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semiconductorTODAY

COMPOUNDS & ADVANCED SILICON

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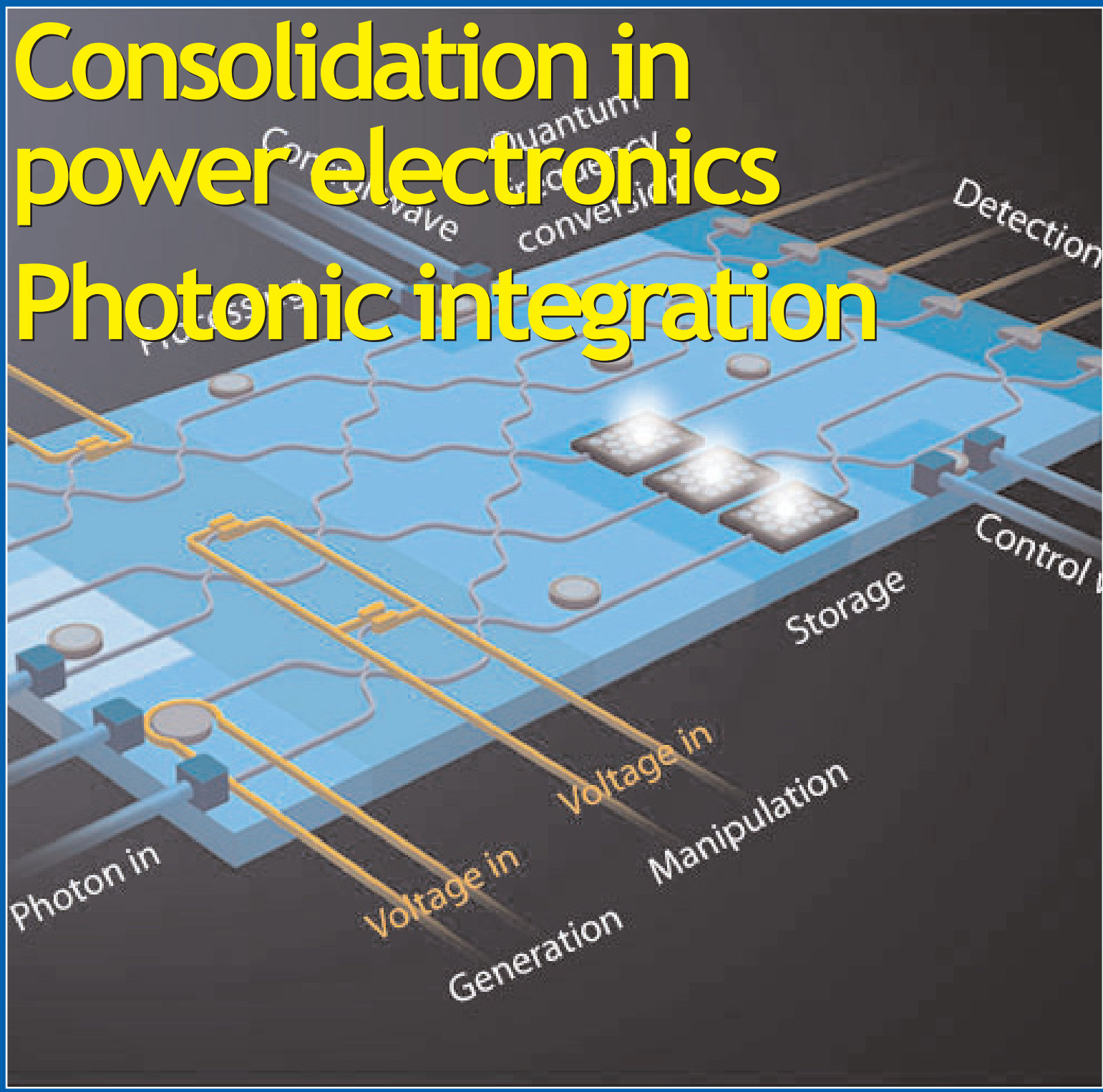
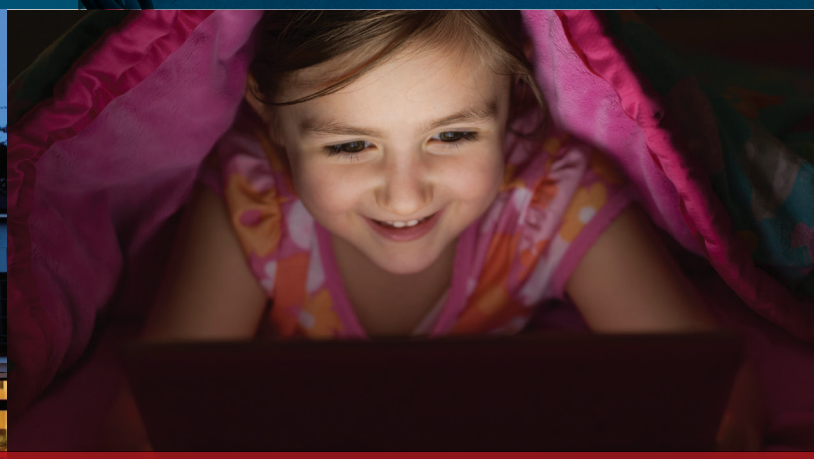
Consolidation in power electronics

Photonic integration



Juniper acquiring Aurrion • ColorChip raises a further $20m • Spectrolab producing 30.7%-efficient space solar cell

Lower Cost LEDs



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

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Veeco's New TurboDisc EPIK700 GaN MOCVD System

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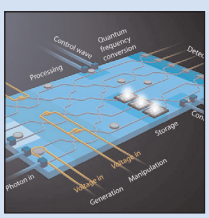
p45 UCSB professor of electrical and computer engineering and of materials John Bowers is to receive the 2017 IEEE Photonics Award for "pioneering research in silicon photonics".



Cover: Under a four-year, $2m grant from the NSF, the University of Rochester will lead a photonics system integration research project to reduce the complexity and increase the capacity of quantum information processing for secure communication, metrology, sensing and advanced computing. **p43**

editorial

III-V/silicon laser integration entering commercialization

After focusing last issue on the topic of integrating III-V materials directly on silicon to enable the integration of optoelectronic functionality on silicon substrates — specifically laser and photodiode devices incorporating indium arsenide (InAs)/gallium arsenide (GaAs) quantum dots — