 2015, Cree filed com-

plaints with the US International Trade Commission (ITC) and the US District Court for the Western District of Wisconsin against Feit and its Asian supplier Unity Opto Technology Co Ltd alleging infringement of 10 patents related to LED lighting and to address what was claimed to be Feit's false and misleading advertising claims that certain of its products meet ENERGY STAR specifications. Cree requested that the ITC issued an order to exclude infringing and falsely advertised articles from entry into the USA, and a cease and desist order requiring the respondents to cease selling infringing and falsely advertised LED bulbs in the USA. In February 2015, the ITC agreed to open an investigation into unfair trade practices, including Cree's allegations of infringement of eight of its US patents related to LED lighting.

www.creebulb.com

Cree settles patent disputes and reaches license agreements

Cree has reached confidential settlements in its separate patent infringement lawsuits with Taiwan-based LED makers Kingbright Inc and Harvatek Corp, each involving agreeing to a royalty-bearing, worldwide license to the Cree patents-in-suit, ending the lawsuits between the parties.

In September 2014, Cree filed patent infringement lawsuits in the United States District Court for the Western District of Wisconsin to prevent Harvatek and Kingbright from infringing its patented intellectual property. The patents protect Cree's LED component portfolio, including the firm's white light LEDs. The US patents included in these cases are:

- 6,600,175 — solid-state white light emitter and display using same;
- 7,943,945 — solid-state white light emitter and display using same;

- 8,659,034 — solid-state white light emitter and display using same;
- 7,910,938 — encapsulant profile for light-emitting diodes;
- 8,766,298 — encapsulant profile for light-emitting diodes; and
- 8,362,605 — apparatus and method for use in mounting electronic elements.

"Cree's focus on innovation has led to sophisticated, energy-efficient lighting products and a significant, broad-reaching, LED and LED lighting patent portfolio," says Brad Kohn, VP legal & general counsel for Cree. "Harvatek filed two meritless patent infringement countersuits in California. Both were quickly dismissed with prejudice and with no compensation paid by Cree," he adds. "Cree's original patent infringement lawsuit has now been settled, resulting in a license agreement

that properly compensates Cree for the use of our IP."

"Cree is committed to protecting the investment of our current licensees, shareholders and customers by defending our rights in court when necessary and by licensing our patents when appropriate," says Kohn. "With this settlement and license agreement, Cree has once again obtained value for our extensive IP portfolio."

Cree says that, after many years of intensive R&D, it has developed an extensive LED patent portfolio, with numerous patents still pending. Major LED makers make use of Cree's patented technology and have signed license agreements to secure these rights.

www.cree.com/About-Cree/Licensing/Licensing-Programs
www.cree.com/About-Cree/Licensing/Licensees

Osram Opto's TEN° binning eliminates disturbances in colour perception between light sources

Research on eye cones solves LED color consistency problem

Osram Opto Semiconductors GmbH of Regensburg, Germany says that it has applied the latest findings of physiological research into how human eyes perceive color in order to solve an 85-year-old challenge around why the same light from two different LED light sources, which are measured to be exactly the same, can still look different.

With its TEN° binning feature, Osram Opto says that it has closed the gap between the measured color coordinates emitted by a single-LED light source and the perception of that color by the human eye. The phenomenon of color perception versus reality color measurement of different light sources has been well known to scientists in various forms for decades. In general lighting, this occurs when there are several LED white-light sources in the same space, such as spotlights, wallwashers and downlights.

In 2015 the International

Commission of Illumination (CIE 170-2:2015) published a new color space based on years of extensive research. Beside the physiological meaningful axis of the color space, the most important improvement is the definition for a 10° observer view. Osram has applied these findings to the general lighting market.

"Color coordinates in general lighting are typically measured with the CIE 1931 2° colour space," explains applications manager Alexander Wilm. "It is assumed that the blue, green and red cones that are responsible for color perception in our eyes are evenly distributed, and that the color perception over viewing angle is constant. In reality, this is not the case, and pigment density varies significantly over the field of view's size," he adds.

"Most people have had this peculiar experience without realising, and it has a big impact on many markets,"

Wilm continues. "In retail and museum applications for example, color inconsistency is not an option, and often unpleasant, as it doesn't show a dress or object in the best possible and consistent illumination. The world's greatest modern artists also want their work to be viewed as they had originally intended."

Osram says that it has solved the problem by complementing the CIE 1931 2° xy color space with the CIE 2015 10° u'v'. By assessing the color consistency not only at 2° field of view but also at a significantly larger 10° field of view, the measurement and binning provides a more accurate assessment of color discrepancies under realistic observation conditions. The resulting TEN binning feature has already been implemented in the firm's the new Soleriq S 13 LED type, achieving what is claimed to be unprecedented color consistency under LED lighting.

www.osram-os.com/tenbinning

Cree unveils complete portfolio of RSW LED streetlights

LED chip, lamp and lighting fixture maker Cree Inc of Durham, NC, USA has unveiled the full range of its RSW LED street luminaires with the launch of three new models that deliver comfortable, uniform and dark-sky-friendly LED lighting to roadway applications. The new streetlights complete the RSW Series portfolio (claimed to be the first generation of LED streetlights to deliver LED energy savings and reliability in preferred color temperatures).

The three new models join the initial launch of the small form factor and replace high-intensity discharge fixtures of 70–100W HPS, 150W HPS, 250W HPS and 400W HPS. The RSW Series now offers a unified solution for towns, cities, states and utilities that addresses

street lighting needs from drive-ways to interstates.

Utilizing Cree's WaveMax technology to deliver uniformity, color quality and efficacy, the RSW Series targets street lighting for residential streets, interchanges and expressways. The new luminaires deliver efficacy of up to 115LPW (lumens per Watt) at color temperatures of 3000K or 4000K and a color rendering index (CRI) of 80. The result is enhanced visual comfort, reduced glare and higher-quality street lighting for roadways using less energy, claims Cree. The series is also smart-city ready, enabled by a standard NEMA 7-pin socket.

"The RSW Series is poised to become our premiere intelligent streetlight solution," says David Elien, senior VP of lighting. "Cree's RSW

Series ensures customers now have the opportunity to utilize warmer color temperatures for their street lighting needs without sacrificing LED performance and energy savings."

The RSW Series features a new housing for easy installation and long-life durability that also mitigates light pollution. It is designed to meet a vast majority of challenging roadway and street-lighting applications and is a suitable platform solution for municipalities, cities and departments of transportation.

The complete RSW Series was at the LIGHTFAIR International show in San Diego, CA, USA (26–28 April). The 70–100W HPS replacement is shipping now, and the rest of the new RSW Series models will be available in late summer.

<http://lighting.cree.com/rsw-series>

European Photonics Industry Consortium and Singapore's LUX Photonics Consortium collaborating

On 22 April, professor Tjin Swee Chuan, chairman of the LUX Photonics Consortium in Singapore, and Carlos Lee, director general of EPIC (European Photonics Industry Consortium), signed a collaboration agreement, witnessed by George Loh, program director at the National Research Foundation of Singapore's Prime Minister's Office.

EPIC and LUX Photonics Consortium aim to cooperate on activities involving technological and commercial advancement in photonics. The partnership will encourage direct contact and cooperation between the two consortia and its members, as well as the exchange of information and contacts. It also aims to be the platform for members of one consortium to reach the other's relevant government representatives, public funding bodies and other entities in the region, and to co-host visits by delegates of each consortium's commercial trade missions and business events.

Representing 250 companies across 28 countries, EPIC is an industry association that promotes



National Research Foundation of Singapore program director George Loh together with LUX Photonics Consortium chairman professor Tjin Swee Chuan and EPIC director general Carlos Lee.

the sustainable development of organizations working in photonics. Members encompass the entire value chain from lighting, photovoltaic, photonics integrated circuits (PICs), optical components, lasers, sensors, imaging, displays, projectors, optic fiber and all other photonics-related technologies.

EPIC aims to foster a vibrant photonics ecosystem by maintaining a strong network and acting as a catalyst and facilitator for technological and commercial advancement.

LUX is an initiative set up at national level with support from Singapore's National Research Foundation, with the vision of establishing a photonics academia and industry network in the Asia Pacific region, bringing academia and industry together for the common purpose of innovating new products or technologies enabled by photonics. With nine competitive research programs supported and 13 founding company members, LUX aims to serve as a platform to translate photonics research into diverse applications underpinned by the value chain created in Singapore. Research expertise includes fiber technologies, III-V optoelectronics and biophotonics, optical and laser applications, nanophotonics and metamaterials, lighting and displays.

www.epic-assoc.com

www.luxphotonicsconsortium-sg.org

Compound Photonics launches smallest native 4K imaging device at Display Summit China

At the Display Summit China 2016 in Yixing (9–11 May), Compound Photonics (a technology firm founded in 2008 that has primary manufacturing and design centers in Phoenix, AZ, USA and Newton Aycliffe, UK) has launched what is claimed to be the smallest native 4K imaging device, measuring only 14mm diagonally and featuring pixels smaller than 3µm.

"We are the company that has succeeded in introducing the world to RGB solid-state laser-based technology, making it finally possible to manufacture a 3000 lumen lamp-less native 4K projector that rivals the performance delivered by

today's solid-state displays," claimed Tim Anderson, VP of product management in his presentation at Display Summit.

The use of RGB laser technology eliminates lamps, creates a huge new color gamut to work with, and enables balancing the color output of each color channel to achieve a perfect white point, says the firm. Compound Photonics has invested significant engineering resources to reduce the cost of RGB lasers and speckle, states Anderson.

"Projector customers around the world want to be able to project a huge image in full daylight and still have an outstanding image,"

Anderson said. "Our engineers have developed specific algorithms that use an expanded color gamut made possible by RGB laser technology. These algorithms combat ambient light and dramatically improve color contrast," he adds.

Compound Photonics offers capabilities ranging from small, bright, full-HD laser light engines for mobile devices; an embedded 1080P projector that is less than 2cm³ in size; infrared (IR) and green lasers; head-up car displays; near-eye augmented reality; and gesture recognition.

www.compoundphotonics.com

www.displaysummit.com/



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Europe's TOP-HIT transfer printing consortium to boost large-scale heterogeneous integration of diverse materials and devices

€5m Horizon 2020 program targets photonic integrated circuits

Ireland's Tyndall National Institute (based at University College Cork) is leading the European consortium TOP-HIT (Transfer-print OPERations for Heterogeneous INtegration) to develop novel technology that will address the challenge of integrating components of different materials in large volumes at the semiconductor scale.

Funded with more than €5m under the European Union's Horizon 2020 program for Smart System Integration and running from 2015 to 2018, the TOPHIT project uses micro-transfer printing (μ TP) technology, which allows a set of potentially many thousands of devices at a time to be taken from one semiconductor wafer and stamped onto another wafer.

As an example, a small platelet of an expensive material can be picked up with a stamp and transfer printed onto a larger surface of another (less expensive) material, on which all electrical and optical waveguide interconnections can then be made. Or, light-emitting devices (such as LEDs or lasers) can be printed onto a material that is more suitable for electronic signal processing. It is even possible to print several types of devices onto the same substrate material to combine, for example, light sources, detectors and signal

processing all on the same platform. Hence, a system-on-a-chip — a photonic integrated circuit (PIC) combining devices made of different materials — can be built up. Printed platelets are typically a few microns thick, and can be printed with a placement precision of about $1\mu\text{m}$.

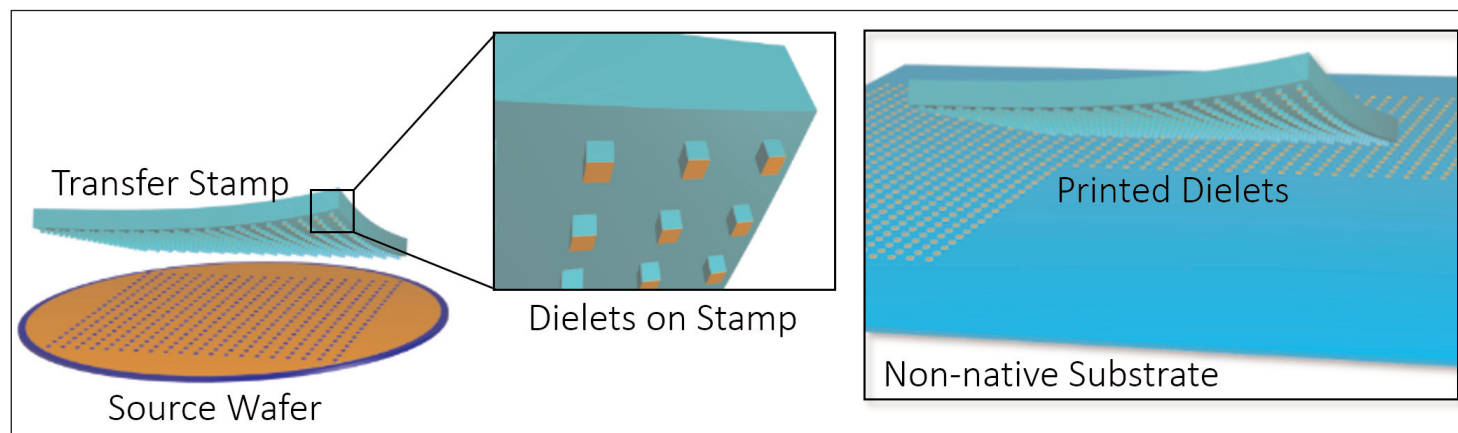
"The transfer print process, by combining diverse optical, electronic and other functional materials, opens up an enormous range of possibilities for new devices with embedded functionality," says project coordinator Brian Corbett (principal investigator at Tyndall). "This will lead to more compact chips and systems for a variety of applications, such as telecommunications, smart sensing, biomedical sensing and data storage, but the key breakthrough will be the application of micro-transfer-printing to address the challenge of integrating non-compatible components in large volumes at the semiconductor wafer level, eliminating the need for current inelegant integration processes such as wire-bonding," he adds.

The consortium partners provide complementary expertise: Ireland-based X-Celeprint is a manufacturer of transfer printing equipment that can print many devices simultaneously, and provides the

printing expertise. Belgium-based nanoelectronics research center Imec (which employs over 1500 people) has its own X-Celeprint equipment, and provides the silicon photonics platforms that form the basis for the photonic products. Belgium-based photonics company Caliopa Huawei develops optical components and circuits for telecoms applications. The Centre for Integrated Photonics (CIP, a subsidiary of Huawei, in the UK) develops indium phosphide (InP)-based components and circuits for telecoms applications. Germany-based analog/mixed-signal and MEMS foundry X-FAB will develop new processes to provide wafers with components that can be transfer printed (and will add this capability to its existing portfolio of modular foundry processes). Seagate is a manufacturer of hard-disk drives and storage solutions whose facility in Northern Ireland ships more than 500 million read/write heads annually. Ireland's Tyndall National Institute provides designs and components that can be transfer printed by X-Celeprint onto platforms provided by Imec and X-FAB.

www.tophit-ssi.eu

www.tyndall.ie/content/photonic-integration



Schematic of the micro-transfer print (μ TP) process.

Ozark wins NASA grant for SiC-based UV imager on a chip

The US National Aeronautics and Space Administration (NASA) has awarded \$754,000 to Ozark Integrated Circuits Inc of Fayetteville, AK, USA (a fabless spin-off from the University of Arkansas that develops analog and mixed-signal ICs for remote sensing and actuation in extreme-temperatures and -radiation environments) to fabricate a silicon carbide (SiC)-based ultraviolet imager prototype for planetary exploration and Earth observation from space, among other applications.

Ozark IC (which designs semiconductors at the Arkansas Research and Technology Park) will develop a complex photo-detecting microchip that can operate in temperatures ranging from -200°C to $+500^{\circ}\text{C}$.

"The uniqueness of our approach is the extreme responsiveness of our imager's sensor and our ability to integrate it with the readout electronics to turn the detector readings into images for a computer or spacecraft system," says Ozark IC's president & CEO Matt Francis. "NASA would be able to use the imager to observe areas on Earth from space as well as other objects in space."

The use of SiC means that the imager can operate at low voltage over a very wide temperature range, making it suitable for planetary exploration that requires space-borne instruments capable of measuring light in the ultraviolet spectrum. Two examples are NASA's Discovery and New Horizons missions (which intend to image planets from orbit or on the surface) and those proposed for Venus (where the imager would need to operate at nearly 500°C).

Francis and chief technology officer Jim Holmes have worked with University of Arkansas electrical engineering professor Alan Mantooh and computer science & engineering professor Jia Di over the last several years to perfect design procedures, tools, characterization and modeling approaches that enable them to design high-temperature electronics

capable of operating at conditions well beyond 300°C .

Ozark will also use the integrated circuit packaging expertise and facilities of the University of Arkansas' High Density Electronics Research Center (HiDEC) at the research park.

The NASA Phase II contract came via the Small Business Innovation

Research (SBIR) program, which allows federal agencies to stimulate technological innovation in the private sector by strengthening small businesses that meet federal R&D needs. The program also aims to increase the commercial application of federally supported research results.

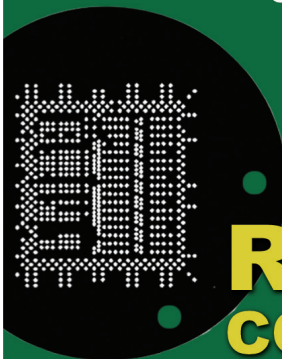
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POET acquiring BB Photonics

Broadened IP portfolio in III-V materials provides source of sustained differentiation in integrated photonics

POET Technologies Inc of San Jose, CA, USA — which has developed the proprietary planar optoelectronic technology (POET) platform for monolithic fabrication of integrated III-V-based electronic and optical devices on a single semiconductor wafer — has agreed to acquire BB Photonics Inc, a privately held designer of integrated photonic solutions for the data communications market. On completion of the transaction (which is subject to applicable regulatory reviews and approvals, including approval of the TSX Venture Exchange), POET will own 100% of BB and its assets, including intellectual property and technologies, with no liabilities assumed on closing.

BB Photonics (a pre-revenue, New Jersey-based photonics firm) develops photonic integrated components for the data-center market utilizing a platform technology approach using embedded dielectric technology that is intended to enable on-chip athermal wavelength control and lower the total cost of data-center photonic integrated circuits.

POET says the strategic acquisition of BB Photonics will provide it with additional differentiated intellectual property and know-how for future product development at its facilities

in Singapore (acquired this month with the purchase of DenseLight Semiconductors Pte Ltd, a privately held designer and manufacturer of photonic sensing and optical light source products for the communications, medical, instrumentations, industrial, defense and security industries). POET reckons that, collectively, this will enable it to better service the end-to-end data communications market and additionally augment its sensing roadmap.

“The acquisition of BB Photonics helps bolster our intellectual property and know-how in integrated photonic solutions and enables broad applications through its unique performance and cost capabilities. These factors will allow us to expand, accelerate and complement our current roadmap,” says POET’s CEO Dr Suresh Venkatesan. “This is another synergistic and timely acquisition for us as we focus on providing our existing and future customers a broader range of differentiated photonics technologies.”

Acquisition by POET will help to enable athermal multi-wavelength photonic integration in high-speed indium phosphide devices, says BB Photonics’ CEO Bill Ring. “We look forward to working closely with POET and DenseLight to bring our

differentiated IP to market,” he adds.

POET will acquire all shares of BB Photonics in exchange for issuing about 2 million common shares from POET’s treasury in the stock-only transaction (subject to adjustment based on the increase or decrease in the US-CDN dollar exchange rate before closing, which should occur no later than 30 days following the agreement). Issuance of the POET shares is subject to compliance with all US and Canada Federal and State or Provincial securities laws and regulations, and the rules of the TSX Venture Exchange. The shares will be restricted and subject to re-sale restrictions, as established by the TSX Venture Exchange and US securities laws. The management shareholders of BB Photonics have agreed not to sell, transfer, pledge or otherwise dispose of the POET shares for a period of six months, when they may each sell up to 25% of their shares. They may sell an additional 25% after 12 months, and the remainder after 24 months. BB Photonics’ non-management shareholders may sell POET shares at various times and in various amounts at 4-, 6- and 12-month periods following issuance.

www.bbphotonics.com

POET’s executive co-chairman Copetti moves on

POET says that Peter Copetti has stepped down from the board and his post as executive co-chairman to pursue other opportunities.

Copetti joined POET at the genesis of today’s refocused enterprise, and has served as both executive co-chairman and interim CEO. He has worked to establish POET as a presence in the integrated optoelectronics industry and has been instrumental in the financial restructuring of the firm.

“His contributions and dedication

to the restructuring of the company has led us to our current state with a strong team, healthy balance sheet, and well defined strategic roadmap,” comments executive co-chairman Ajit Manocha.

“His leadership, through our recently announced acquisition [of DenseLight Semiconductors], has been commendable,” he adds.

“Peter’s mix of passion and business intelligence has helped establish a solid foundation for this company, as we now focus on our

‘lab to fab to monetization’ path,” says CEO Dr Suresh Venkatesan.

“His leadership over the past four years has had a tremendous impact on this company in terms of its vision, mission and financial turnaround,” he adds.

“Ajit, Suresh and their team will lead this company to new heights and I look forward to continued successes from this team as they focus on product development and achieving revenue,” says Copetti.

www.poet-technologies.com

POET acquires Singapore device maker DenseLight

POET gains fab, sales and channel distribution networks, and broader III-V product portfolio for end-to-end datacom market

POET Technologies Inc of San Jose, CA, USA — which has developed the proprietary planar optoelectronic technology (POET) platform for monolithic fabrication of integrated III-V-based electronic and optical devices on a single semiconductor wafer — has acquired Singapore-based DenseLight Semiconductors Pte Ltd, a privately held designer and manufacturer of photonic sensing and optical light source products and solutions for the communications, medical, instrumentations, industrial, defense and security industries.

After approval by the TSX Venture Exchange, POET now owns 100% of DenseLight and its global photonics business and assets, including fabrication facility, intellectual property and technologies.

DenseLight Semiconductor processes indium phosphide and gallium arsenide III-V based optoelectronic devices and photonic integrated circuits (PICs) through its in-house wafer fabrication and assembly & test facilities. The firm is recognized for its high-performance infrared super-luminescent light sources and lasers, with a proven track record in deployed applications.

POET says the revenue-accretive acquisition will provide it with a fab infrastructure for future product development, access to product sales and channel distribution networks, and a broader product portfolio of photonic products. Collectively, this will enable POET to better service the end-to-end datacoms market, it is reckoned. Additionally, POET expects to gain intellectual property and know-how that will enhance its presence in the fast-growing telecom access network markets for passive optical networks (PON) and in other markets complementary to datacoms.

POET aims to expand the operation of DenseLight's existing manufacturing facilities in Singapore, which generated revenue of US\$2.6m in

2015 and a consistent gross profit of over 40% in each of the three previous years. POET anticipates that DenseLight as a division will achieve positive net income by fiscal 2017.

Ancillary benefits of the strategic acquisition include DenseLight's test and reliability capabilities, which will accelerate new product introduction (NPI). Also, DenseLight's location should increase supply-chain efficiencies, as existing suppliers are located within the same geographic zone, facilitating ease of communication, interaction and real-time testing on future and current product development. POET will also benefit from an investment of more than S\$50m made to date by DenseLight shareholders to enhance the firm's core competencies. While DenseLight is a strategic acquisition, POET is also engaged in advanced stages of other avenues that it expects will accelerate the path to revenue over the next 12 months and further its monetization strategy.

"The acquisition of DenseLight Semiconductor reflects a new chapter in our history, and serves as a significant step in realizing the promise of our product roadmap and strategic plan we established in September 2015," says POET's CEO Dr Suresh Venkatesan.

"This synergistic combination can provide our customers a broader range of differentiated photonics technologies. The resulting enhancement of our design, test and packaging capabilities also promises to optimize time-to-revenue for our customers. POET now has a

larger product portfolio to enhance our mission of enabling integrated photonic products for our expanded end-markets," he adds.

"DenseLight is tailor-made to solidify POET's goal of attaining a leadership position in III-V integrated optoelectronics technology development and manufacturing," comments DenseLight's chairman & CEO Jerry Rodrigues. "We at DenseLight are delighted to be an integral part of the POET family and to play a strategic role in the company's growth plans in the rapidly developing III-V integrated optoelectronics market and particularly the exciting application demands for the Internet of Things (IOT)."

POET executed the acquisition via a combination of stock and cash. A significant portion of the cash was used to repay DenseLight's outstanding debt and other liabilities. POET funded the purchase price of the acquisition with cash on hand.

In accordance with the terms of the share purchase agreement of 28 April, DenseLight shareholders will be issued about 16 million common shares of POET. Also, about 1.3 million POET shares will be issued (subject to monetary exchange rate adjustment at the time of issuance) to DenseLight shareholders if DenseLight meets or exceeds a pre-determined revenue target during 2016.

"Our combined capabilities will drive continued opportunities in serving the growing photonics market, with a comprehensive suite of product solutions, while strengthening the company's finances and operations," believes Venkatesan. "With the strong support of the DenseLight management team, we have already begun to map our integration plans for the combined entity with a goal of achieving profitable and sustainable growth targets."

www.denselight.com

www.poet-technologies.com

POET expects to gain IP and know-how that will enhance its presence in the fast-growing telecom access network markets for PON and in other markets complementary to datacoms

NeoPhotonics' revenue rises 11% in Q1 to record \$99.1m Full-year revenue growth forecast raised from 15% to 20–25%

For first-quarter 2016, NeoPhotonics Corp of San Jose, CA, USA (a vertically integrated designer and manufacturer of hybrid photonic integrated optoelectronic modules and subsystems for high-speed communications networks) has reported record revenue of \$99.1m, up 11.2% on \$89.1m last quarter and up 21.8% on \$81.4m a year ago (and above expected \$92–98m), driven by strength in demand across key 100G products (components, modules and switches).

Revenue for Network Products and Solutions (lower-speed transceivers, <100Gb/s) has declined further, from \$37.4m last quarter to \$35m (35% of total revenue). Meanwhile, growth in revenue for High Speed Products (100G-and-beyond) accelerated, rising 24% to a record \$64.1m (65% of revenue, which is believed to be the highest 100G percentage in the industry).

There were two 10%-or-greater customers: US-based Ciena comprised 16% of total revenue, and China's Huawei Technologies 54%. Of total revenue, 20% came from the Americas, 62% from China, 5% from Japan, and 13% from the rest of the world.

"The rapid increase in demand for 100G products from China and worldwide is a very positive contrast to our normal seasonal pattern in the first quarter as we sold out our capacity for certain key products," says chairman, president & CEO Tim Jenks.

On a non-GAAP basis, gross margin has hence risen further — in contrast to normal seasonality — from 31.3% a year ago and 32.4% last quarter to 32.8% (close to the high-end of the 30–33% guidance range), driven by the favorable product mix and improved fab utilization, as well as being able to maintain favorable pricing for certain products due to industry supply constraints.

Driven by continuing investments in 100G components, modules and switches, operating expenses have

risen from \$20.2m a year ago and \$22.6m last quarter to \$23m (23% of revenue). However, as a proportion of revenue, OpEx is just 23%, reduced from 25.4% last quarter (and 24.8% a year ago), i.e. within the 25% target.

Net income has risen further, from \$4.2m (\$0.13 per diluted share) a year ago and \$6.9m (\$0.16 per diluted share) last quarter to \$7m (\$0.15 per diluted share). This represents the firm's seventh consecutive non-GAAP profitable quarter. Likewise, adjusted EBITDA has risen further, from \$9.9m a year ago and \$11.8m last quarter to a record \$12.3m.

During the quarter, cash and cash equivalents, short-term investments and restricted cash rose from \$102m to \$103.8m. Total debt at the end of March was \$44.8m.

"Capacity for our key 100G products was booked out, and in the first quarter we shipped at full capacity for certain products, resulting in record revenue," says chief financial officer Ray Wallin. "Our capacity remains booked out for the second quarter as well, and we see demand continuing to grow from the convergence of strength in China, and from data-center and metro deployments. Therefore, we are augmenting and accelerating the capacity expansion plans we discussed last

Capacity remains booked out for the second quarter as well, and we see demand continuing to grow from the convergence of strength in China, and from data-center and metro deployments. Therefore, we are augmenting and accelerating expansion plans, adding module, component and chip-level capacities

quarter, adding module, component and chip-level capacities. We expect to double our capacity for switches and increase coherent receiver, ultra-narrow-linewidth tunable laser and 100G module capacities by 50% or more over previously planned levels. And, of necessity, these capacity increases will occur incrementally over the next quarters," he adds.

For second-quarter 2016, NeoPhotonics expects revenue of \$97–102m. "We do expect our second-quarter manufacturing capacity to be up incrementally as compared to our first quarter, while demand continues to grow. Therefore, as our new capacity adds come on line, we expect to see increasing benefits from the third quarter on, and we expect that in Q2 gross margins will be impacted by the realization of ASP [average selling price] changes together with our ramping up manufacturing inventories to enable our higher volumes overall," says Wallin. Gross margin should be 29–31%, and diluted earnings per share should be \$0.08–0.15. "With these higher purchase volumes, we anticipate that we will see continued cost reductions that will be favorable to forward margins."

"Our quarterly non-GAAP operating expense run rate continues to reflect the controls we established to be consistent with our target model, reflecting leverage in our operating model," says Wallin. "In the last seven quarters we have operated at or below our target model of 25% for operating expenses, which we continue through 2016," he adds.

NeoPhotonics' target model for 2016 comprises 35% gross margin, OpEx of 25% of revenue, 10% operating margin, and 15% EBITDA margin. However: "We see the overall environment for 100G products globally as very robust and, given the acceleration in our organic demand, we are bringing

► additional capacity on line over the next quarters [raising the CapEx forecast for full-year 2016 to 7–9% of revenue],” says Jenks. “As a result, we anticipate revenue growth to be in the range of 20–25% for the year [up from the previous forecast of 15%],” he adds.

“We believe that the industry has entered an expansion cycle where 100G deployments are expanding globally for both telecom and data-center applications and that these two segments are in sync,” says Jenks. “Within the China market, we expect the strength we’ve seen in 100G deployments to continue as we anticipate awards for approximately 30,000 100G ports for the second half of the year and into 2017. Outside of China, we continue to see an on-going worldwide ramp of 100G deployments, particularly in North America and Europe, driven by Verizon and other major carriers, as well as strong growth in the datacenter interconnect market. Within the various end-markets, long-haul remains strong while metro 100G build-outs are beginning and are expected to ramp materially in the second half of 2016,

through 2017 and beyond,” he adds.

“We have previously articulated several drivers affecting our business. Cloud services are driving a shift in communications architectures to enable high bandwidth, connection density and rapid reconfiguration. Further, 100G coherent transmission is the technology of choice for long-haul, metro and DCI connections, and the use of contentionless switching architectures in coherent networks is expanding, and is critical for software-defined networks for content providers’ datacenters,” Jenks continues. “Finally, data lanes in datacenters are rapidly moving to 25G from 100G and increasingly using single-mode instead of multi-mode fiber. These trends are favorable to NeoPhotonics. As a result, demand for our coherent product suite, our multi-cast switch products, our client and datacenter 100G transceivers, our EML lasers and our high-speed IC components is expected to continue to grow throughout 2016 and beyond.”

“Continuing our leadership in 100G-and-beyond solutions, we

introduced a number of exciting new products and technologies at OFC [Optical Fiber Communication conference] in March and at the recent FOE [Fiber Optics Expo] trade show in Japan,” notes Jenks. “On the line side, these included our multi-rate CFP2-ACO coherent module as well as our new high-bandwidth coherent receiver, which enables 400G transmission using a single DWDM wavelength,” he adds. “For applications inside the datacenter, we announced development of a 400G transceiver based on eight of our 28Gbaud EML lasers using PAM4 transmission, and followed up with 56Gbaud EML lasers that can reach 400G with only four lasers, again utilizing PAM4,” continues Jenks. “Our leading product performance in ultra-narrow linewidth tunable lasers, high-speed and high-sensitivity coherent receivers, and high-data-rate EML lasers has allowed us to rapidly move to new 400G telecom and datacenter applications and to provide our customers with future-proof solutions for today and tomorrow.”

www.neophotonics.com

Lumentum recognizes Sanmina with ‘Excellence In Value Innovation’ award

Sanmina Corp of San Jose, CA, USA, a provider of integrated end-to-end manufacturing solutions making optical, electronic and mechanical products, has been recognized for its outstanding performance with the ‘Excellence in Value Innovation’ award by optical and photonic product maker Lumentum Operations LLC of Milpitas, CA, USA.

The award acknowledges Sanmina’s performance in areas including excellence in operations, engineering, cost optimization and NPI (new product introduction) services. Lumentum and Sanmina have been working together since 2009 to design and produce active and passive optical components, pump lasers, optical transceivers and

optical circuit packs.

“Sanmina is more than a top supplier; they are a long-term partner we consistently rely on to meet dynamic market conditions,” comments Joelle Prather, VP, supply chain at Lumentum. “Sanmina’s design expertise in optical technology, their gateway business model, and global manufacturing prowess are important factors in our partnership,” he adds.

“We are proud to be recognized for our ongoing commitment to excellence in design and manufacturing operations,” says Mike Landy, Sanmina’s executive VP & chief operating officer, Asia, EMEA and global services. “Lumentum is developing some of the most

advanced optical networking products available today, and we are proud of the partnership that brings these innovative products to market.”

Sanmina’s Optical, RF and Micro-electronics division designs and manufactures products for the communications, medical, aerospace and industrial markets. The firm’s design expertise includes the highest-speed optical transceivers and modulators, along with optoelectronics and complex systems. Sanmina also designs and produces RF technology for satellite systems, radar and industrial IoT (Internet of Things) products.

www.lumentum.com

<http://sanmina.com/solutions/optical-rf-microwave>

Oclaro reports 100G revenue growth for fourth consecutive quarter, up 94% year-on-year

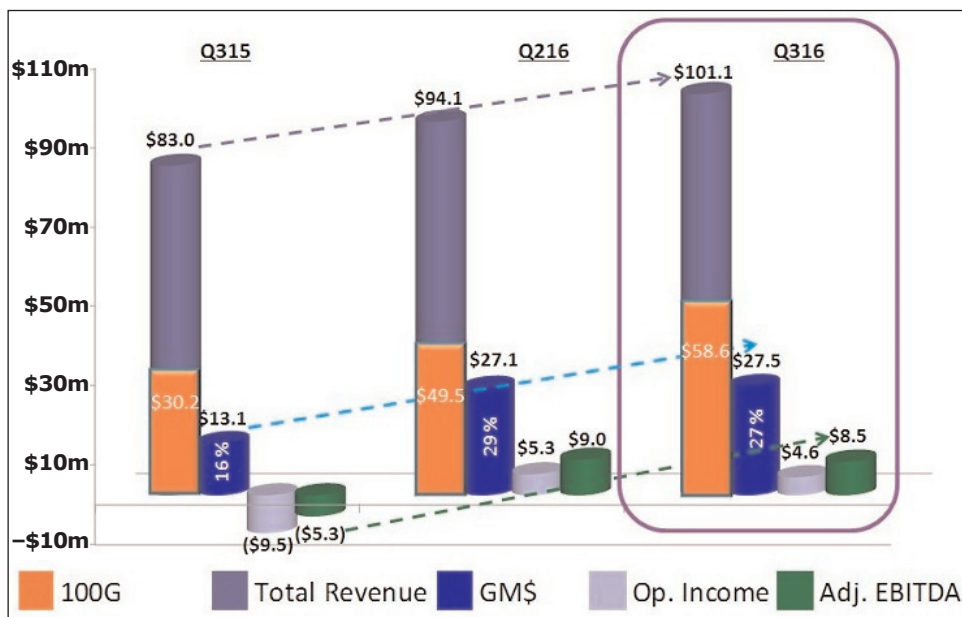
CapEx to ease capacity constraints for 100G and tunable 10G demand

For its fiscal third-quarter 2016 (to 26 March), Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications) has reported revenue of \$101.1m, up 7.4% on \$94.1m last quarter (a third consecutive quarter of approximately 7% sequential growth, despite the annual March-quarter price reductions) and up 22% on \$83m a year ago.

Growth was again fueled by 100G product revenue of \$58.6m (58% of total sales), up 18% on \$49.5m (53% of total sales) last quarter and up 94% (nearly doubling) on \$30.2m (36% of total sales) a year ago.

This more than offset the expected decline for 40G-and-below products, to \$42.5m (42% of total sales), down 5% on \$44.6m (47% of total sales) last quarter and down 19.5% on \$52.8m (64% of total sales) a year ago. Of this, 40G specifically contributed just \$11.5m (11.4% of total sales), down as much as 39.5% on \$19m (23% of total sales) a year ago, while 10G contributed \$31m (30.7% of total sales), down only 8.3% on \$33.8m (41% of total sales) a year ago. "We are seeing unanticipated strong demand for 10G transceivers and tunable products," notes CEO Greg Dougherty.

Both the client-side and line-side businesses grew. Line-side (telecom) revenue was \$47.7m (47% of total sales), up 11% on \$43.1m last quarter. "We saw very good growth in our lithium niobate modulators and our tunable narrow-linewidth lasers used in 100G coherent systems," notes Dougherty. "We also saw our first production revenues from the CFP2-ACO." Client-side (datacom) revenue was \$53.4m (53% of total sales), up 5% on \$51m last quarter and up 40% on \$40.4m (49% of total sales) a year ago. "We continue to see very strong demand worldwide for our 100G pluggable CFP product family," says



Dougherty.

By region (compared with last quarter), China rose from 37% to 43% of total revenue, while the Americas fell from 35% to 28% and Europe fell slightly from 16% to 15%, as Southeast Asia rose from 10% to 11%, and Japan rose from 1% to 2%. There were four customers with greater than 10% of sales (20%, 14%, 12% and 11%, respectively).

"These results are a testament to our improved execution," says Dougherty. "In spite of the seasonal price reductions, we delivered strong gross margin and operating income."

On a non-GAAP basis, gross margin was 27.2%, down only slightly from 28.8% last quarter (as expected, absorbing annual price reductions) but up significantly from 15.8% a year ago, driven by a stronger mix of 100G sales, improved factory efficiencies, and leveraging of manufacturing overhead.

Operating expenses rose from \$21.8m last quarter to \$22.9m, due mainly to seasonal beginning-of-the-year payroll taxes in the USA and the UK (remaining 23% of sales, although this should fall to about 21% in future as the firm

grows further).

Operating income was \$4.6m, down slightly from \$5.3m last quarter but much improved from a loss of \$9.5m a year ago. Likewise, net income was \$2.9m (\$0.03 per diluted share), down slightly from \$3.1m (\$0.03 per diluted share) last quarter but a big improvement on a loss of \$9.6m (\$0.09 per diluted share) a year ago. Adjusted EBITDA was \$8.5m, down slightly from \$9m last quarter but an improvement on -\$5.3m a year ago.

Capital expenditure (CapEx) was \$8.6m (making \$24.3m year-to-date, and on target for \$30-40m full-year). During the quarter, cash, cash equivalents and restricted cash hence fell from \$115.7m to \$106.8m.

"Our success in 100G and beyond, together with the incredibly strong demand from China, is currently fueling our growth," says Dougherty. "China continues to be very strong for us and we are well positioned with all four of the major network equipment manufacturers in the region. We have a robust demand for all of our 100G products, as well as unanticipated demand for 10G parts," he adds. "As an industry analyst research firm recently reported, the outlook is for contin-

► used strong growth in China not just for the balance of this calendar year, but well into 2017. We believe that demand for 100G is for a widely publicized backbone in metro networks, while the 10G products are from metro networks and access aggregation," continues Dougherty.

"This strength in 10G is important as we now have a final plan for the end-of-life of our 40G line-side business," says Dougherty. As part of the firm's exit, it expects that the 40G business will drop by \$3–4m in both fiscal Q4 and fiscal Q1/2017. But, given the strength of 10G business, Oclaro expects total 40G-and-below business to drop by only 5% in fiscal Q4 and then to remain fairly flat in the mid-\$30m for the rest of calendar 2016.

"Our 100G growth is not just coming from China, but also being driven by more 100G being deployed in packet optical networks, the move to single-mode 100G in the data center, and the emerging metro market," notes Dougherty.

"We continue to lead the CFP2-ACO market based on many ongoing field trials and design wins. Our customers are telling us that our product performance is much better than the competition, particularly

for 200G applications which are emerging as the preferred solutions for the datacenter interconnect market," Dougherty says. "During the quarter, we launched production from Asia [from Malaysian contract manufacturer Venture] of our CFP2-ACO product... the production ramp in Asia for the ACO is going much better than our initial plan," he notes. "We expect the ramp of the ACO, and increase in capacity for both our client- and line-side 100G portfolios, will drive further improvement in our financial results for the June quarter and the rest of this calendar year."

Oclaro has also substantially increased its production capability for lithium niobate modulators and narrow line-width lasers for coherent transmission. "We have gained and are continuing to gain market share for both of these products," believes Dougherty.

Oclaro is also continuing to increase its 100G client-side manufacturing capacity for CFP, CFP2 and CFP4 products. "We expect the extra capacity to begin having a positive impact this quarter," he adds.

On top of the high market demand for the CFP family, Oclaro is experiencing much stronger and earlier-than-expected demand for QSFP28

transceivers both for CWDM and LR4. "We have several design wins at traditional packet optical network equipment manufacturers, as well as routing and switching companies," notes Dougherty. "We have also had initial successes with the QSFP28 by working directly with some of the Web 2.0 hyperscale customers." Oclaro is currently production constrained on the QSFP28 and recently allocated a significant amount of capital spending to grow capacity. "We will continue to ramp production of the QSFP28 family through the balance of this calendar year," he notes.

"Once again, our growth in Q4 will not be gated by demand, but will be limited by what we are able to ship. We continue to run very tight on capacity for most of our 100G products, as well as for our tunable 10G offerings [for which the strong demand is expected to continue over the next few quarters]," cautions Dougherty.

For fiscal fourth-quarter 2016 (a 14-week quarter, ending 2 July), Oclaro expects revenue to rise to \$115–123m. The firm also expects gross margin of 27–30%, operating income of \$7–11m (doubling on the prior quarter) and EPS of \$0.04–0.07.

www.oclaro.com

Emcore wins largest purchase order of \$4.7m to supply RFoG optical networking units for major cable network deployments

Emcore Corp of Alhambra, CA, USA — which designs and manufactures indium phosphide (InP)-based optical chips, components, subsystems and systems for the broadband and specialty fiber-optics markets — has been awarded a \$4.7m purchase order to supply RFoG optical networking units (ONU) to a major US supplier of network infrastructure solutions for the cable TV market. The products are expected to be shipped over the next year.

RFoG (Radio Frequency over Glass) technology extends hybrid fiber coax (HFC) networks deeper into neighborhoods to handle increasing user bandwidth demand. Emcore's RFoG

ONU supports 1610nm burst-mode analog return-path conversion for triple-play voice, video and data signals in single-family and multi-dwelling unit applications. It resides at the customer's location and provides the interface between the optical network and the subscriber coaxial network.

Emcore's RFoG ONU is designed to support standard CATV downstream and upstream transmission bands. Downstream it receives a 1550nm forward-path optical signal carrying an RF CATV spectrum up to 1.0GHz, making it compatible with the cable industry's DOCSIS 3.0 standard. For return path it supports digital or

QAM upstream transmission utilizing a burst-mode DFB transmitter that operates at 1610nm and supports a 5–42MHz spectrum. The RFoG ONU is compliant with the SCTE (Society of Cable Telecommunications Engineers) RF-over-Glass specification.

"Our CATV broadband transport and access products are ideal for network systems providers that demand the highest-quality, economical delivery of high- and ultra-high-definition video and audio, along with the highest-bandwidth data transmission for their customers," says president & CEO Jeffrey Rittichier.

www.emcore.com

Emcore grows margin and income year-on-year despite seasonal drop in quarterly revenue

Rising CATV orders driven by shift to DOCSIS 3.1

For its fiscal second-quarter 2016 (to 31 March), 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 \$21.5m (towards the low end of the \$21-24m guidance), down 4.3% on \$22.5m last quarter but up 12.6% on \$19.1m a year ago in a typically seasonally weak quarter. “Similar to last quarter, the results reflect demand in our CATV and components product lines [with cable TV comprising 60–65% of revenue], despite seeing continuing pressure on our chips product line,” says chief financial officer Mark Weinswig.

Revenue for chip-level device products has been relatively flat for the last two quarters, at \$4m (19% of total revenue, mostly from GPON applications), as an unseasonal increase in shipments from Q1 to Q2 was counteracted by pricing pressure. Nevertheless, revenue has grown significantly over the prior two years (with first-half fiscal 2016 chip revenue already exceeding the total for full-year fiscal 2015).

The rapid rise in GPON volumes (starting at the end of February) has not only helped to accelerate top-line growth but also significantly improved manufacturing utilization and allowed Emcore to greatly reduce the fixed-cost burden allocated to remaining businesses, including its core CATV business.

On a non-GAAP basis, gross margin was 32.6%, on the low side of the mid-30s target range but down only slightly from 32.9% last quarter despite the \$1m drop in revenue.

Total operating expenses were \$7.4m (flat on last quarter but down from \$8m a year ago), comprising \$2.6m in R&D expenses and \$4.8m in selling, general & administrative (SG&A) expenses (which included \$0.3m from legal activities).

Net income is up from \$3m (\$0.10 per share) a year ago and \$1m (\$0.04 per share) last quarter to \$4m (\$0.15 per share). However, this includes \$3.8m (\$0.16 per share) of income from discontinued operations related mainly to the Sumitomo Electric Industries (SEI) arbitration ruling in April. Income from continuing operations was \$0.6m (\$0.02 per share), down from \$1.3m (\$0.05 per share) last quarter but up from \$0.25m (\$0.01 per share) a year ago.

Capital expenditure (CapEx) was about \$1m (making \$2.2m in first-half fiscal 2016 — CapEx is expected to be hit \$5m for full-year fiscal 2016, exceeding the target of 5% of revenue).

During the quarter, cash and cash equivalents fell from \$115.5m to \$110m, due mainly to an increase in accounts receivable and inventory (but excluding the receipt of cash from the Sumitomo arbitration finding announced in April).

Regarding Emcore’s cable TV business, the firm has seen an overall backdrop of strength in infrastructure spending along with turbulence over the past two quarters relating to inventory build up in the channel and some consolidation in the market. “We see this turbulent period ending, as we’ve seen significant strength in new orders as we finish Q2 and in our first month of Q3,” notes president & CEO Jeffrey Rittichier. “Going forward, we expect to see a return to growth in cable television. The strength of our most recent orders clearly demonstrates that MSOs are making their planned shift to DOCSIS 3.1 deep fiber deployment. These new architectures allow them to compete more aggressively with telco and satellite products, offering a faster network that can deliver 4K and over-the-top services much more efficiently. Given our leadership position in the market and the sig-

nificant investments that we’ve made in cable TV chip technology over the past few years, Emcore is enabling the shift to DOCSIS 3.1,” he adds.

“Importantly, the successful conversion of our linear EML [LEML] is a new opportunity for our cable TV business over the next few years, as LEMLS have superior cost:performance ratios to the traditional externally modulated transmitter technology that exists in the market today,” says Rittichier. “Over the next year, as we roll out new products based on the LEML and its derivatives, we expect that those products will set the standard for both DOCSIS 3.1 and RF-over-glass deployments in the future.”

“Despite consolidation at both the MSO and OEM levels, and a strong competitive market overall, Emcore’s technical position and strong market share has allowed us to keep pace with and even exceed overall market growth by entering new segments where we have not competed in the past,” continues Rittichier. “Given our position in the market, our strong relationship with customers, broad suite of product technology and leadership, we have good reason to be excited about the outlook for cable TV going forward. CapEx spending and network upgrade deployments are healthy and, given our market share leadership and relationships with customers, we have an excellent technical position and a good handle on the dynamics in the market. Consequently, we feel confident in our ability to continue to provide differentiated products over time. Coupled with our manufacturing and operating cost reduction initiatives, cable television remains a very attractive stable foundation upon which to grow into other areas,” he adds.

With trends in cable TV continuing to improve, for fiscal third-quarter 2016 (ending 30 June) Emcore

► expects revenue to rise to \$22–24m.

Rittichier notes that Emcore is implementing its hybrid EMS (electronics manufacturing services) model to reduce cost and convert fixed cost to variable cost. So, commodity processes will no longer be done at Emcore, even in China. Emcore is removing satcom assembly & test from its US facilities to Thailand this quarter, and several commodity processes have already been moved from its Chinese facility to its two primary EMS partners (e.g. TO-can packaging, box builds and turnkey assembly, which can hence be done more efficiently). "We've already started to insert robotics into our Alhambra chip fab operation, and just finished installing new automated processes (which reduced labor by 80%) in our transmitter tune and test processes in China. This produces much better return on assets, improves operating leverage and ultimately reduces cost," says Rittichier.

"While we are implementing new strategies that should improve our operating model in future periods, those activities will lead to some additional cost in the next couple of quarters and take some time to realize," notes Weinswig. Emcore hence expects gross margins to be in the low-to-mid 30s for fiscal Q3/2016.

"Within our chip business, we have a number of process and technology initiatives in the fab, which will help drive down cost, such as migration to 3" wafers, outsourcing of commodity epi growth, and automated techniques for coding, simulation, test and sort," elaborates Rittichier. "These steps will enable us to compete more aggressively in the market over the long-term. Automation is especially important to this initiative, as chip fab operations have been labor-intensive. New equipment is being installed to modernize our fab and improve its productivity," he continues. "We have determined that supplying bars to third-party dicing, packaging and sorting vendors provides the right mix of value-added

services on Emcore's part versus what could be done more efficiently elsewhere. As these products begin absorption in the market within the next year, we expect that they will drive higher gross margins in our chip products, while marginally reducing ASPs [average selling prices] since the product will not have undergone as many manufacturing steps, and thus will be sold at a lower price from Emcore."

"As we implement these initiatives and others across their business, you should expect to see some inventory build up over the next couple of quarters," says Rittichier. "Additionally, we've been incurring some double costs on the personnel side during the transition of certain manufacturing processes, which will improve as we exit the calendar year," he adds.

"We're now two quarters into this transformation of our manufacturing operation and are beginning to realize improvements in operating leverage, cycle times, yields and product costs," says Rittichier. "Even last year's revenue dip came with slightly better margins. Once our manufacturing initiatives are complete, we expect to see further upside in the model over time." Emcore's current model is for breakeven on a non-GAAP basis at revenue of about \$20m per quarter.

"While the competitive pressure within GPON has increased in the last two quarters, the chip business remains important to us, because it spreads our fixed manufacturing cost over larger numbers of devices while laying the foundation for next-generation applications," says Rittichier. "One can think of our GPON business as really just our initial offering in the merchant chip market, as Emcore intends to become a broad supplier of chip-level products to the entire telecom industry. As the market shifts from 2.5G GPON to the 10G standard, Emcore will be in a far more favorable position given our long history as one of the industry's premier optical semiconductor manufacturers."

"Although GPON is an important

opportunity, we've also been working to ship our chip product," continues Rittichier. "As we exit fiscal year 2016, we expect a third of our chip revenue to come from non-GPON chips. As a result, we will optimize our product mix between captive and merchant use to drive a higher blended margin for both our chip business and the rest of the company's products."

While smaller than cable TV, Emcore enjoys a strong market share in satellite communications and a close relationship with customers. "Unlike the migration from DOCSIS 3.0 to DOCSIS 3.1 in the CATV market, the satcom business has not historically been network-upgrade driven. However, this has the potential to change with the proliferation of distributed antenna solution and ultimately 5G networks in general," says Rittichier. "With the build out of 5G networks on the horizon, DAS (distributed antenna systems) represents an important new opportunity for our existing satcom technology as the sheer number of devices needed in DAS application is an order of magnitude greater than our served market today," he adds. "As wireless networks are upgraded to the new 5G standard, we expect the linear fiber transmission between equipment racks and smaller more densely populated antennas will be critical. Additionally, not having to convert from digital to RF, but the antenna itself, provides significant cost saving," continues Rittichier. "We see Emcore's linear optics technology continuing to reach further into wireless applications going forward and are excited about the partnership that we have with one of the world leaders in DAS technology for their 5G system deployments. While this market remains in its early stages, the progress over the past years have been healthy and we look forward to continuing to work with customers in this space and increase our number of design wins ahead of full scale deployments in the years ahead."

www.emcore.com

UNSW boosts unconcentrated solar cell conversion efficiency to record 34.5%

Spectrum-splitting, four-junction device edges closer to theoretical limits of solar cell efficiency

A new solar cell configuration developed by the University of New South Wales (UNSW) has set an solar energy conversion efficiency record of 34.5% for unfocused sunlight, nudging closer to the theoretical limits for such a device.

The record was set by Dr Mark Keevers and professor Martin Green (senior research fellow and director, respectively) at UNSW's Australian Centre for Advanced Photovoltaics (ACAP) using a 28cm² four-junction mini-module — embedded in a prism — that extracts the maximum energy from sunlight. It does this by splitting the incoming rays into four bands, using a hybrid four-junction receiver to squeeze more electricity from each beam of sunlight.

The record-setting UNSW mini-module combines a silicon cell on one face of a glass prism, with a triple-junction solar cell on the other.

The triple-junction cell targets discrete bands of the incoming sunlight, using a combination of three layers: indium gallium phosphide (InGaP), indium gallium arsenide (InGaAs), and germanium (Ge). As sunlight passes through each layer, energy is extracted by each junction at its most efficient wavelength, while the unused part of the light passes through to the next layer, and so on.

Some of the infrared band of incoming sunlight, unused by the triple-junction cell, is filtered out and bounced onto the silicon cell, extracting almost all of the energy from each beam of sunlight hitting the mini-module.

The new result, confirmed by the US National Renewable Energy Laboratory (NREL), is almost 44% better than the previous record cell — made by Alta Devices of the USA, which reached 24% efficiency, but over a larger surface area of 800cm².

"This encouraging result shows

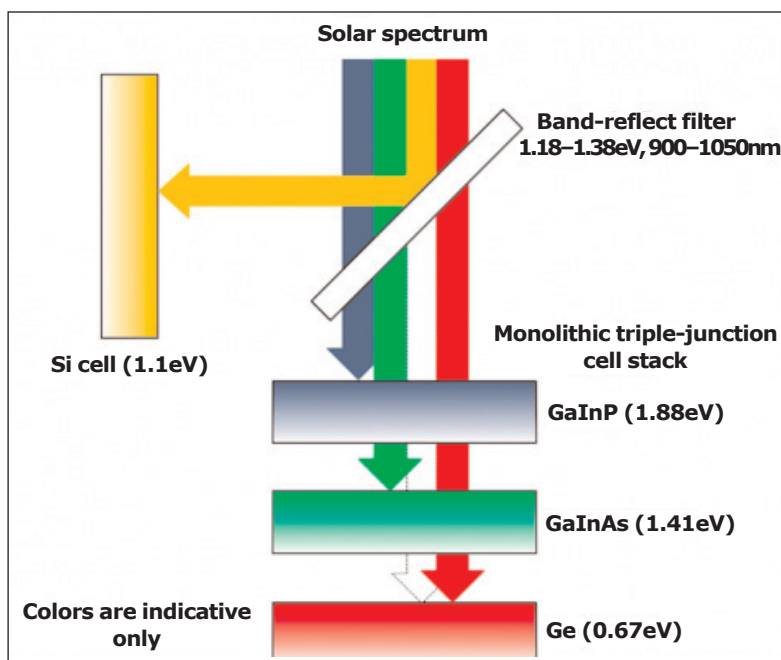


Diagram of spectrum-splitting, four-junction mini-module developed at UNSW.

that there are still advances to come in photovoltaics research to make solar cells even more efficient," says Keevers. "Extracting more energy from every beam of sunlight is critical to reducing the cost of electricity generated by solar cells as it lowers the investment needed, and delivering payback faster."

The result was obtained by the same UNSW team that set a record in 2014, achieving conversion efficiency of over 40% by using mirrors to concentrate the light in CPV (concentrator photovoltaics), and then similarly splitting out various wavelengths. However, the new result was achieved using unconcentrated sunlight.

"This level of efficiency had not been expected for many years," remarks Green. "A recent study by Germany's Agora Energiewende think-tank set an aggressive target of 35% efficiency by 2050 for a module that uses unconcentrated sunlight, such as the standard ones on family homes," he adds. "So,

things are moving faster in solar cell efficiency than many experts expected." Australia's photovoltaics research has already generated flow-on benefits of more than \$8bn to the country, Green says. Gains in efficiency alone, made possible by

UNSW's PERC (passivated emitter rear-contact) cells, are forecast to save \$750m in domestic electricity generation in the next decade. PERC cells were invented at UNSW and are now becoming the commercial standard globally, it is claimed.

The 34.5% result with the 28cm² mini-module is already a world record, but scaling it up to a larger 800cm² — thereby leaping beyond Alta Devices' 24% — is within reach. "There will be some marginal loss from interconnection in the scale-up, but we are so far ahead that it's entirely feasible," Keevers says. The theoretical limit for such a four-junction device is thought to be 53%, which puts the UNSW result two-thirds of the way there.

Multi-junction solar cells of this type are unlikely to find their way onto the rooftops of homes and offices soon, as they require more effort to manufacture and therefore cost more than standard crystalline silicon cells with a single junction. But the UNSW team is working on

► new techniques to reduce the manufacturing complexity, and create cheaper multi-junction cells.

However, the spectrum-splitting approach is perfect for solar towers, like those being developed by Australia's RayGen Resources, which use mirrors to concentrate sunlight which is then converted directly into electricity.

The research is supported by \$1.4m grant funding from the Australian Renewable Energy Agency (ARENA),

whose CEO Ivor Frischknecht said the achievement demonstrated the importance of supporting early-stage renewable energy technologies.

The UNSW team is working with ARENA-supported RayGen to explore how the receiver could be rolled out at concentrated solar PV power plants.

"With the right support, Australia's world leading R&D is well placed to translate into efficiency wins for households through the ongoing roll out of rooftop solar and utility-

scale solar projects such as those being advanced by ARENA through its current \$100m large-scale solar round," says Frischknecht. "Over the longer term, these innovative technologies are also likely to take up less space on our rooftops and in our fields."

Other research partners working with UNSW include PV module manufacturer Trina Solar and NREL.

www.acap.net.au

www.pv.unsw.edu.au

Sol Voltaics raises \$17m in Series C funding following breakthrough in nanowire solar cell efficiency

Funding to speed commercialization of efficiency-boosting GaAs nanowire films for tandem-layer PV

Sol Voltaics AB of Lund, Sweden, which provides nanomaterial technology for enhancing solar panels and other products, has raised \$17m in a Series C round of equity investment and grant funding, led by new investor Riyadh Valley Company (RVC), the venture capital investment arm of King Saud University in Riyadh, Saudi Arabia. Long-term investors Umoe, FAM, Industrifonden, and Nano Future Invest also contributed to the \$12.5m in equity. In addition, the Swedish Energy Agency and the European Union's Horizon 2020 research and innovation program contributed over \$4.5m in additional grants.

The new funding will bolster Sol Voltaics' efforts to accelerate commercialization of its nanowire-based solar efficiency-boosting film tandem-layer technology to market. The firm recently announced a major technological breakthrough with the successful alignment of gallium arsenide (GaAs) nanowires in a thin film. When integrated in a tandem-junction architecture on mainstream crystalline silicon panels, Sol Voltaics' nanomaterials developments can enable photovoltaic module efficiencies of more than 27% (a 50% enhancement in energy generation

compared to existing solar panels).

In addition, over the past few quarters Sol Voltaics has progressed through several generations of development of its Aerotaxy technology. Stemming from Lund University in Sweden, this patented process is the foundation for producing nanowire solar cells and films in a cost-effective manner (a key parameter in the commercialization process, says Sol Voltaics).

"There is a tremendous amount of interest in a number of competing tandem-layer technologies designed to significantly boost the efficiency of existing solar modules," says CEO Erik Smith. "Following our recent nanowire alignment breakthrough and several other critical technological advances, this latest investment from new and long-term partners reflects the confidence they have in Sol Voltaics' ability to become the premier commercial solution for stacked tandem-junction solar modules," he adds.

"With the company's recent technology breakthroughs and nanowire efficiency world record we believe Sol Voltaics can lead the tandem solar cell revolution," comments RVC's CEO Dr Khalid Al Saleh.

Berlin-based Apricum – The Cleantech Advisory acted as financial advisor to Sol Voltaics in the transaction. According to Apricum, the capital raised represents the largest solar-technology funding round in Europe in the past 18 months.

"To overcome the physical limits of current mainstream single-junction technology, the photovoltaic industry needs to find a low-cost dual-junction technology," says Apricum partner Moritz Borgmann. "Sol Voltaics, with its drop-in product, provides a game-changing yet simple solution to this problem."

Sol Voltaics says that RVC's investment is an example of Saudi Arabia's increasing interest in renewable energy as the country moves toward realizing its huge potential for solar energy.

Deputy Crown Prince Mohammed bin Salman recently unveiled the 'Saudi Arabia Vision 2030' plan as part of the new King Salman Renewable Energy Initiative, a wide-ranging economic and social policy effort to achieve an initial domestic deployment target of 9.5GW of solar and other renewable energy sources by 2023.

www.solvoltaics.com

<http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=7298402>

Alta Devices sets 31.6% one-sun cell efficiency record Power-to-weight ratio of thin, flexible dual-junction PVs targets UAVs

Alta Devices of Sunnyvale, CA, USA (a Hanergy company) has set a new solar energy conversion efficiency record of 31.6% for a one-sun cell, using its most recent dual-junction solar cell, as measured and certified by the US Department of Energy's National Renewable Energy Laboratory (NREL). This is the seventh overall solar efficiency record set since 2010 by Alta Devices, which now holds both the dual-junction and single-junction records (at 31.6% and 28.8%, respectively).

Alta has achieved the increase in efficiency by modifying its basic 'single-junction' gallium arsenide (GaAs) technology (which the firm is currently shipping in production). The firm's dual-junction technology builds on the basic GaAs approach, but implements a second junction with indium gallium phosphide (InGaP). Because InGaP uses high-energy photons more efficiently,

the new dual-junction cell generates more electricity from the same amount of light than a single-junction device.

Alta notes that, due to its unique thinness and flexibility, its solar technology is of particular interest in the UAV (unmanned aerial vehicle) market. The increased power-to-weight ratio enables greatly different possibilities for an aircraft using this technology versus any other types of solar power, it is claimed.

As an example, on a typical HALE (high altitude long endurance) UAV aircraft, Alta's solar material requires less than half of the surface area and weighs a quarter as much while providing the same amount of power as competing thin-film technologies, says Alta Devices. Such savings open UAV designers to alternative design options. Additional batteries can be installed on the vehicle, providing

longer operational life spans and flight times than originally considered. Alternatively, payload functionality can be tailored for higher-speed or longer-distance wireless communications. Either of these design optimizations translate into a considerable increase in economic value to the aircraft operator, the firm adds.

"Our goal has always been to enable solar power to be useful in configurations and applications that have never before been possible," says chief marketing officer Rich Kapusta. "The UAV application is an important example."

Alta Devices also provides solar technology for other applications including wearable devices and the Internet of Things (IoT) in order to eliminate the need for battery replacement or recharging.

www.altadevices.com/technology-overview

Von Ardenne to supply CIGS & CdTe thin-film PV coating systems to subsidiaries of China's CNBM

At the SNEC's 10th International Photovoltaic Power Generation Conference & Exhibition (SNEC PV Power EXPO 2016) in Shanghai, China (24-26 May), Von Ardenne of Dresden, Germany (which manufactures equipment for industrial coatings on materials) signed contracts with subsidiaries of state-owned building material industry group China National Building Materials (CNBM) for the delivery of several coating systems for producing thin-film photovoltaic modules.

The coating systems deposit ultra-thin functional layers by magnetron sputtering onto glass substrates, which are then processed into solar modules.

The equipment will be used for the production of copper indium gallium diselenide (CIGS) solar modules in two 300MW plants in Bengbu (Anhui province) and



Signing ceremony at SNEC.

Jiangyin (Jiangsu province) as well as the production of CdTe (cadmium telluride) solar modules in a 100MW plant in Chengdu (Sichuan province).

The equipment will be delivered and put into operation over the next two years. The investment is part of CNBM's long-term plan to

build factories worldwide for the production of photovoltaic modules with an overall annual capacity of 15GW.

Founded in 1984, CNBM is China's largest building materials group. In 2012 it acquired Germany's CTFSolar GmbH, which provides production equipment and plant for

manufacturing cadmium telluride (CdTe) thin-film photovoltaic modules. In September 2014, CNBM acquired CIGS solar module maker Avancis GmbH of Torgau, Germany.

www.sneec.org.cn
www.cnbm.com.cn/EN
www.vonardenne.biz

First Solar's CFO Mark Widmar to succeed CEO Jim Hughes, who remains on board as advisor

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 — says that chief financial officer Mark R. Widmar has been appointed chief executive officer, effective 1 July, when he will also join the board of directors. As part of a transition plan, he will succeed James A. Hughes, who plans to step down as CEO on 30 June but will continue to support the firm in an advisory role and remain on the board.

Widmar has been chief financial officer since joining First Solar in April 2011 and served as chief accounting officer from February 2012 through June 2015, overseeing the firm's industry-best balance sheet and strong financial performance. Widmar also serves as CFO and as a director on the board of 8point3 Energy Partners LP, the joint yieldco formed by First Solar and SunPower Corporation in 2015 to own and operate a portfolio of



First Solar's CFO Mark R. Widmar.

selected solar generation assets.

"As we enter a new phase of growth and development for the company, we believe that

Mark's proven leadership and expertise make

this an ideal time for him to take the helm," comments chairman of the board Michael J. Ahearn.

"Under Jim's astute guidance, First Solar achieved the strongest technology position in our history, with record bookings of new business and unparalleled financial strength in the industry... We look forward to benefiting from his continued involvement as an advisor and director," he adds.

First Solar also announced that Alexander Bradley, VP, treasury & project finance, has been appointed interim chief financial officer, effective 1 July.

Prior to joining First Solar, Widmar served as chief financial officer at GrafTech International Ltd (a manufacturer of advanced carbon and graphite materials) from May 2006 through March 2011 and as president, engineered solutions, from January 2011 through March 2011.

Prior to GrafTech, Widmar served as a business unit chief financial officer from November 2002 to 2005 then as corporate controller until 2006 at NCR Inc.

Prior to NCR, he served as a division controller at Dell Inc from August 2000 to November 2002. Widmar also held several financial and managerial positions with Lucent Technologies Inc, Allied Signal Inc, and Bristol Myers/Squibb Inc.

He began his career in 1987 as an accountant with Ernst & Young. Widmar holds a Bachelor of Science in Business Accounting and a Master of Business Administration from Indiana University.

www.firstsolar.com

First Solar's US president made chief commercial officer, overseeing global project and business development

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 — says that Georges Antoun, president – US, has been appointed chief commercial officer (effective 1 July).

Antoun will have comprehensive leadership responsibility for Global Project and Business Development, with a primary focus on increased sales and sustainable growth in emerging markets. Reporting to Antoun will be First Solar global project development, business development and strategic marketing teams.



Georges Antoun, First Solar's chief commercial officer.

"Georges has a deep and broad grasp of every aspect of our operations," says chief financial officer Mark Widmar, who will become CEO on 1 July. "I am confident that he can lead a fully integrated

international business development organization that will deliver on our strategic objectives while focusing on deeper customer intimacy."

As president – US, Antoun oversees project and business develop-

ment for the USA. Previously, he was chief operations officer, joining First Solar in June 2012 after working in the international IT and telecommunications industries.

"I am honored to take on this expanded role as we enter a new phase of growth and development," says Antoun. "I look forward to working with the management team and global associates to execute on our strategies."

As part of this transition, Joe Kishkill, First Solar's president – International, is leaving the company to pursue other interests. "Joe played an important role in positioning First Solar as a global player," comments Widmar.

www.firstsolar.com

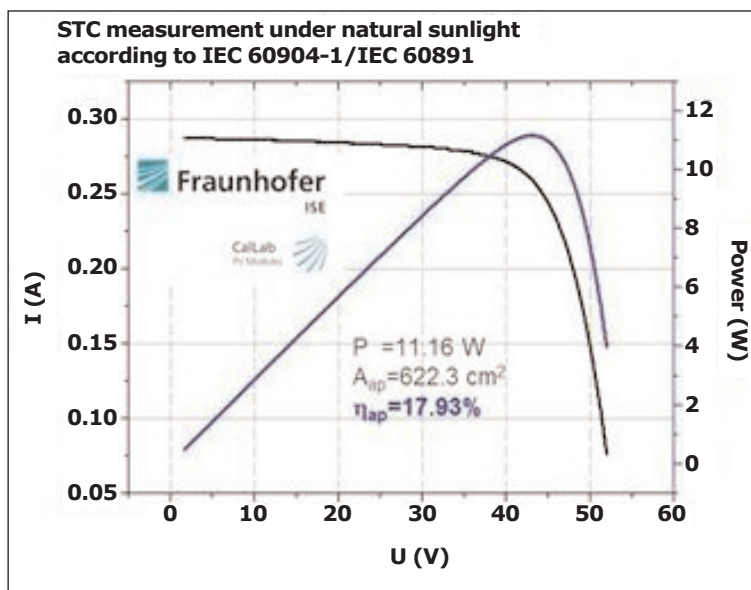
Avancis sets encapsulated CIGS solar module efficiency record of 17.9%

Efficiency raised from 16.6% record certified in January 2014

Copper indium gallium diselenide (CIGS) thin-film photovoltaic module maker Avancis GmbH of Torgau, Germany has achieved record solar energy conversion efficiency of 17.9% for encapsulated CIGS thin-film modules, using its latest 30cm x 30cm champion cadmium (Cd)-free module (with an aperture area of 622cm²), as certified by the Fraunhofer Institute for Solar Energy Systems (ISE) in Freiburg, Germany. The firm's previous aperture efficiency record was 16.6% for its champion module, as certified by the US Department of Energy's National Renewable Energy Laboratory (NREL) in January 2014.

The 30cm x 30cm champion module is based on a mass-produced CIGS absorber from Avancis' production plant in Torgau, complete with a refined window and module process steps developed by the firm's R&D center in Munich.

The optimized indium-based buffer is deposited in an environmentally benign manner and with enhanced material yield by a completely



unbroken dynamics of thin-film development," says Avancis' chief technology officer Dr Jörg Palm. "Transferring that result into production would lead to CIGS modules with the impressive power of 170Wp on a PowerMax

dry vacuum-coating processes. The improvement in efficiency was achieved through a modified design with reduced cell width, an optimized ZnO:Al front contact, and improved application of laser processes in order to reduce the dead zone between the series-connected cells.

"This achievement is not just another world record for CIGS solar modules, it generally shows the

product size of 1m²," he adds. "Our products exhibit not only typical application advantages of thin-film modules, but also efficiency ranges previously restricted to poly-silicon based products. Our products are therefore increasingly eligible for area-constrained installations, which have been previously dominated by conventional silicon modules."

www.Avancis.de

Midsummer exceeds China's 13% CIGS module efficiency requirement for government support of solar installations

Midsummer AB of Järfälla, near Stockholm, Sweden — a provider of turnkey production lines for manufacturing flexible, lightweight copper indium gallium diselenide (CIGS) thin-film photovoltaic (PV) solar cells — says that, after China's National Energy Bureau in June 2015 raised the minimum requirement for CIGS thin-film module solar energy conversion efficiency from 11% to 13%, it has recently surpassed this by increasing its module efficiency to above 13% (corresponding to 14.3% aperture-area efficiency), meeting the requirements of the Chinese authorities for receiving govern-

ment support for solar installations in China. The tests were carried out and verified this March by the certified Japanese independent testing laboratory Chemitox Inc.

The Chinese government's new guidelines for CIGS modules are that the conversion efficiency must exceed 13% in order for qualification to its 'elite program', which gives access to large government subsidies, priority in government contracts, bank loans or any public/private projects. "It is very important to gain entry to China's 'elite program' in order to enjoy all the benefits and subsidies by the Chinese government," notes

Midsummer's CEO Sven Lindström.

With the production system from Midsummer the solar cells are manufactured individually and then strung together into modules (just like crystalline solar cells). This way, lightweight flexible modules can easily be made in any size and shape.

The dry, all-vacuum process has less stringent requirements for cleanrooms. Also, avoiding cadmium in the manufacturing process is desirable for the sake of the production staff, and makes it easier to commence low-cost manufacturing of CIGS solar cells.

www.midsummer.se

Solar Frontier Tohoku begins commercial production

New production technology cuts investment per megawatt by a third

Tokyo-based Solar Frontier — the largest manufacturer of CIS (copper indium selenium) thin-film photovoltaic (PV) solar modules — has begun commercial production at its 150MW Tohoku Plant in Miyagi Prefecture, Japan.

Due to using the firm's most advanced production technology, compared with its main production plant in southern Japan (the 900MW Kunitomi Plant) the Tohoku Plant requires only two-thirds the investment and manpower per megawatt. It also requires only one-third the time to manufacture a CIS solar panel. The technology also enables Solar Frontier to achieve what are claimed to be best-in-class production costs globally, and serves as a template for future production lines.

Solar Frontier first announced its decision to build the Tohoku Plant in December 2013. After completing construction in April 2015, the firm began ramping up the newly



The Tohoku Plant's first panel.

installed production lines. The plant now manufactures CIS solar panels of the same grade and higher compared to the Kunitomi Plant, prompting the decision to initiate sales.

New Tohoku Plant modules will go on sale this summer in their home prefecture of Miyagi before being made available in other areas of Japan. Solar Frontier aims to

provide solar panels with output of 180W and beyond once the Tohoku Plant reaches full production.

Also, new features are claimed to offer benefits for installers and end-users. For example, the addition of a busbar in the middle of the module improves the panel's ability to perform when partially covered by shadows.

Another key feature is lower module voltage, which enables greater flexibility when designing systems. Tohoku-produced panels also include modifications to the frame and junction box, making installation and maintenance easier.

The start of commercial production at the Tohoku Plant marks the continued cooperation between Solar Frontier, Ohira Village and Miyagi Prefecture.

www.solar-frontier.com

Solar Frontier modules chosen for Enilso solar projects in Mexico

Solar Frontier Americas, the US subsidiary of Tokyo-based Solar Frontier, says that the firm's solar modules have been selected to be installed in a pipeline of residential, agri-business and agro-industrial solar power generation projects in and around Sonora, Mexico, by Enilso, a rapidly growing solar distribution and installation organization serving Mexico.

The solar projects range from 5–10kW residential projects to 200–500kW agricultural installations. Scheduled to be installed in third-quarter 2016, the residential projects are targeted at reducing homeowner's monthly electricity bills. Meanwhile, in the arid climate of Sonora, agri-business is a key part of the economy where local farmers grow asparagus, table grapes, and melons. The second phase of solar projects will be self-

consumption ag-solar installations constructed to generate renewable energy for crop irrigation pumping, cooling facilities for freshly harvested fruits and vegetables, and industrial processing and freezing of produce. The investments aim to stabilize agricultural businesses by supporting energy independence, reducing energy costs, and freeing capital for important equipment purchases.

Enilso's founders stem from generations of farmers. In 2010, they saw the value that solar brought to agricultural businesses and spearheaded several solar projects. That small business has now grown to an experienced, full-service installer serving the residential and large commercial solar markets of Mexico.

"We're impressed with the consistent, organic growth of

Enilso and their commitment to quality in both the solar components and construction of their solar projects," comments Solar Frontier Americas' chief operating officer Charles Pimentel.

Solar Frontier says that its CIS modules were selected by Enilso for their higher energy yield in real-world conditions. For example, in the hot climate of Sonora the low temperature coefficient of CIS ensures a smaller loss in power output compared with crystalline silicon technologies.

"Enilso selected Solar Frontier to provide our clientele with a solar module that can withstand the torrid climatic conditions of Mexico and continue to deliver the highest energy yields over the life of the solar system," says Enilso's CEO Gustavo Borquez.

www.enilso.com.mx

Australia's University of New South Wales sets 7.6% efficiency record for non-toxic, thin-film solar cells

CZTS aiming to catch up with CdTe and CIGS PV technology

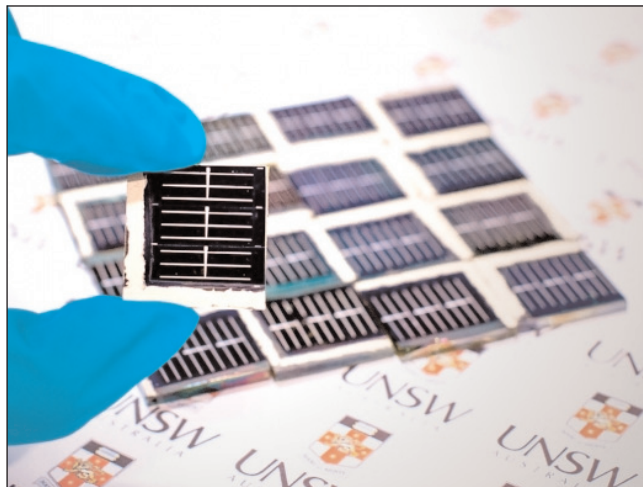
A team led by Dr Xiaojing Hao of the Australian Centre for Advanced Photovoltaics at the University of New South Wales (UNSW) School of Photovoltaic and Renewable Energy Engineering has achieved record efficiency of 7.6% for a full-sized (1cm²) thin-film solar cell using CZTS technology, as confirmed by the USA's National Renewable Energy Laboratory (NREL).

Unlike its thin-film competitors, CZTS cells are made entirely from earth-abundant materials: copper, zinc, tin and sulphur. Also, CZTS has none of the toxicity problems of its two thin-film rivals CdTe (cadmium telluride) and CIGS (copper indium gallium diselenide). Cadmium and selenium are toxic at even tiny doses, while tellurium and indium are extremely rare.

"This is the first step on CZTS' road to beyond 20% efficiency, and marks a milestone in its journey from the lab to commercial product," says Hao (who was named one of UNSW's 20 rising stars last year). "There is still a lot of work needed to catch up with CdTe and CIGS, in both efficiency and cell size, but we are well on the way."

"In addition to its elements being more commonplace and environmentally benign, we're interested in these higher-bandgap CZTS cells for two reasons," says professor Martin Green (a mentor of Dr Hao). "They can be deposited directly onto materials as thin layers that are 50 times thinner than a human hair, so there's no need to manufacture silicon 'wafer' cells and interconnect them separately," he adds. "They also respond better than silicon to blue wavelengths of light, and can be stacked as a thin-film on top of silicon cells to ultimately improve the overall performance."

By being able to deposit CZTS solar cells on various surfaces,



The new high-efficiency, low-toxicity solar cells developed by UNSW's Australian Centre for Advanced Photovoltaics.

Hao's team believes that this puts them firmly on the road to making thin-film photovoltaic cells that can be rigid or flexible, and durable and cheap enough to be widely integrated into buildings to generate electricity from the sunlight that strikes structures such as glazing, façades, roof tiles and windows.

However, because CZTS is cheaper — and easier to bring from lab to commercialization than other thin-film solar cells, given already available commercialized manufacturing method — applications are likely even sooner. UNSW is collaborating with a number of large companies that are keen to develop applications well before it reaches 20% efficiency — probably within the next few years, Hao says.

"I'm quietly confident we can overcome the technical challenges to further boosting the efficiency of CZTS cells, because there are a lot of tricks we've learned over the past 30 years in boosting CdTe and CIGS and even silicon cells, but which haven't been applied to CZTS," she adds.

Currently, thin-film photovoltaic cells like CdTe are used mainly in large solar power farms, as the cadmium toxicity makes them

unsuitable for residential systems, while CIGS cells is more commonly used in Japan on rooftops. First Solar, a \$5bn-turnover firm that specializes in large-scale photovoltaic systems, relies on CdTe, while CIGS is the preferred technology of China's Hanergy, the world's largest thin-film solar power company.

Thin-film technologies such as CdTe and CIGS are also attractive because they are physically flexible, which

increases the number of potential applications, such as curved surfaces, roofing membranes, or transparent and translucent structures like windows and skylights.

However, their toxicity has made the construction industry — mindful of its history with asbestos — wary of using them. The scarcity of the elements also renders them unattractive, as price spikes are likely as demand rises. Despite this, the global market for building-integrated photovoltaics (BIPV) is already \$1.6bn.

Hao believes that CZTS' cheapness, benign environmental profile and abundant elements may be the trigger that finally brings architects and builders onboard to using thin-film solar panels more widely in buildings. Until now, most architects have used conventional solar panels made from crystalline silicon. While these are even cheaper than CZTS cells, they do not offer the same flexibility for curved surfaces and other awkward geometries needed to easily integrate into building designs.

www.acap.net.au

www.pv.unsw.edu.au

<https://research.unsw.edu.au/people/dr-xiaojing-hao>

Solliance sets record 10% aperture-area conversion efficiency for scaled-up perovskite-based PV modules

Efficiency of 15% targeted using low-cost materials and processes

Solliance, a European thin-film photovoltaic (TFPV) solar energy R&D consortium in the ELAT (Eindhoven-Leuven-Aachen) region, has demonstrated a record 10% aperture-area power conversion efficiency for its up-scaled thin-film perovskite photovoltaic modules, measured on an aperture area of 168cm².

Twenty-five cells were serial connected through an optimized P1, P2, P3 interconnection technology. The module was realized on a 6-inch x 6-inch glass substrate using industrial scalable slot die coating in combination with laser patterning. Further, the PV module was packaged by applying a flexible barrier using a lamination process.

Based on previous optimization on 16cm² modules, the Solliance team was able to quickly transfer this to a 6-inch x 6-inch sized glass substrate using the developed blade coating process and the optimized mechanical patterning technology. In this case, a 156cm² aperture-area module with 10% efficiency was realized comprising 24 interconnected cells. This was then used as starting point for the realization of above-mentioned 168cm² PV module.

Solliance says that the results demonstrate the ability to scale up the emerging new thin-film PV technology. Apart from the electrodes that are currently used, all layers can be processed in an

ambient environment and at temperatures below 120°C, demonstrating the potential for low production costs. Further, the deposition and interconnection technologies used for obtaining these results are industrially available for sheet-to-sheet as well as for roll-to-roll manufacturing. The latter can allow high-volume production in the future.

The existing efficiency record for a small lab-scale perovskite-based PV cell is 22.1%. "The challenge is to upscale perovskite cells to larger-size industrially processable modules with high efficiency and long lifetimes at low cost," says Ronn Andriessen, program manager of the perovskite-based PV program at Solliance. "The current result, presented on an aperture area comparable to standard commercial silicon solar cells, shows that Solliance, with its in-depth know-how on processing of organic PV and CIGS [copper indium gallium diselenide] and its vast sheet-to-sheet and roll-to-roll pilot production infrastructure, is excellently placed to realize this upscaling. These 10% up-scaled perovskite-based PV modules are first and important steps in this development," he adds. "We are confident to boost quickly the up-scaled perovskite-based PV module efficiency further above 15% by using very low-cost materials and processes. But, besides

demonstrating the up-scalability of these highly efficient perovskite-based PV devices, we are also currently working hard to stabilize further the performance of these devices under real-life operational conditions."

Together with its industrial partners Nano-C, Solartek, DyeSol and Panasonic, Solliance is conducting research on the development of perovskite-based PV modules and its applications. With the latest result, the Solliance R&D partners and their industrial partners have demonstrated their research framework for the development of industrial perovskite-based PV modules.

Solliance partners include ECN, imec, TNO, Holst Centre, TU/e, Forschungszentrum Jülich, University Hasselt and Delft University of Technology. The consortium is supported by the Dutch province of North Brabant, which has dedicated €28m to Solliance. In June 2014, Solliance opened a large shared laboratory at the High Tech Campus in Eindhoven that includes pre-pilot production facilities, complementing partners' labs (which are also available to the other partners). To make optimal use of these lab facilities, they are open to valorization programs in joint research with industry.

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Quantum well/barrier intermixing blue-shift of indium gallium phosphide

Thick silicon dioxide strain layer encourages thermal diffusion of aluminium to give largest shift reported for material system, according to researchers.

King Abdullah University of Science & Technology (KAUST) in Saudi Arabia has developed a quantum well intermixing (QWI) technique to blue-shift indium gallium phosphide (InGaP) quantum well bandgaps to give 628nm red, 602nm orange and 585nm yellow electroluminescence [A. A. Al-Jabr et al, J. Appl. Phys., vol119, p135703, 2016]. The researchers see potential application in solid-state lighting, photodynamic therapy (PDT), medicine, and visible light communication.

The team reports: "A maximum blue-shift of 75nm (250meV) is achieved, which is the highest ever reported in this material system." The aim is to bridge the gap for high-efficiency light-emitting devices in the green-yellow-orange part of the visible spectrum between III-nitride (blue-violet) and III-phosphide (red) semiconductors.

Although the structure is designed as for a single QW (SQW) laser diode (LD), the researchers do not at this stage quote any laser characteristics such as current thresholds. "Our results show that this new QWI method technique may pave the way for the realization of high-efficiency orange and yellow light-emitting devices based on the InGaP/InAlGaP material system," they write.

The technique involves introducing strain into indium aluminium gallium phosphide (InAlGaP) heterostructures on gallium arsenide (GaAs) by depositing a thick layer of silicon dioxide (SiO₂) and then applying a variety of thermal annealing processes.

The researchers believe the blue-shift is associated with the high strain arising from the thermal expansion mismatch between the silicon dioxide layer and the underlying semiconductor material.

The researchers explain: "During annealing, the mismatch in expansion at the interface of the dielectric and semiconductor induces high compressive strain, whereas the QW is under tensile strain. The opposite strains applied on the barriers create point defects at (1) the interface of the dielectric and the laser structure and (2) the interface of the barrier and the QW... These point defects, with energy given to the atoms by heat, facilitate the inter-diffusion of (group III) atoms

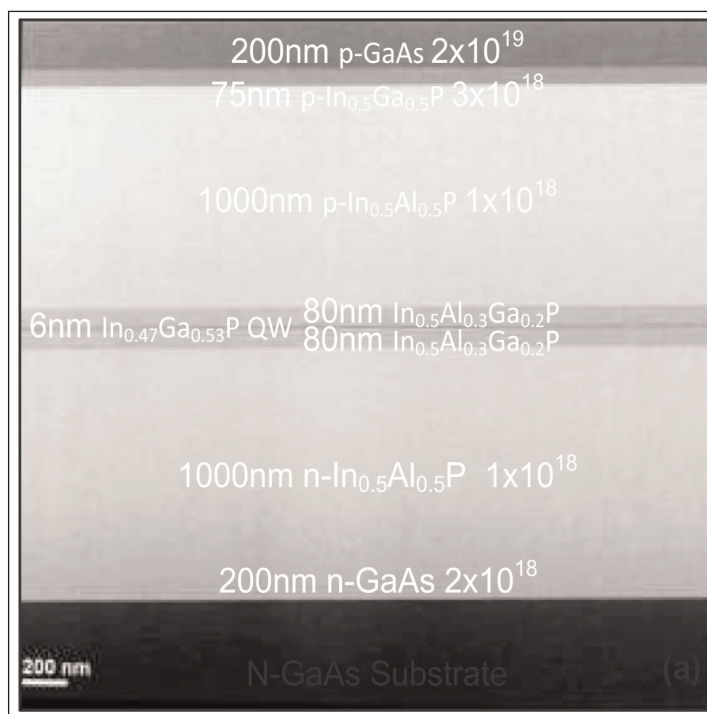


Figure 1. Dark-field (002) cross-sectional transmission electron microscope (TEM) image of InGaP/InAlGaP laser structure with a single QW.

between the QW and the barrier."

The researchers believe that the effect of the intermixing is to increase the bandgap by the incorporation of Al in the InGaP and to alter the shape of the quantum well. The Al incorporation also reduces the strain of the QW, which also has a blue-shifting effect. The change in shape of the QW, making it effectively thicker, could subtract a small red-shift, but the total effect is to increase the bandgap over the as-grown material.

The waveguide properties are also affected by the intermixing between the InAlGaP barriers and InGaP QW. In particular, the defects will increase optical losses, leading to less efficient devices. Further problems are expected from the shift to yellow where optical losses in GaAs are higher.

High-Al-content InAlGaP layers grown directly by metal-organic chemical vapor deposition (MOCVD) or

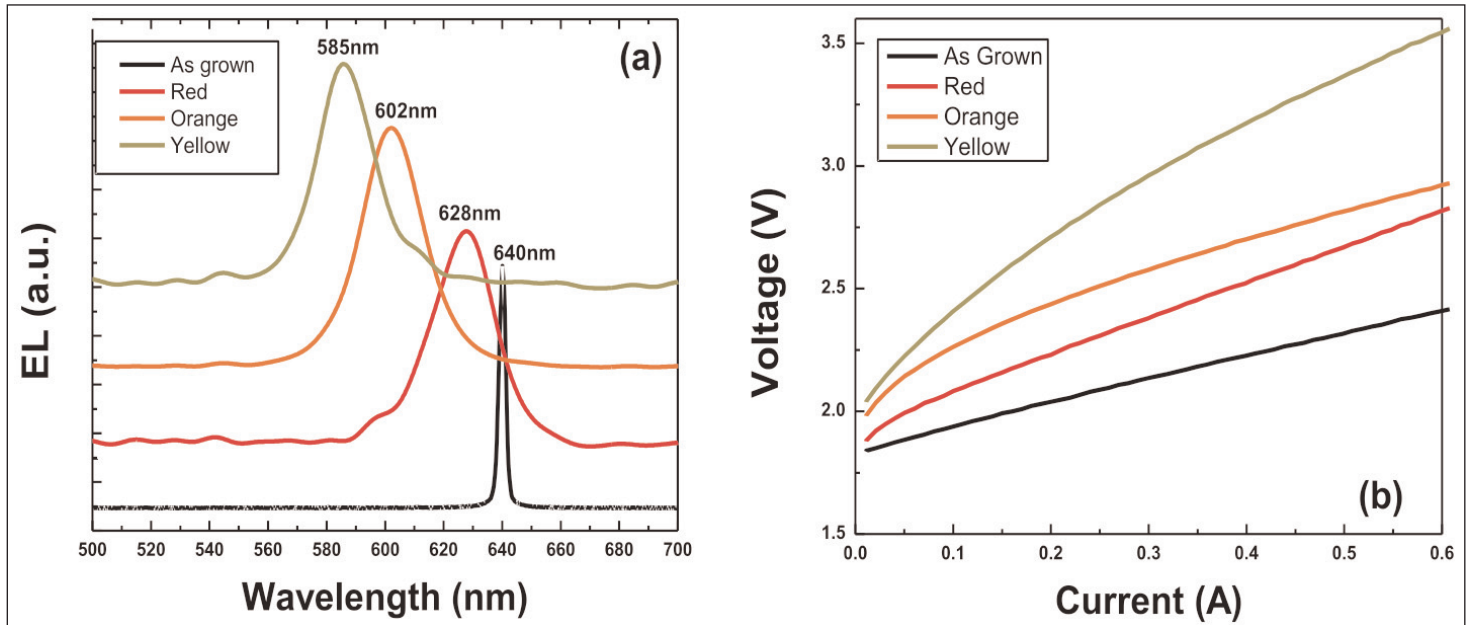


Figure 2. (a) Electroluminescence spectra for as-grown and intermixed devices emitting at 628nm, 602nm and 585nm and (b) voltage versus current characteristics of corresponding devices.

molecular beam epitaxy (MBE) tend to suffer from the presence of oxygen-related defects. The QW intermix technique is aimed at reducing or even eliminating such defects in the active QW layer.

The light-emitting structure consisted of a single InGaP quantum well in InAlGaP barrier/waveguide grown by MOCVD on 10°-offcut GaAs (Figure 1). The cladding layers were InAlP. The p-contact layers consisted of InGaP for injection barrier reduction and p-GaAs. The as-grown structure had peak room-temperature photoluminescence at 635nm±3nm.

The laser diode wafer was cleaved into approximate 2mm x 2mm pieces. These samples were coated with 1µm of silicon dioxide through plasma-enhanced chemical vapor deposition (PECVD) and annealed using a rapid thermal process.

The temperature and time of the rapid thermal anneal (RTA) was optimized to maintain strong photoluminescence intensity, narrow full width at half maximum (FWHM), and good surface morphology.

The desired blue-shift was found to occur at temperatures higher than 900°C for a 120s anneal processes. Between 900°C and 950°C the rate of shift was around 1meV/°C. Above 950°C, the rate increased to around 3meV/°C. At 1000°C, the blue-shift was more than 60nm (200meV). Photoluminescence and surface morphology quality was maintained at temperatures up to 975°C.

Varying the anneal duration at 950°C also affected the blue-shift with an almost linear relation at a rate of 0.67meV/second, starting from about 45 seconds. Beyond 180 seconds the photoluminescence intensity decreased and the FWHM increased, indicating a reduction in quality. At 240 seconds, the peak wavelength shifted by 45nm (~140meV) to 595nm.

The problem of material quality deterioration was

ameliorated by a cyclic process of a number of anneals at shorter intervals. The researchers considered the optimum step to consist of annealing at 950°C for 30s. The researchers comment: "With this process, we were able to blue-shift the peak emission from red (640nm) to yellow (585nm) (250meV) with a number of cycles of annealing, which is the largest blue-shift reported for this material system."

Samples annealed for 2, 5 and 9 cycles had peak wavelengths at 620nm (red), 595nm (orange) and 575nm (yellow), respectively.

Devices for electroluminescence studies were fabricated by removing the capping dielectric and depositing front and back contacts. The electroluminescence peaks (Figure 2) were red-shifted between 5nm and 10nm due to self-heating effects from the broad-area current pumping.

The yellow-emitting device had a turn on voltage of 2.1V, which is consistent with the bandgap of a device operating at 585nm. The series resistance of less than 5Ω is described as 'low'. "These good electrical characteristics for the yellow emitter with the highest degree of intermixing are evidence of the superiority of our intermixing process," the team writes. "In addition, the result confirms that the dopant concentration in the top contact and the cladding layers remained at a similar level and did not diffuse into the active region of the laser structure, even after the successive annealing at elevated temperatures."

Experiments varying the silicon dioxide thickness up to 2µm (2000nm) showed increasing blue-shift. However, the dielectric cracked at 2µm thickness, damaging the top surface of the semiconductor material. ■

<http://dx.doi.org/10.1063/1.4945104>

Author: Mike Cooke

Aluminium gallium nitride nanowire UV LED fabricated on metal foil

Researchers see development as first step towards scalable roll-to-roll manufacturing of nanomaterial based solid-state optoelectronics.

Ohio State University in the USA has produced aluminium gallium nitride (AlGaN) nanowire ultraviolet (UV) light-emitting diodes (LEDs) on flexible metal foil [Brelon J. May et al, *Appl. Phys. Lett.*, vol108, p141103, 2016]. The researchers comment: "The realization of operational nanoLEDs grown directly on flexible metal foils provides a first step towards scalable roll-to-roll manufacturing of nanomaterial based solid-state optoelectronics."

Due to the confined attachment of nanowires to substrates, lattice mismatching is less important than for normal III-nitride heterostructures with planar films. Large lattice mismatch can be accommodated in nanowire heterostructures without generating dislocations.

Advantages of growing nanowires on flexible metal foils include lower costs, thermal management, and increased light extraction in top-emitting devices. Demonstrations have already been carried out on metal films on rigid substrate. Successful development of processes on flexible foils opens up the possibility of very-large-scale roll-to-roll manufacturing.

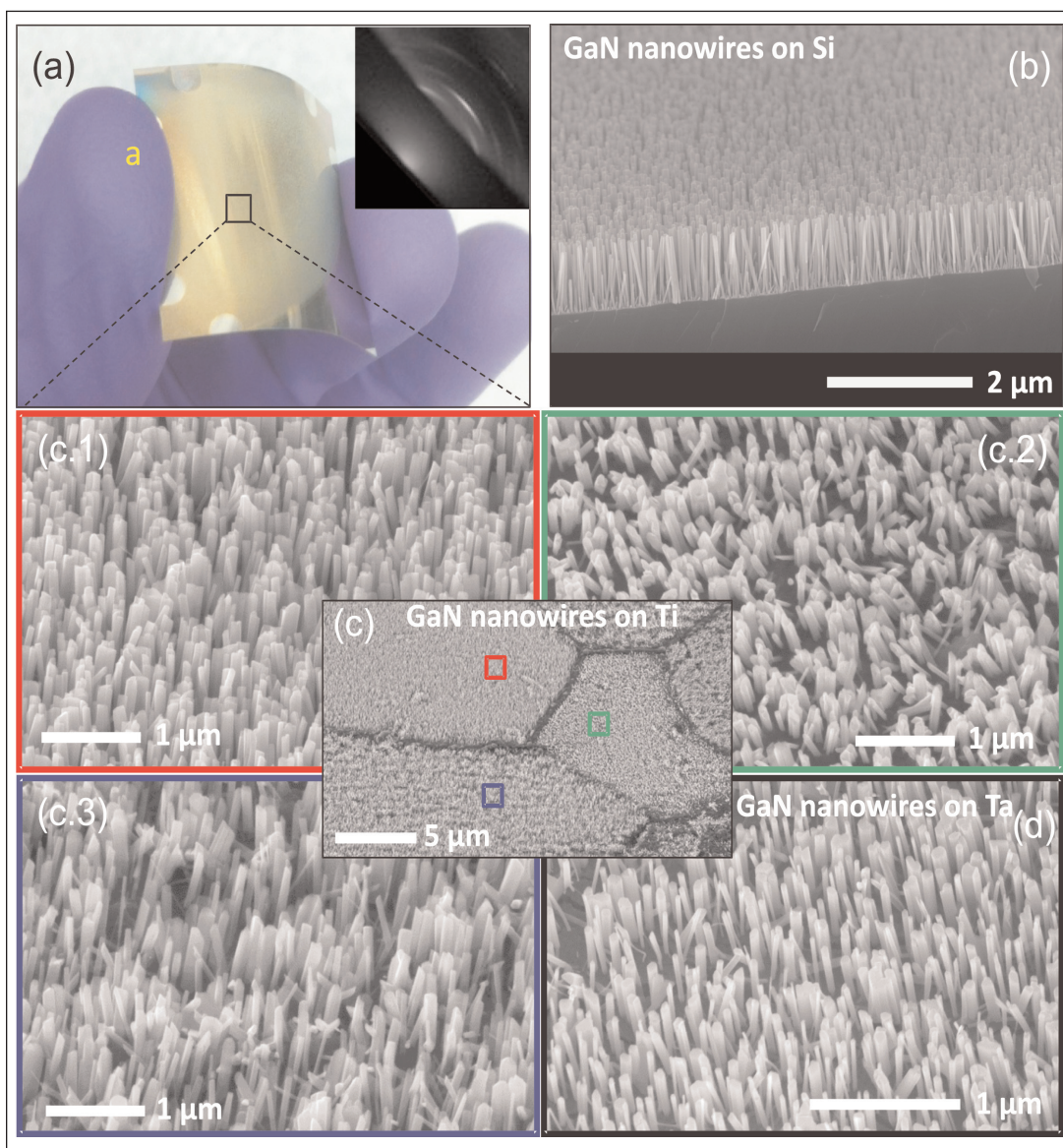


Figure 1. (a) GaN nanowires on flexible Ti foil (the inset shows a reflection high-energy electron diffraction (RHEED) pattern of nanowires on Ti foil) and scanning electron microscope (SEM) images of GaN nanowires on (b) silicon single-crystal (111) substrate, (c) different grains in the Ti foil, and (d) Ta foil.

The nanowires were grown on titanium (Ti) and tantalum (Ta) metal foils through molecular beam epitaxy (MBE). The researchers believe that a wider variety of

metal foils compatible with the growth temperatures could be used.

The 1"-square Ta and Ti foil substrates were 99.9% and 99.6% pure, respectively. The GaN nanowires were grown with a III/V ratio of 0.18. The substrates were rotated away from the nitrogen plasma source to avoid nitridation. A two-step MBE process was used with nucleation at 750°C for 5 minutes and main growth at 800°C for two hours. The same process was also used to grow GaN nanowires on silicon.

The nanowires grew approximately perpendicular to the silicon substrates along the c-axis of the GaN crystal structure (Figure 1). The nanowires on foil were tilted according to the crystal grain structure of the metals. The grains also affected the density of nanowires.

The researchers report: "The Ta foil gives less variation between regions, and the individual regions are larger than those compared to the Ti foil."

The nanowire heights and diameters were similar on the different substrates.

Micro-photoluminescence studies at 27.6K showed a dominant peak from neutral-donor-bound exciton (D0, XA) recombination ($\sim 358\text{nm}$, $\sim 3.472\text{eV}$).

There was also a shoulder on the short-wavelength side of the peak from free excitons (XA, $\sim 357.5\text{nm}$, $\sim 3.477\text{eV}$). A broad peak around 362.7nm , 3.427eV , was also observed, most strongly on Ta (~ 0.45 main peak height) and weakly on Ti and Si (both ~ 0.1 , shoulder-like).

The broad peak has been seen before in nanowires and possible explanations include surface-related excitons, excitons bound to structural defects, or emission from defects near the bottom surface of the nanowires.

Poor-quality GaN can give rise to yellow luminescence from defects, but this was not seen in any of the nanowire samples.

Time-resolved photoluminescence also showed that the nanowires on Ta have similar behavior to those on Si. The nanowires on Ti had reduced emission on short time-scales and enhanced emission on longer time-scales. "Even with this variation, the relatively similar recombination characteristics for all the samples indicate that the nanowires grown on metal foils are of similar optical quality to those grown on single-crystalline Si substrates," the researchers comment.

AlGaIn nanowire LEDs with integrated tunnel junction were produced on Ta foil. The heterostructure design followed previous work on silicon: 750°C n-GaN nucleation, 100nm 790°C n-GaN, polarization-

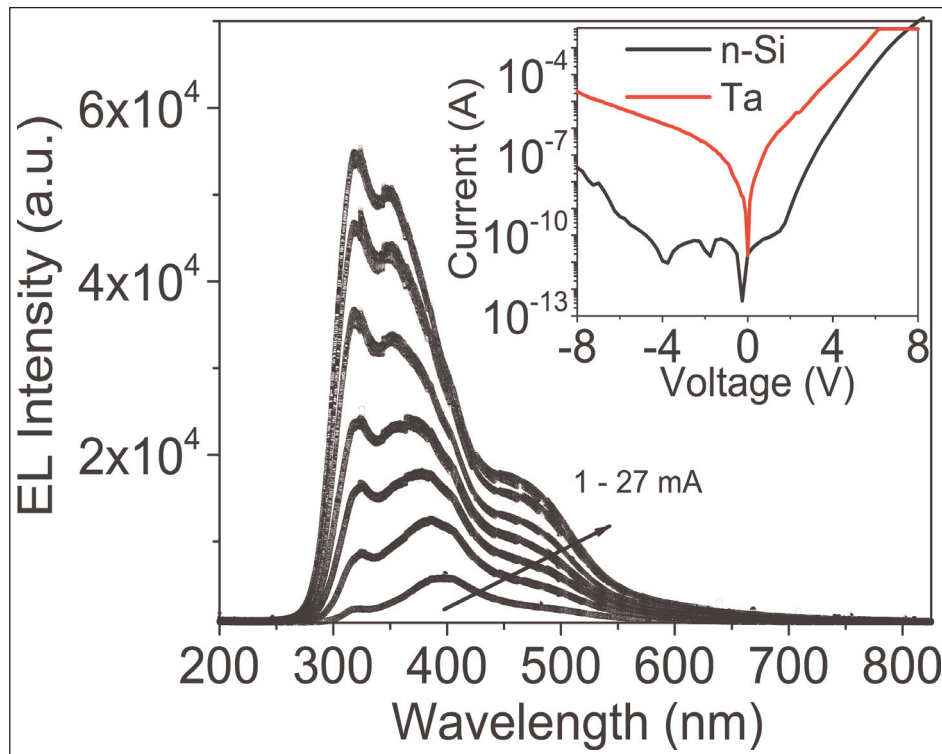


Figure 2. Electroluminescence measurements of nanowire LEDs grown directly on flexible Ta foil; inset shows current-voltage characteristics of LED on Ta (red) compared to similar device on Si (black).

engineered indium gallium nitride tunnel junction, polarization-doped p-AlGaIn graded from GaN to AlN, 840°C 3-period AlGaIn quantum wells in AlN barriers, and finally an AlN to GaN graded n-contact.

The LED fabrication consisted of hydrochloric acid etch to remove surface oxides from the nanowires and deposition of titanium/gold semi-transparent metal top contact. The bottom contact was fabricated by mechanically removing nanowires and diffusing an indium dot on the Ta foil.

The resulting LED emitted ultraviolet light around 350nm wavelength (Figure 2). The turn-on voltage was around 5V, similar to devices fabricated on n-type silicon. Charge-polarization effects were seen in a quantum-confined Stark effect (QCSE) blue-shift at higher currents.

The intensity of the electroluminescence (EL) was a factor of 16 lower than in devices on n-Si. The team comments: "This is likely from the inhomogeneous distribution in nanowire tilt and density. Such variations could result in metal deposition on the sidewalls of the nanowires and substrate during fabrication of the top contact. Consequently, a leakage pathway is formed, reducing the number of active nanowires, thus decreasing the overall EL intensity."

The researchers hope to improve performance through optimizing the growth conditions for more uniform nanowire density and planarization. ■

<http://dx.doi.org/10.1063/1.4945419>

Author: Mike Cooke

SiO₂ charge inverter boosts hole injection in InGaN LEDs

External quantum efficiency increased 20% at 20mA current.

Researchers based in China, Singapore and Turkey have used an extremely thin layer of silicon dioxide (SiO₂) insulator as a charge inverter in indium gallium nitride (InGaN) light-emitting diodes (LEDs), improving light output power and external quantum efficiency (EQE) [Zi-Hui Zhang et al, Appl. Phys. Lett., vol108, p133502, 2016].

The aim of the SiO₂ charge inversion layer is to improve hole injection past the electron-blocking layer (EBL) into the multiple quantum well (MQW) active light-emitting region (Figure 1). Poor hole injection is an undesirable

feature of InGaN LEDs due to the low ionization of the magnesium doping that is used to create p-type GaN. The knock-on effect is that hole injection into InGaN MQWs is restricted to a couple of wells at the p-GaN end.

Further, since there are few holes in the MQW region, electrons tend to overshoot, ending up in the p-GaN contact where non-radiative recombination is more likely. Aluminium gallium nitride (AlGaN) electron-blocking layers are used to avoid this, but these layers also unfortunately inhibit hole injection.

The proposed effect of the thin layer of SiO₂ insulator is

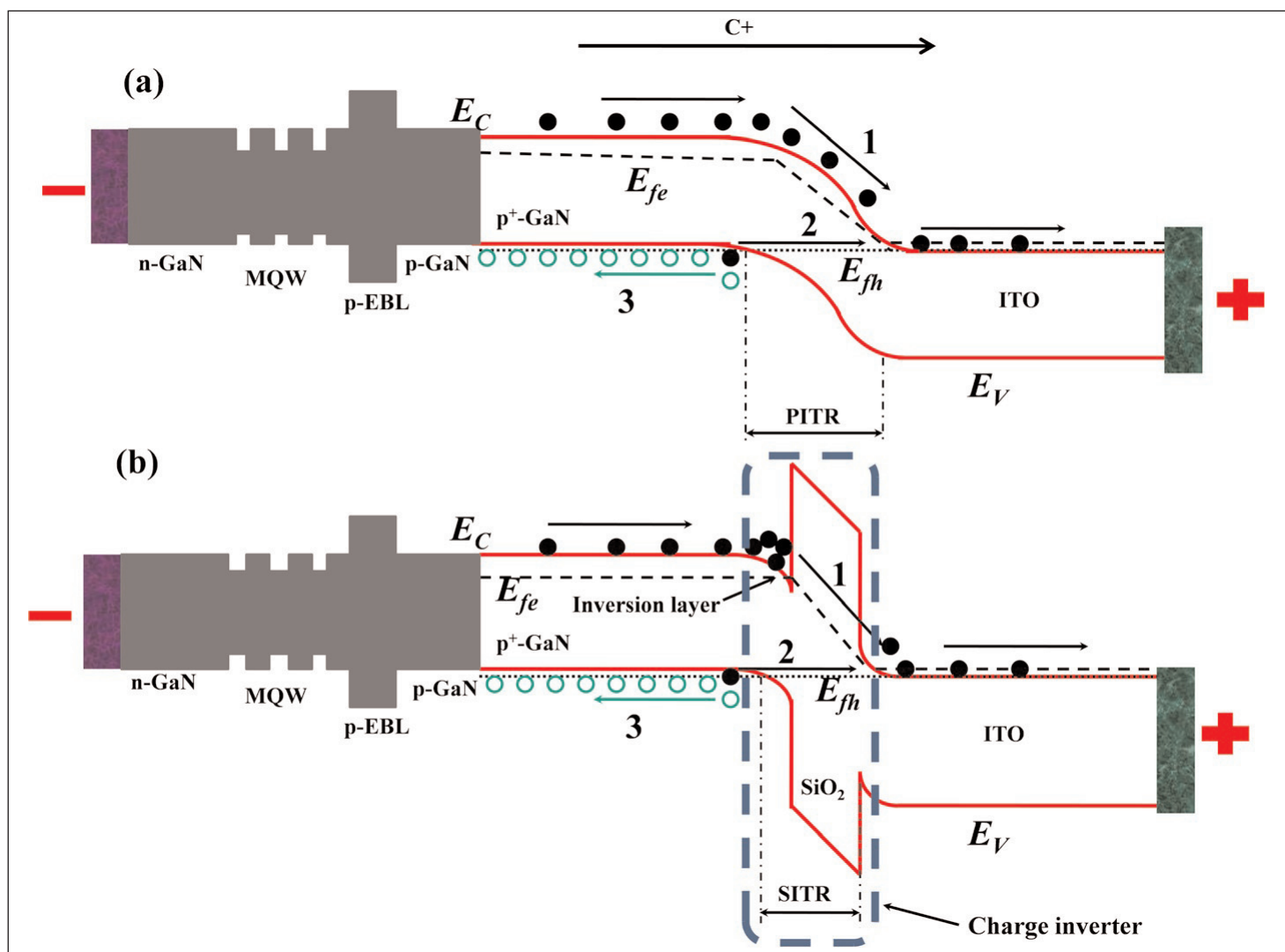


Figure 1. Schematic energy band diagrams (layer thickness not to scale) for (a) device A without SiO₂ charge inverter and (b) device B with charge inverter. Carrier transport processes: 1. non-equilibrium electrons (solid circles) travel to the ITO layer from the conduction band of the p⁺-GaN layer; 2. electron interband tunneling simultaneously produces holes (open circles), and holes then travel (3) to MQW region. E_C conduction and E_V valence bands. E_{fe} electron and E_{fh} hole quasi-Fermi levels.

to reduce the thickness of the barrier for electrons to be removed from the valence band of the p-type GaN layer of the LEDs into the conduction band of the indium tin oxide (ITO) transparent current-spreading layer.

Simulations suggest the SiO₂ forms a weak inversion layer on the p-GaN side where electrons accumulate. The researchers from Hebei University of Technology in China, Nanyang Technological University in Singapore, Bilkent University in Turkey, and South University of Science and Technology in China, explain: "The inversion layer is able to attract and confine the electrons at the p⁺-GaN/insulator interface. This can then substantially shorten the width of the tunnel region, which can significantly increase the carrier tunnel efficiency."

Simulations suggest the tunneling width of ~3.5nm without SiO₂ can be cut to ~2nm by the thin insulator layer.

Another effect of the SiO₂ is to increase the magnitude of the electric field in the tunneling region due to the lower dielectric constant of SiO₂ (3.9) relative to GaN (8.9), giving smoother, more effective hole transport from better tunneling. With better removal of electrons into the ITO layer under forward bias, there are more holes available for injection into the MQW.

The team also suggests that the SiO₂ charge inverter structure could provide an easy way to enhance hole injection and quantum efficiency in ultraviolet (UV) LEDs with p-AlGaIn hole injection layers. According to the researchers, a p⁺-AlGaIn layer would have an even larger surface depletion region with improved tunneling of valence-band electrons into ITO.

The epitaxial material for the LEDs was grown by metal-organic chemical vapor deposition (MOCVD) on [0001] sapphire: 20nm GaN nucleation, 4μm GaN buffer, 2μm silicon-doped GaN, five-period 3nm/12nm In_{0.15}Ga_{0.85}N/GaN MQW, 25nm magnesium-doped p-Al_{0.20}Ga_{0.80}N EBL, 0.2μm magnesium-doped p-GaN hole source, and 20nm heavily magnesium-doped p⁺-GaN ohmic contact. The complete epitaxial wafer was annealed at 700°C in situ for 10 minutes in nitrogen.

The LED wafers were processed into 350μm×350μm mesas with ~1nm plasma-enhanced chemical vapor deposition (PECVD) silicon dioxide and 50nm ITO transparent conductor on the p⁺-GaN ohmic contact. LEDs without the extremely thin SiO₂ layer were also produced. The thinness of the SiO₂ was enabled by the less than 1nm root-mean-square roughness measured by atomic force microscopy (AFM) over a 1μm×1μm field on the p⁺-GaN surface.

The ITO layers of both device types were annealed at 630°C for a minute in a nitrogen/oxygen mix. The researchers believe that the final devices could be further improved by optimizing this step. The p- and n-contact metals were titanium/gold.

One effect of the SiO₂ layer was to reduce the forward voltage of the LEDs, due to improved hole injection according to the researchers. The light output

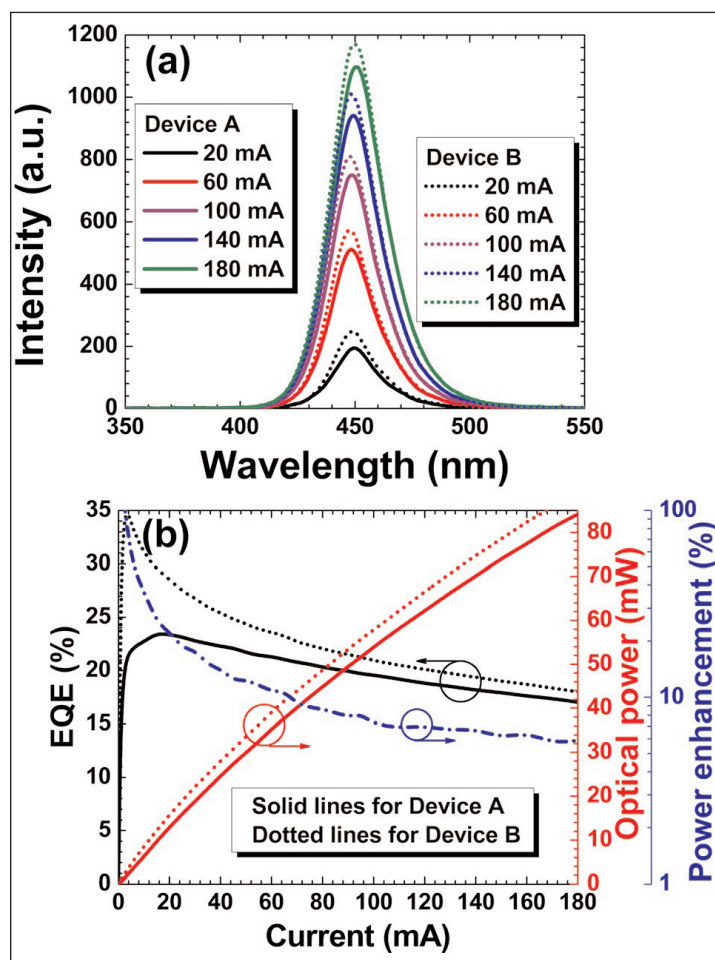


Figure 2. Experimentally measured (a) electroluminescence spectra, (b) EQE, optical power and power enhancement at different injection current levels for devices A and B.

was also increased with SiO₂ layer across the current injection range (Figure 2). The spectral peaks of both device types first underwent a blue-shift associated with charge polarization screening and then red-shift at higher currents due to self-heating effects.

At 20mA, the external quantum efficiency (EQE) for the LED B with SiO₂ layer was 20% greater than the value for LED A without. However, the efficiency enhancement fell to 10% at 180mA.

The higher EQE peak for device B also implies a larger droop: 48.6% at 100mA, compared with 27.6% for LED A. The researchers comment: "The observed efficiency droop for device B is likely due to the electron leakage caused by the inversion layer at the p⁺-GaN/SiO₂ interface, given that more non-equilibrium holes are produced at the p⁺-GaN/SiO₂ interface and the inversion layer occurs, which attracts more electrons to bypass the MQW region. Thus, more efforts are necessary to optimize the electron injection layer and/or the p-EBL so that both efficiency enhancement and reduced efficiency droop can be obtained." ■

<http://dx.doi.org/10.1063/1.4945257>

Author: Mike Cooke

Coplanar fabricated indium gallium nitride light-emitting diodes

Simpler technique cuts photolithography and metal deposition steps and offers potential path towards LED displays.

Xiamen University in China has created a simplified fabrication process for indium gallium nitride (InGaN) light-emitting diodes (LEDs) with a view to lower-cost display applications [H Long et al, *Semicond. Sci. Technol.*, vol31, p065019, 2016].

Rather than the conventional process with mesa etching and metal contacts on two different levels, the Xiamen method produces LEDs with coplanar metal-semiconductor-metal (CMSM) contact structures on one level with one round of photolithography and electrode deposition. By contrast, the conventional process requires "at least three levels of photolithography, two steps of metal deposition and excessive chemical and thermal treatments," according to the Xiamen team.

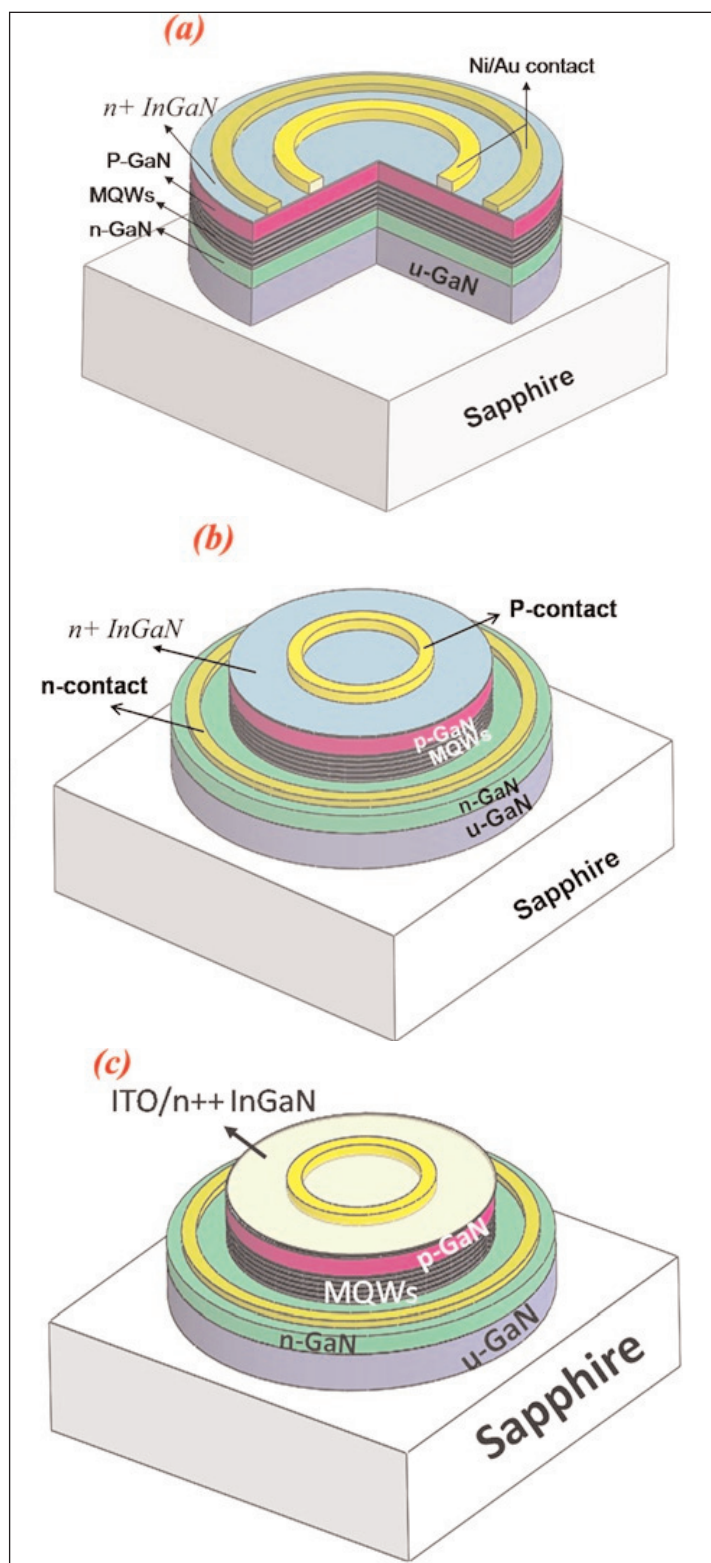
The complicated conventional process rules out the use of LEDs as display elements on production-cost grounds, although they are now widely used as back-lighting in liquid-crystal displays (LCDs).

The metal-organic chemical vapor deposition (MOCVD) epitaxial material used for the LEDs consisted of (0001) sapphire substrate, a low-temperature GaN buffer, unintentionally doped GaN, 2 μ m n-GaN, a 5-period In_{0.15}Ga_{0.85}N/GaN multiple quantum well (MQW), 100nm of p-GaN, and 5nm of heavily doped n⁺⁺-In_{0.15}Ga_{0.85}N. The aim of the n⁺⁺-InGaN was to improve contact with the p-GaN and underlying n-GaN layers.

The contacts with the LED consisted of two concentric nickel/gold rings with inner diameters/widths of 90 μ m/10 μ m and 225 μ m/50 μ m. The fabrication consisted of electrode deposition through one step each of photolithography, magnetron sputtering, and thermal annealing at 500°C in oxygen.

Conventional mesa-type devices were also produced, with and without indium tin oxide (ITO) transparent conducting current-spreading layer (Figure 1).

Figure 1. Schematic structure of CMSM LED (a) and conventional LEDs without (b) and with (c) ITO capping layer.



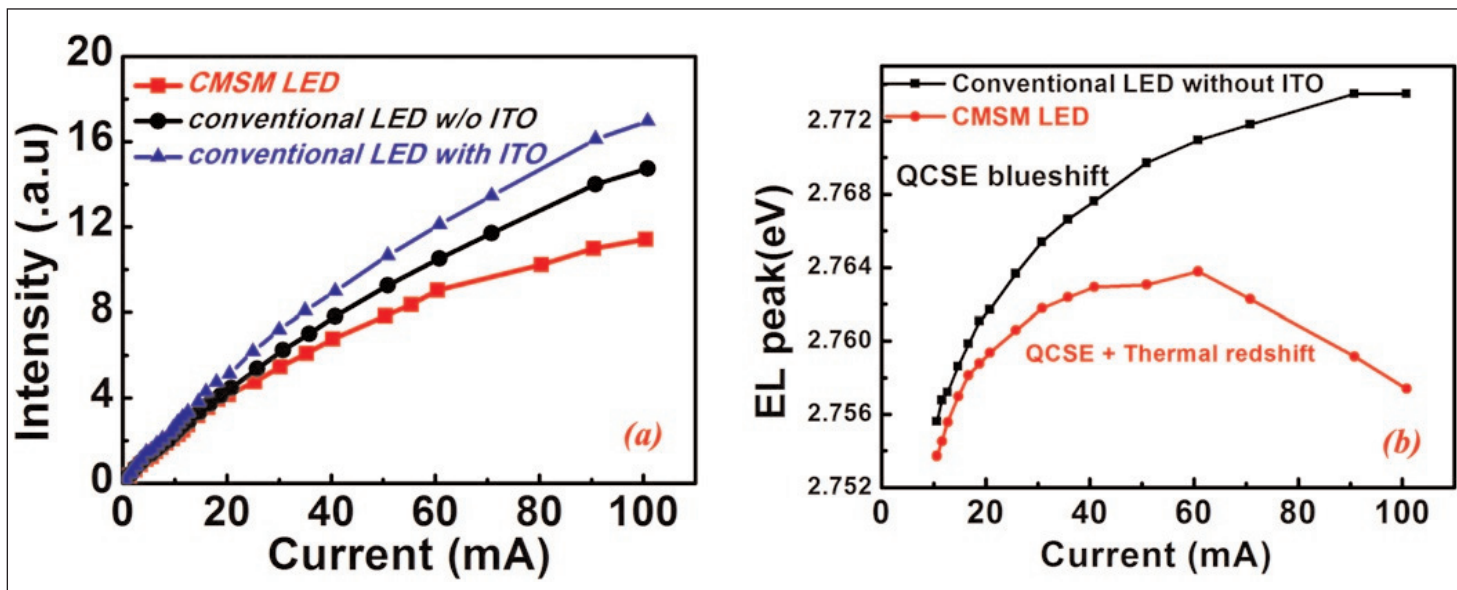


Figure 2. (a) Electroluminescence intensities of CMSM and conventional LEDs and (b) electroluminescence peak positions of CMSM LED and conventional LED without ITO as function of injected current.

The researchers applied positive bias to the inner ring and negative bias to the outer, giving blue light emission from inside the inner ring. The emission spectrum at 20mA was around 450nm wavelength without 365nm GaN near-band-edge emission or 500nm yellow emission. This indicates that the emissions come from the MQW and not from GaN (365nm) or defect (~500nm) transitions.

The current-voltage behavior was considered to be a combination of a linear resistance of 2.3k Ω between the rings through the very thin 5nm n^{++} -In_{0.15}Ga_{0.85}N layer and 100nm p-GaN and a non-linear portion from a path down from the inner ring to the n-GaN layer (p1/n), across the n-GaN layer, and then up to the outer ring. The down part of the latter current path was a forward biased p-GaN/MQW/n-GaN LED. At 20mA, the drop across this section was estimated at 3.1V, although the total was around 7.5V. The difference between 7.5V and 3.1V represents lost power (4.4V \times 20mA = 88mW) and of course the quantum efficiency of the 3.1V drop will be nowhere near to 100%.

The researchers comment: "Since the luminescence region was confined within the inner circle of 100 μ m diameter, the current density of the forward p1/n junction could be derived as 67Acm² at 3.1V and 20Acm² at 2.7V, which was similar to the electrical parameters of conventional LEDs."

The linear 2.3k Ω was estimated to be mainly through the thicker p-GaN layer rather than the 5nm n^{++} -InGaIn. The outer ring upward current path of n-GaN/MQW/p-GaN/ n^{++} -InGaIn was seen as being like an npn bipolar transistor with the p-GaN/ n^{++} -InGaIn junction forward biased. "Electrons from the n^{++} layer can diffuse into the n-layer after passing through the p-region," the researchers write.

Up to 20mA, the emission intensity was 6.7% and 11% short of the conventional LEDs without (A) and with (B) ITO current spreading, respectively (Figure 2). The performance of the CMSM LED fell further behind with greater than 20mA current injection.

The researchers estimate that at 20mA, some 3.3mA is shunted through the 2.3k Ω surface layer. At higher current, the extra self-heating of the surface region degraded the CMSM LED performance, compared with the conventional devices. Also the extra self-heating somewhat compensated the blue-shift attributed to the quantum-confined Stark effect (QCSE) that arises from electric fields caused by charge polarization of the partially ionic bonds of the III-nitride materials.

A proof-of-concept array of LEDs was produced in the shape of Xiamen University's roman initials (XMU) to indicate the potential for active-matrix (AM) and passive-matrix (PM) displays. The researchers point out that LCD external quantum efficiencies max out at 8% and theoretical organic light-emitting displays could only reach 25%. State-of-the-art GaN LEDs have efficiencies greater than 50%.

The researchers comment: "The conventional LED has the p- and n-electrodes on different planes, leading to huge difficulty in AMLED and PMLED fabrication. Our CMSM LED introduced a coplanar electrode configuration and, in our opinion, could simplify the AMLED and PMLED process."

Based on the 100 μ m electrode size, the estimated resolution of such displays would be around 250 pixels per inch. Although the performance of the proof-of-concept was not comparable with LCDs or OLEDs, the researchers believe that follow-up work will enhance light intensity and luminous efficiency. ■

<http://dx.doi.org/10.1088/0268-1242/31/6/065019>

Author: Mike Cooke

Wafer-scale lift-off of III-nitride epitaxial layers with boron nitride

New technique could reduce process times and costs compared with laser and chemical techniques.

Researchers based in USA and France have been studying hexagonal boron nitride (h-BN) as a means to ease wafer-scale separation of III-nitride epitaxial layers from sapphire substrates [Taha Ayari et al, Appl. Phys. Lett., vol108, 171106, 2016]. The team from Georgia Institute of Technology in the USA and its European campus Georgia Tech Lorraine, France, and Université de Lorraine, France, see the technique as potentially having advantages over laser- and chemical-based alternatives for such 'lift-off'.

Hexagonal BN has a crystal structure based on sp² bonding, which creates strong links in a hexagonal lattice plane but weak van der Waals links between planes. This is similar to a number of material groups such as graphene, black phosphorus, and transition metal dichalcogenides (e.g. molybdenum/tungsten disulfide/diselenide).

Using h-BN, the team believes that problems such as laser damage, long process times and high equipment

cost can be ameliorated in epitaxial layer lift-off. Other groups have reported some preliminary results for h-BN lift-off of areas of epitaxial material up to a couple of square centimeters.

The structure (Figure 1) was grown on 2-inch sapphire by metal-organic vapor phase epitaxy (MOVPE). The process precursors were triethylboron (TEB), trimethylgallium/ triethylgallium (TMGa/TEG), trimethylindium (TMIn), trimethylaluminum (TMAI), and ammonia (NH₃). Doping was achieved by adding silane (SiH₄, n-type) and bis(cyclopentadienyl)-magnesium (Cp₂Mg, p-type).

The h-BN layer was grown at 1300°C, followed by aluminium gallium nitride (Al_{0.14}Ga_{0.86}N) at 1100°C as nucleation for the overlying n-GaN. The multiple quantum well (MQW) consisted of five 2.5nm indium gallium nitride (In_{0.15}Ga_{0.85}N) wells separated by 12nm GaN barriers.

The growth of h-BN is described as van der Waals epi-

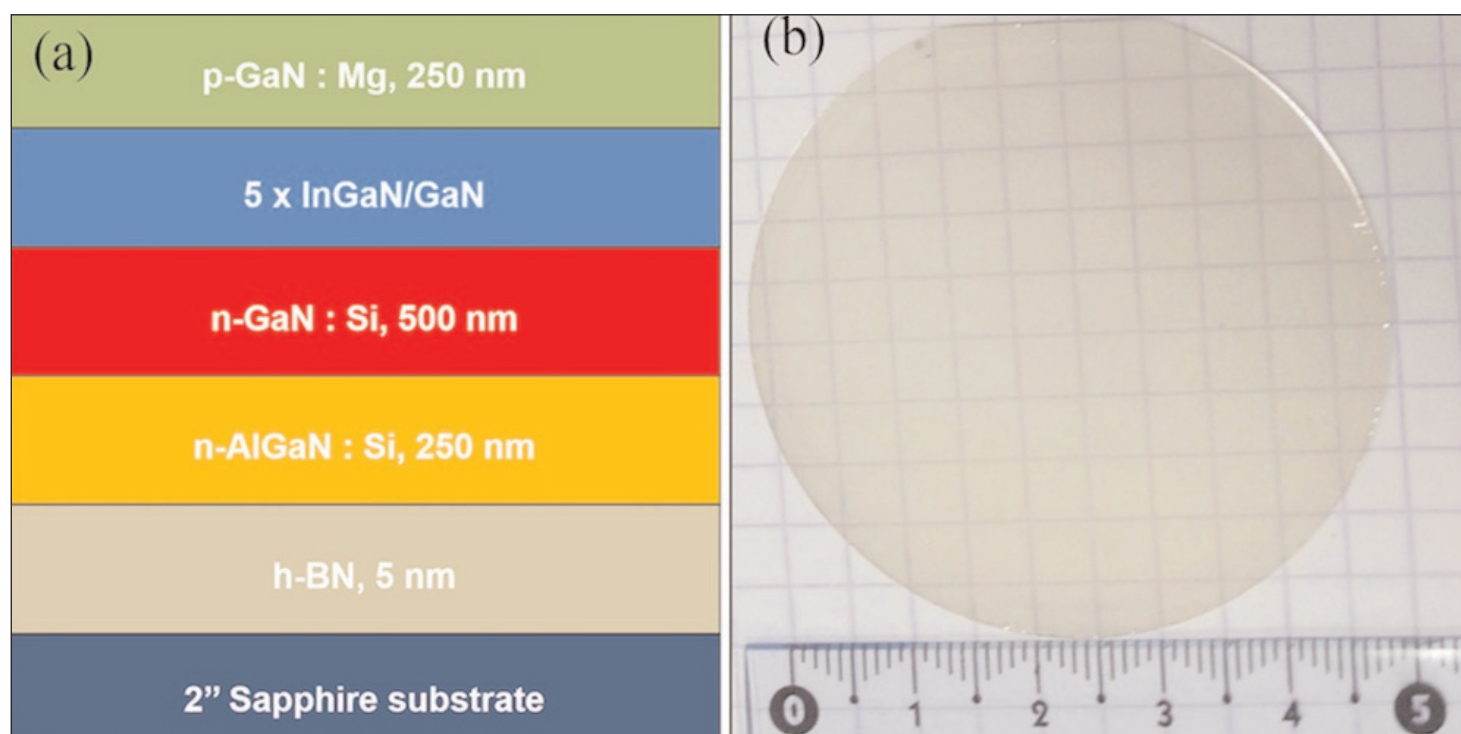


Figure 1. (a) Schematic of grown structure and (b) resulting transparent wafer photograph after epi-growth.

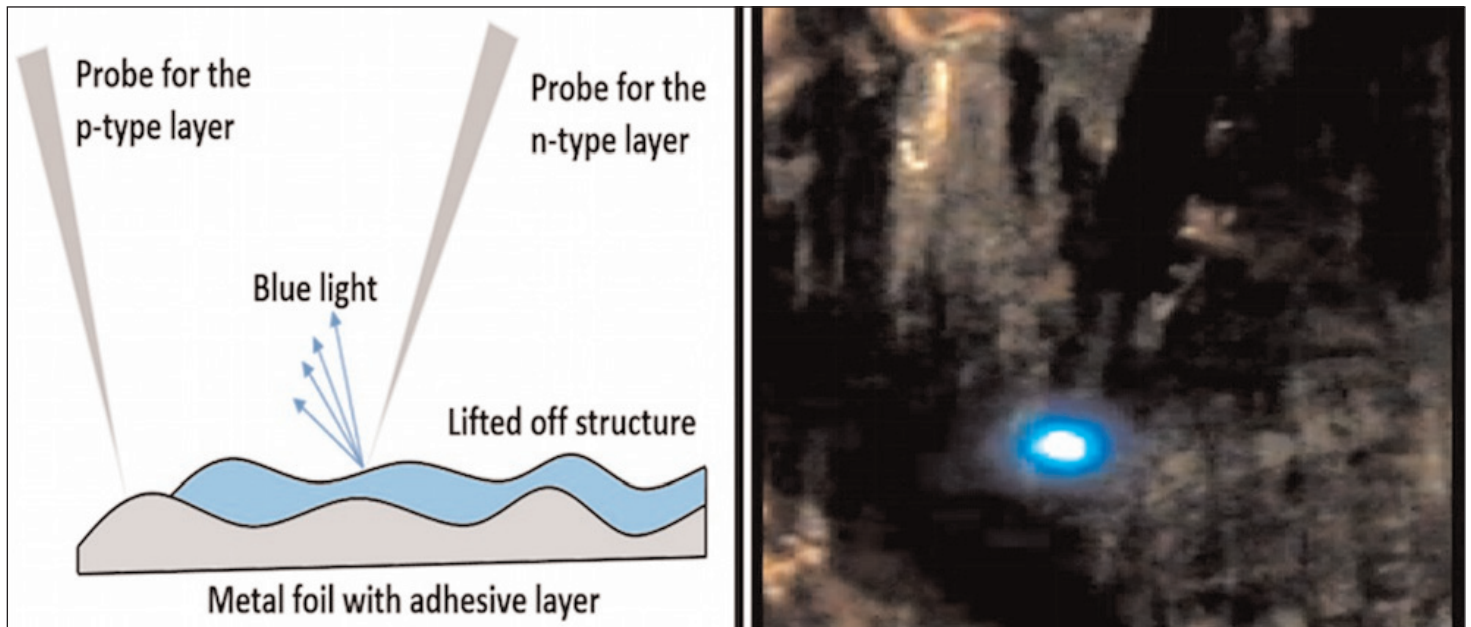


Figure 2. Blue light emission by electrical injection from exfoliated MQW structure.

taxy (vdWE). The researchers explain: "As opposed to conventional 3D crystals, vdWE does not involve strong chemical bonds between the epilayer and the substrate; instead, it only requires either the substrate or the overlayer to have a surface free of active dangling bonds, such as layered materials which is the case for h-BN."

Atomic force microscopy (AFM) of the p-GaN surface over a $5\mu\text{m}\times 5\mu\text{m}$ field gave a root-mean-square (RMS) roughness of 1.6nm.

Separation of the epitaxial layers from the sapphire substrate was attempted using acrylic conductive adhesive on aluminium and copper foils. The exfoliation occurred across the 2-inch wafer with crack-free regions of several square millimeters, according to the researchers. The team comments: "This is greater than the typical device size of commercially available light-emitting diodes (LEDs) ($300\mu\text{m}\times 300\mu\text{m}$). We believe that the cracks can be reduced by using a wax support or an elastomeric stamp."

X-ray analysis before and after exfoliation suggested that the MQW stack maintained structural integrity. The RMS roughness was found to be 1.14nm over a $5\mu\text{m}\times 5\mu\text{m}$ AFM scan. "This smooth surface indicates that the exfoliation occurred by breaking the bonds between the 2D-layered BN layers and not at the interfaces of the sp^3 -bonded III-nitride layers which would result in a surface with increased roughness," the researchers write.

Cathodoluminescence (excitation by electron beam) emitted light with an MQW peak at 454nm before exfoliation and 458nm after exfoliation. The researchers attribute the 4nm red-shift to partial residual strain relaxation. The ratio between GaN near band-edge emission and the MQW was the same before and after lift-off, although overall intensity reduced by about 15%.

Electroluminescence was obtained with probe tips, but without contact metal deposition (Figure 2). ■

<http://dx.doi.org/10.1063/1.4948260>

Author: Mike Cooke

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Fully vertical gallium nitride p-i-n diode grown on silicon substrate

Researchers claim the first demonstration of GaN vertical p-i-n diodes on silicon with high performance.

Researchers in Hong Kong and China have claimed the first demonstration of gallium nitride (GaN) fully vertical p-type-intrinsic-n-type (p-i-n) junction diodes on silicon (Si) [Xinbo Zou et al, IEEE Electron Device Letters, vol 37 (2016), issue 5. p636]. The devices were grown on silicon and transferred to a silicon carrier wafer. The team from Hong Kong University of Science and Technology (HKUST) and Xi'an Jiaotong University believes the technique is a promising path for achieving cost-effective high-power switching devices.

The wide 3.4eV energy gap of GaN allows high critical electric fields to be achieved for high-voltage operation. Vertical GaN diodes for high-power, high-frequency electronics have been the subject of increasing interest, but most reports are of devices grown on bulk or free-standing GaN because the resulting epitaxial material is of higher quality with low dislocation density. However, the cost of such substrates is still very high.

Quasi-vertical GaN devices (e.g. standard light-emitting diodes with laterally placed n- and p-contacts on the epi-side of the wafer) on foreign substrates such as silicon, silicon carbide, or sapphire tend to suffer from electric field and current crowding effects.

The epitaxial material for the fully vertical diodes (Figure 1) was grown on 6" (111) Si by metal-organic chemical vapor deposition (MOCVD). The researchers estimated the dislocation density at $9 \times 10^8/\text{cm}^2$.

Fabrication consisted of etching trenches down to the silicon growth substrate with inductively coupled plasma, depositing and annealing nickel/gold on the p-GaN contact layer, bonding to a (100) Si carrier wafer with copper-tin-copper, removal of the (111) growth substrate by mechanical grinding and plasma etch, plasma-enhanced chemical vapor deposition (PECVD) of silicon dioxide (SiO_2) sidewall passivation, removal of the aluminium gallium nitride (AlGaN) buffer, and chromium/gold electrode deposition on the n-GaN contact layer.

The copper-tin-copper bonding step was carried out at 280°C for only 30 seconds to avoid degrading the p-GaN material quality. The researchers also took

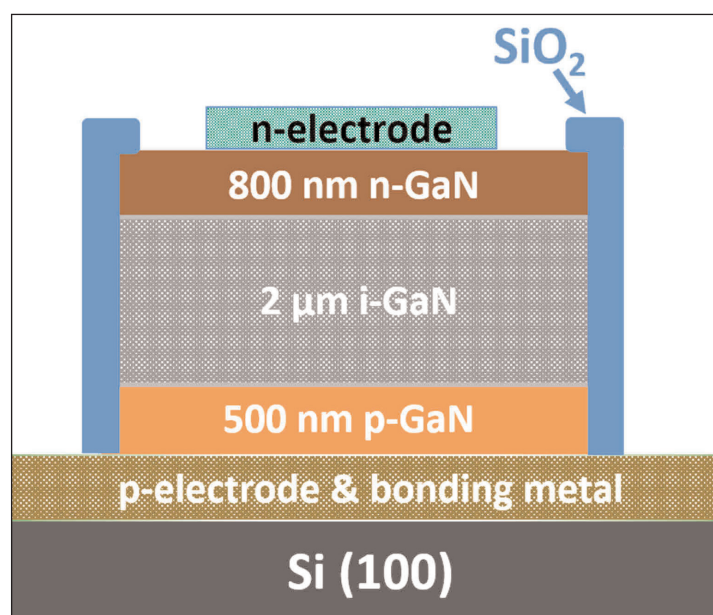


Figure 1. (a) Main steps in fabricating vertical p-i-n diodes on Si; (b, c) As-grown p-i-n diode surface characterized by optical microscopy and atomic force microscopy (AFM); (d) Image of p-i-n epilayers bonded onto Si (100); (e, f) scanning electron microscope (SEM) images of a fabricated p-i-n diode on Si with n-GaN facing up; (g) AFM image of n-GaN surface after AlGaN buffer removal.

particular care in etching the AlGaN buffer to limit surface roughness of the n-GaN contact layer to 4.96nm root-mean-square. Rough surfaces lead to increased leakage currents due to electric field spikes.

A 0.11mm²-area device had a forward voltage of 3.35V at 1A/cm² current density, consistent with the ~3.4eV bandgap of GaN. The resistance was relatively large at low current injection due to the 2μm-thick undoped n⁻-type i-GaN drift region. At higher current injection of 300A/cm², the forward voltage was 8.38V and the differential resistance was 3.3mΩ-cm².

The team comments: "The small differential on-resistance of 3.3mΩ-cm² demonstrated in this work was attributed to conductivity modulation from carrier injection and excellent current spreading in the

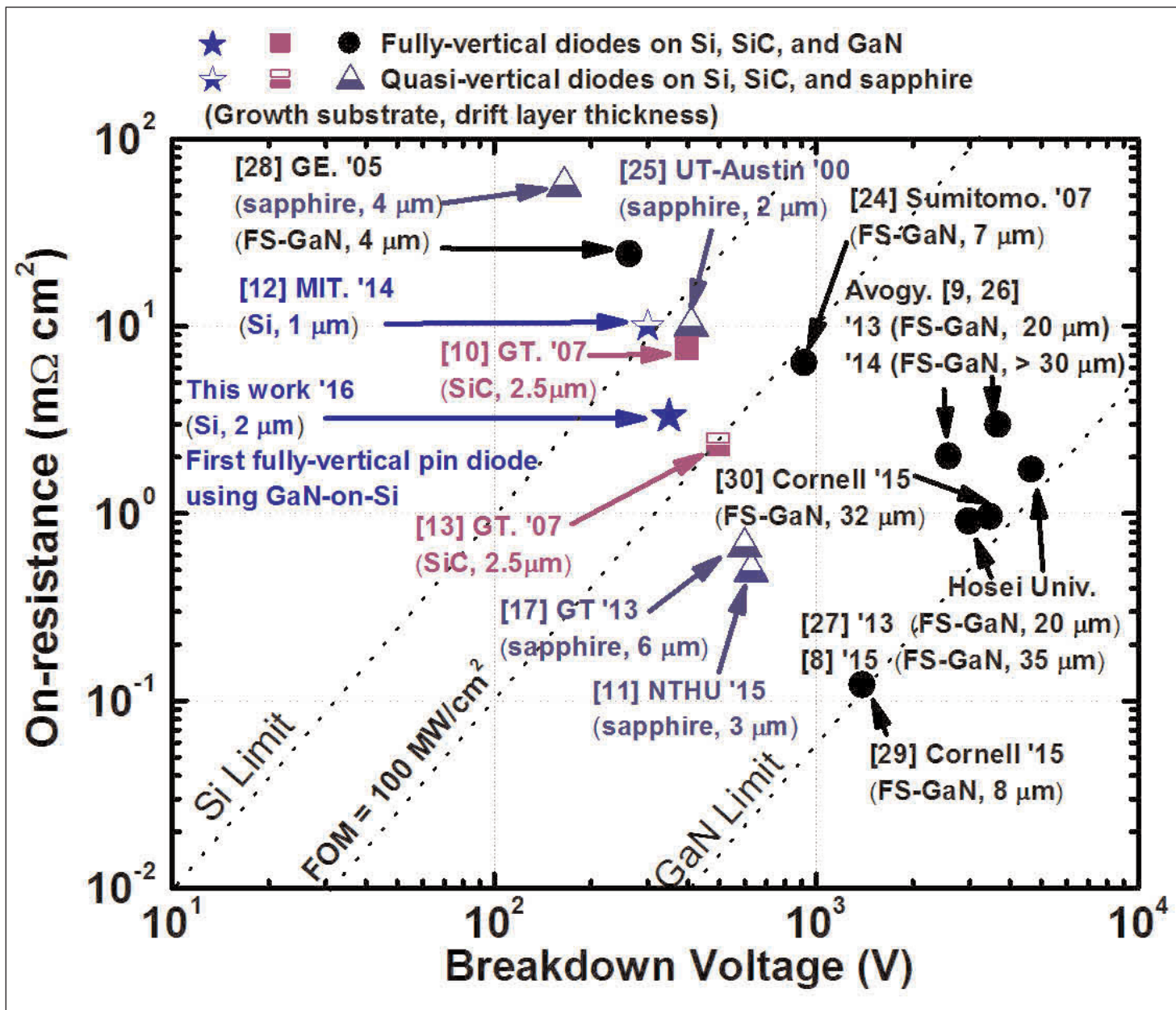


Figure 2. Relationship between specific on-resistance and breakdown voltage of GaN vertical p-i-n rectifiers on various substrates.

fully vertical structure.”

The researchers also estimate that 1.3V of the 8.38V drop was due to the drift layer with the remainder blamed on contact and series resistance of the p-GaN. Optimizing the p-GaN mobility and ohmic contact metals should reduce the forward voltage and on-resistance.

Under -200V reverse bias, the current was $1 \times 10^{-2} \text{A/cm}^2$, which is comparable to other p-i-n diodes on foreign substrates, according to the researchers. The team believes the reverse leakage could be reduced using edge-termination techniques such as sidewall treatment and enhanced passivation. The breakdown voltage was -350V .

“In our diode, when the reverse voltage was larger than 40V , acceptor traps have been fully ionized and donor traps started to get neutralized,” the researchers explain. “As the Fermi level kept moving towards the

conduction band, more free electrons were generated in the conduction band, leading to a rapid increase of reverse current.”

The Baliga figure of merit for the device was 37.0MW/cm^2 ($350\text{V} \times 350\text{V} / 3.3 \text{m}\Omega\text{-cm}^2$). The researchers compare this with values obtained on other substrates (Figure 2) and comment: “To our knowledge, this is the best reported data for GaN p-i-n rectifiers grown on Si substrates. Considering the simple active GaN epi-layers with a drift region of only $2\mu\text{m}$ that can be grown on large-area Si substrates, the methods reported here showed great potential in achieving cost-effective GaN vertical devices for high-power and high-voltage switching applications.” ■

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Author: Mike Cooke

III-nitride high-electron-mobility transistors on flexible tape

Researchers claim the first demonstration of 10GHz large-signal microwave power performance for flexible AlGaN-barrier HEMTs.

Researchers in France claim the first demonstration of 10GHz large-signal microwave power performance for flexible aluminium gallium nitride (AlGaN) barrier high-electron-mobility transistors (HEMTs) [S. Mhedhbi et al, IEEE Electron Device Letters, vol 37 (2016), Issue 5, p553]. The devices were produced on low-cost silicon substrates and transferred to flexible tape.

The team comments that their work “demonstrates the capability of flexible GaN-based HEMTs for the development of applications requiring mechanical flexibility, high-frequency operation as well as high-power performance.”

The researchers came from Institut d’Electronique de Microélectronique et de Nanotechnologie (IEMN), Centre de Recherche sur l’Hétéro-Epitaxie et ses Applications, and 3M France Company.

The material for the HEMTs was grown by molecular beam epitaxy (MBE) on high-resistivity (111) silicon: 44nm AlN nucleation, 250nm Al_{0.15}Ga_{0.85}N and 130nm AlN stress mitigation, 1.73µm GaN buffer, 1nm AlN spacer, 10nm Al_{0.29}Ga_{0.71}N barrier, and 0.5nm GaN cap.

The ohmic source–drain electrodes consisted of annealed titanium/aluminium/nickel/gold. Devices were isolated with nitrogen ion implants.

The 100nm-long nickel/gold gate was T-shaped. The gate width was 2x50µm (100µm total). The gate–source and source–drain spacings were 1µm and 2.75µm, respectively.

The HEMTs were passivated with plasma-enhanced chemical vapor deposition (PECVD) of silicon nitride and silicon dioxide dielectrics. The contact pads were titanium/gold.

The silicon substrate was removed by bonding the front-side of the wafer to a sapphire carrier with

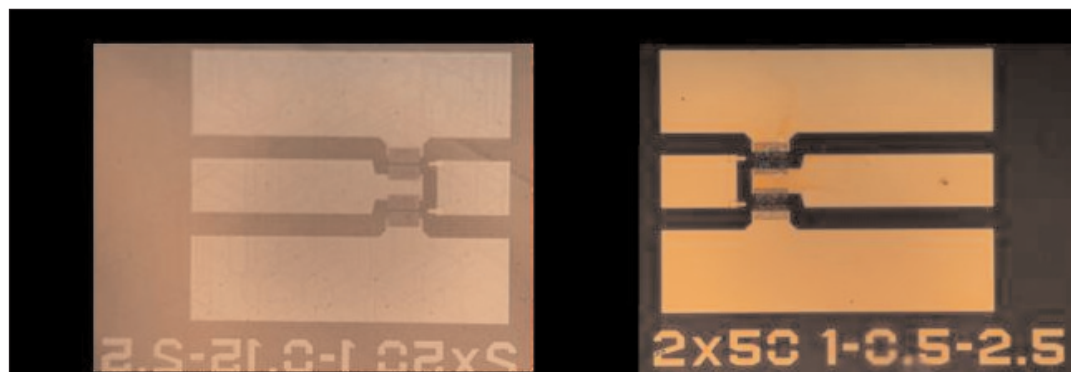


Figure 1. Optical images of device (a) backside after silicon etching and (b) after transfer onto 3M flexible tape.

photoresist. Chemical-mechanical lapping ground down 100µm of the silicon wafer. Dry etching removed the remaining silicon down to the AlN nucleation layer that was used as etch stop (Figure 1).

The thinned devices were transferred to thermally conductive tape under development by 3M. The tape is designed to withstand temperatures up to 260°C for short periods (of the order of minutes). The tape was 250µm thick.

The elastomeric-silicone carrier material of the tape was highly loaded with thermally conductive filler. One side of the tape was coated with high-temperature-resistance silicone adhesive. The tape was also designed to be chemically resistive to common solvents.

The sapphire carrier was removed by dissolving the photoresist adhesion layer in acetone.

Hall measurements of transferred material gave a sheet resistance of 437Ω/square, a high mobility of 1831cm²/V-s and sheet carrier density of 9x10¹²/cm².

Coplanar propagation waveguides (CPWs) were also fabricated on the tape with gold/titanium metal. A 1mm-long CPW had as low as 0.2dB/mm loss at 10GHz. This value is comparable to the values for microwave circuits on high-resistivity silicon.

The maximum drain current for the HEMTs was 620mA/mm at 3V drain bias and 0V gate potential. At the same drain bias, the maximum extrinsic transconductance was 293mS/mm at –2.2V gate potential.

The pinch-off voltage was estimated at -3.3V . The researchers comment: "Despite the lack of materials and technology developments for transferred devices, the drain current ratio $I_{\text{ON}}/I_{\text{OFF}}$ ratio is equal to 10^5 ."

Using the maximum transconductance parameters as bias point (3V drain, -2.2V gate), the cut-offs for current gain (F_T) and Mason's gain (F_{MAX} , extrapolated from 67GHz maximum RF measurement with assumed -20dB/decade fall off) were 38GHz and 75GHz , respectively.

Large-signal measurements were made with 10GHz continuous wave (CW) operation of an active load-pull setup. The drain and gate bias points were 5V and -3V , respectively, giving AB class amplification. The linear power gain was 15.8dB . The saturated output power and power-added efficiency were 0.42W/mm and 29.6% , respectively.

"To our knowledge, this performance constitutes the current state of the art at 10GHz for flexible devices," the team writes. The researchers believe that the

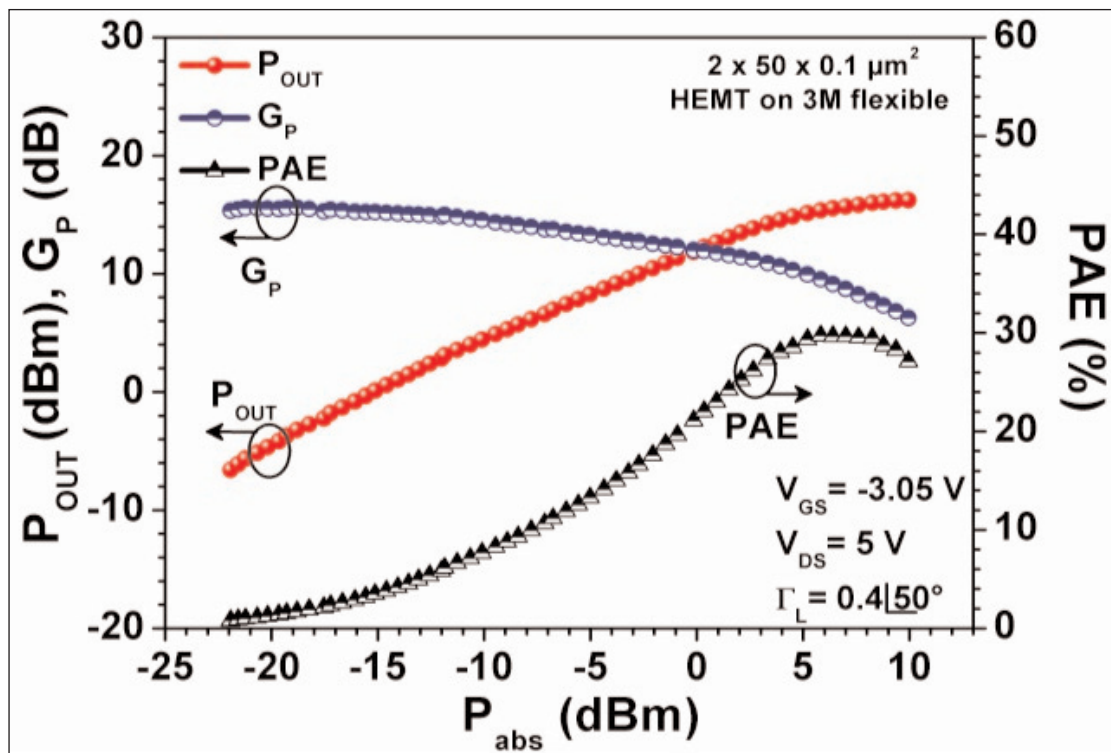


Figure 2. Output power, power gain and power-added efficiency versus absorbed power at 10GHz for $2 \times 50 \mu\text{m} \times 0.1 \mu\text{m}$ AlGaIn/GaN HEMT on 3M flexible tape at 5V drain.

saturated power density figure represents the first such result ever reported in the field of flexible electronics. The team also suggests improved performance and reliability could come from tape with better thermal conductivity. ■

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Looking to the future with III-V finFETs

Mike Cooke reports on recent separate TSMC- and IBM-led research.

Combining high-mobility III-V materials with silicon has been the subject of much research in recent years with the hope of introduction into mainstream electronics in the near future. Getting all the parts to work together at the right scale has been, is and will continue to be a challenge. Silicon is well established as the premier electronics material for low cost and seemingly ever improving speed and power performance. However, improving silicon electronics has become increasingly difficult and new processes, materials and structures have been introduced to meet expectations.

The traditional planar complementary metal-oxide-semiconductor (CMOS) transistor is presently being replaced by three-dimensional (3D) fin structures to allow better access for the gate electrode on three sides of the channel, and the next step in this progression is nanowire transistors with the gate wrapped around all four sides. Intel already uses finFETs made from silicon in some of its products (since 2011). FinFETs can be seen as intermediate between planar and gate-all-around nanowire transistors. These developments for silicon have their counterparts in III-V research.

However, some argue [e.g. Synopsis' Victor Moroz, 'Technology Inflection Points', International Symposium on Physical Design, 2016, www.ispd.cc/slides/2016/3_1.pdf] that the window of opportunity for III-V channels is closing due to large source/drain tunnel currents, which reduce on/off current ratios in the nanowire transistor gate-all-around designs that are being proposed for sub-5nm technology (circa 2021?) nodes. The tunneling currents are controlled by the effective mass. Unfortunately, high-mobility III-V materials correlate with effective masses that are too low for high-performance nanowire transistors. According to simulations, the range of effective masses needed is better covered by strained silicon.

Despite these countervailing (Cassandra?) prophecies, the European Union has set up 'Integration of III-V Nanowire Semiconductors for next Generation High Performance CMOS SOC Technologies' (INSIGHT, www.insight-h2020.eu) — a consortium under the Horizon 2020 Research and Innovation Action program.

INSIGHT involves Sweden's Lund University, the UK's University of Glasgow, Ireland's Tyndall National Institute, Germany's Fraunhofer IAF, LETI in France, and

IBM Research GmbH in Switzerland. The funding is €4.3m over 36 months from 2016. The aim is to develop III-V nanowire CMOS technology for millimeter-wave applications in a system-on-chip approach, combining RF and logic for the 10nm node and beyond.

In the USA, Jesús A. del Alamo of the Massachusetts Institute of Technology leads the Xtreme Transistors Group, which recently reported record transconductance for III-V field-effect transistors (FETs) [see Mike Cooke, *Semiconductor Today*, p88, April/May 2016]. The MIT group aims at higher frequencies, higher speed, smaller size, extremely low power consumption, higher operating temperature, to switch electrical power, and to amplify electrical signals at higher power levels. Along with planar devices, MIT's work also includes III-V finFET and nanowire devices.

At the beginning of 2016, Taiwan Semiconductor Manufacturing Corporation (TSMC) and IBM Research GmbH reported on III-V finFETs. The finFET configuration should give better electrostatic control over channel conduction compared with planar devices like MIT's record device.

Unstrained indium arsenide

The TSMC work was led by its R&D Europe B.V. facility in Belgium. The researchers claim the first demonstration of an unstrained indium arsenide (InAs) fin field-effect transistor (finFET) with 20nm fin height (H_{fin}) [R. Oxland et al, *IEEE Electron Device Letters*, vol37, p261, 2016]. The team also included researchers from University of Glasgow in the UK, Texas State University in the USA, and TSMC in Taiwan.

The use of InAs rather than indium gallium arsenide (InGaAs) should increase mobility, lowering on-resistance. Since the present devices were the first of their kind, they did well to give performance comparable in some respects with scaled and optimized planar transistors.

The finFET material was grown by molecular beam epitaxy on p-InAs substrates (Figure 1). The 500nm undoped lattice-matched buffer was designed to isolate the 20nm undoped InAs channel from the conducting substrate. A quaternary indium aluminium arsenide antimonide (InAlAsSb) buffer composition gives improved top interface flatness, process and composition repeatability, and increased oxidation resistance over ternary AlAsSb, according to the

researchers. Further carrier confinement was provided by a pseudo-morphically strained 7nm InAlAs layer between the InAs channel and InAlAsSb buffer.

The fins were etched using inductively coupled plasma etch with methane, hydrogen, chlorine and oxygen chemistry. The fin height was 20nm and the width (W_{fin}) 25–35nm. The InAlAs acts as an etch stop, protecting the structure from uncontrolled oxidation, which is a particular concern for etching compound Sb-based semiconductors containing aluminium.

Before forming the gate stack, native oxide was removed

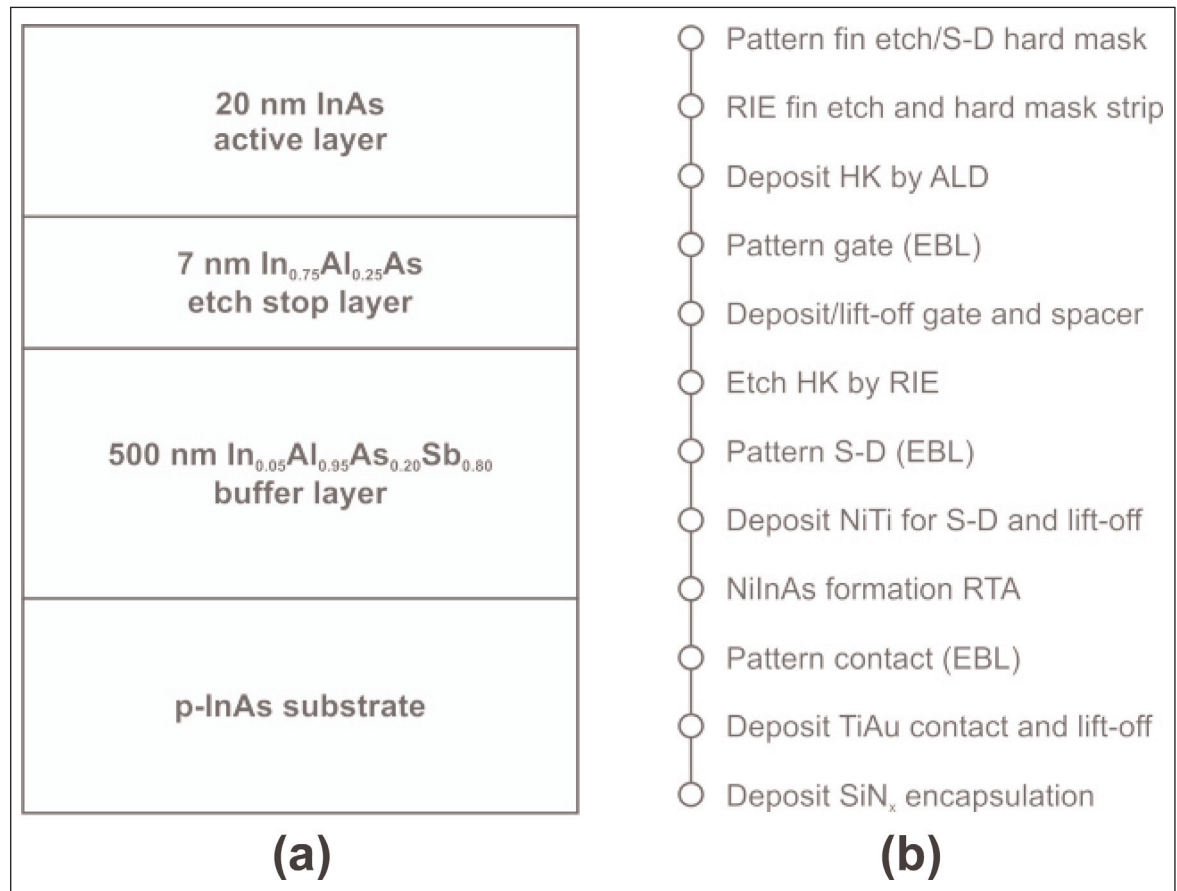


Figure 1. (a) The layer structure that was used, showing the pseudomorphic InAlAs etch stop layer and (b) the process flow for fabrication of InAs finFETs, starting with the first step after wafer growth.

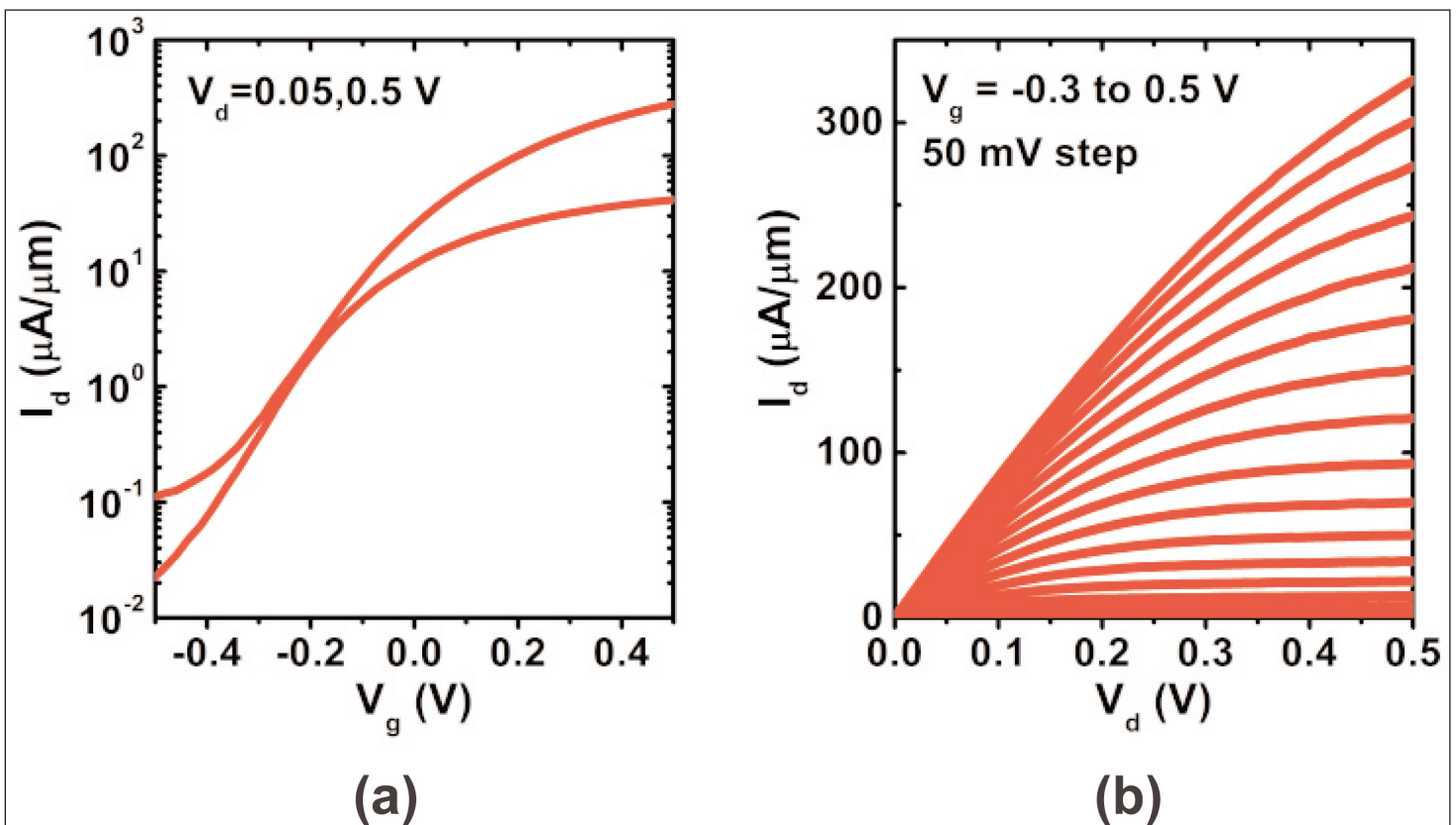


Figure 2. (a) Drain current versus gate voltage (I_d - V_g) of typical device at 0.5V and 0.05V drain bias (V_d). (b) Drain current and voltage of same device with $V_g = -0.25\text{V}$ to 0.50V in steps of 50mV.

Table 1. Benchmark of III-V finFET devices. Quoted g_m and S values extracted at $V_d = 0.5V$ on same device where given, otherwise not reported. Bold entry (top) is TSMC finFET. *Italic entry is planar device, included for comparison. InAs channel quantum well thickness is 10nm.*

InAs mole fraction	H_{fin} (nm)	W_{fin} (nm)	L_g (nm)	g_m ($\mu S/\mu m$)	S (mV/dec)
1.0	20	25	1000	650	148
		35	1000	1430	310
0.7	25	50	100	280	190
0.53	40	40	60	1100	95
0.53	20	30	80	1800	82
0.7	10	20	120	1620	114
0.53	16	40	200	—	150
0.53 ^a	9	40	30	1640	84
1.0	—	—	130	2720	85

a. Mole fraction averaged over total fin height, including InAs quantum well (3nm) and $In_{0.3}Ga_{0.7}As$ cladding layers (6nm in total).

before controlled oxygen termination. The gate insulation consisted of 5nm of atomic layer deposition zirconium dioxide, giving 1.2nm equivalent oxide thickness. The gate metal was palladium. Spacers consisted of silicon nitride. The gate length (L_g) was $1\mu m$.

The devices consisted of 10 fins. The $3\mu m$ -wide source/drain electrodes were fabricated of nickel/titanium, which was annealed to give a NiInAs metallic phase. Titanium and gold were then applied for contacts. The devices were encapsulated in 50nm of silicon nitride. The encapsulation also induced electrostatic source/drain extensions by pinning the Fermi level inside the conduction band of the InAs quantum well.

A 25nm-wide fin device had a minimum subthreshold swing (S) of 148mV/decade with 0.5V drain bias. The extrinsic transconductance (g_m) was $650\mu A/\mu m$. The minimum drain current was $110nA/\mu m$ with $-0.5V$ gate potential. Gate leakage was less than $2 \times 10^{-8} A/\mu m$ for the entire measurement range. The drain induced barrier lowering was 27mV/V — this compares well with the 30mV/V value of a planar InAs device of similar gate length.

A device with wider 35nm fins had 310mV/decade S and $1430\mu S/\mu m$ g_m with 0.5V drain. The minimum drain current of $8\mu A/\mu m$ occurred at $-0.5V$ gate potential. The gate leakage was the same as for the 25nm devices. The higher off-state current was attributed to reduced gate control from the wider fin and the different interface trap densities on the sidewall and top surface.

The Q-factors g_m/S for the 25nm- and 35nm-wide finFETs were 4.4 and 4.8, respectively. The researchers compared their devices to the InGaAs finFETs of other groups (Table 1).

InGaAs on insulator

The IBM Research GmbH, Switzerland, work developed an n-channel InGaAs on insulator (-OI) finFET process and the team claims the highest on-current to date for CMOS-compatible InGaAs devices integrated on silicon (Si) [Vladimir Djara et al, IEEE Electron Device Letters, vol37, p169, 2016].

The InGaAs-OI/Si wafer was produced using metal-organic chemical vapor deposition (MOCVD) and direct

wafer bonding. The 20nm $In_{0.53}Ga_{0.47}As$ layer was doped with $\sim 5 \times 10^{17}/cm^3$ silicon. The buried oxide (BOX) insulator layer was 37nm thick.

Transistor fabrication (Figure 3) began with a digital wet etch of fins 15nm wide and 17nm high. A dummy gate was formed before creating 12nm silicon nitride (SiN_x) spacers with plasma-enhanced atomic layer deposition (PEALD) and dry etching. The raised source-drain (RSD) $In_{0.53}Ga_{0.47}As$ contacts were re-grown using

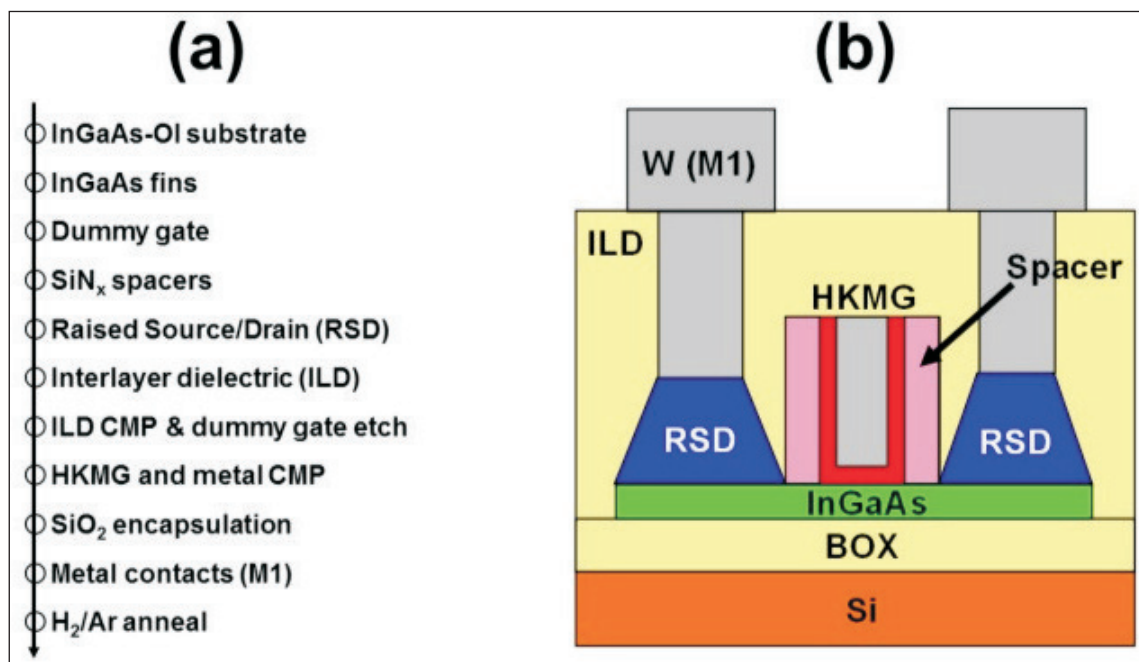


Figure 3. (a) CMOS-compatible replacement metal gate (RMG) fabrication process flow and (b) cross-sectional schematic of self-aligned InGaAs-OI FinFET architecture.

selective low-temperature MOCVD. The contacts were doped with $\sim 6 \times 10^{19}/\text{cm}^3$ tin.

A 250nm interlayer dielectric was applied by plasma-enhanced chemical vapor deposition. The material was subjected to chemical mechanical polishing (CMP) that exposed the dummy gate; the dummy gate was then removed.

PEALD was used to create a high-k aluminium oxide/hafnium dioxide metal gate stack (HKMG) with a capacitance equivalent thickness of $\sim 1.5\text{nm}$. The gate metal was 150nm tungsten. This tungsten layer was planarized with CMP.

The device was encapsulated in silicon dioxide and metal contact pads created. An optimized hydrogen/argon anneal was carried out to reduce the interface trap density to $\sim 1.5 \times 10^{12}/\text{cm}^2\text{-eV}$ at 0.25eV below the conduction band edge, according to high-low frequency capacitance-voltage analysis.

The gate leakage current for a 50nm gate-length (L_G) transistor was below 400pA/ μm with 0.5V and gate potential in the range -0.2V to $+1\text{V}$. The saturation transconductance peaked at $\sim 615\mu\text{S}/\mu\text{m}$. The saturation subthreshold swing had a minimum of 92mV/decade. The drain-induced barrier lowering was 57mV/V. The threshold in saturation was 0.09V.

The on-current (I_{ON}) was $156\mu\text{A}/\mu\text{m}$ (Figure 4). The researchers comment: "Although the I_{ON} value of $156\mu\text{A}/\mu\text{m}$ obtained at $L_G = 50\text{nm}$ represents the highest value reported to date for CMOS-compatible

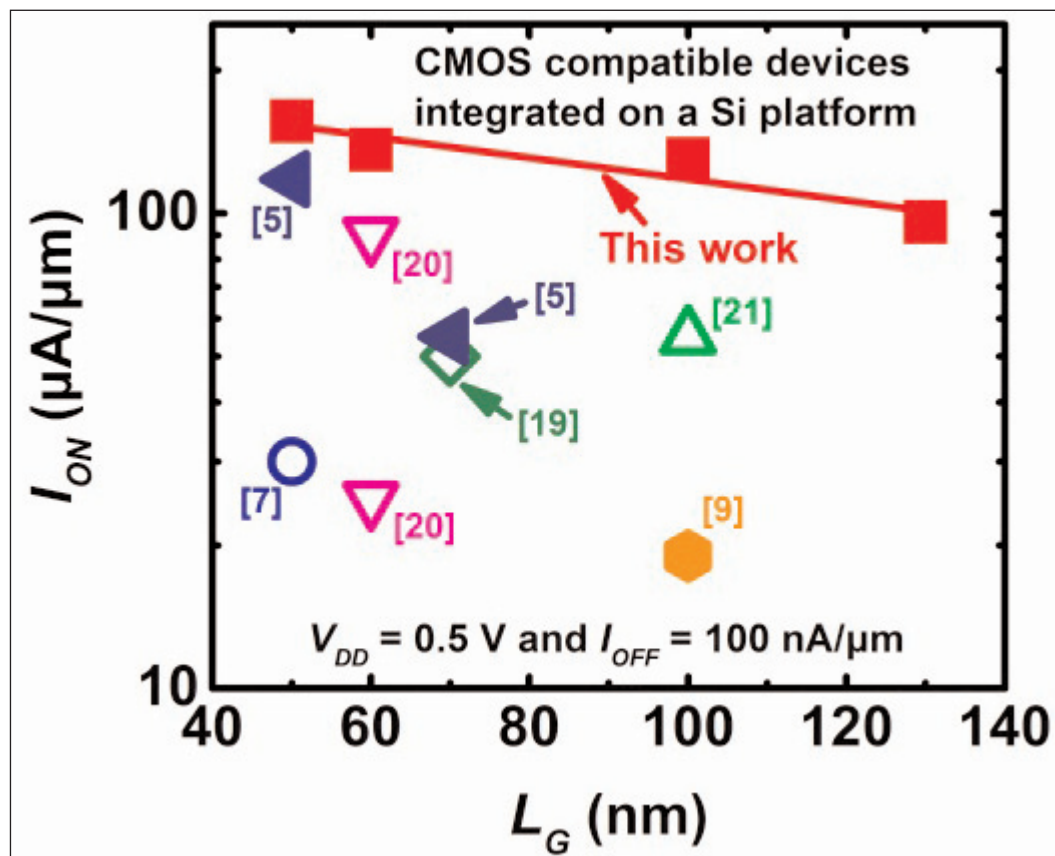


Figure 4. I_{ON} versus L_G benchmark of CMOS-compatible InGaAs FETs integrated on silicon platform. I_{ON} values are extracted at 0.5V operating voltage and an I_{OFF} of 100nA/ μm .

InGaAs FETs integrated on a silicon platform, significant improvements are still needed to reach the performance of state-of-the-art III-V n-FETs integrated on bulk InP and be competitive for advanced technology nodes. We speculate that the required performance boost could be obtained through the use of source and drain extensions."

Long $1\mu\text{m}$ -gate devices had a 10^6 maximum/minimum drain current ratio and subthreshold swing of 62mV/decade. ■

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

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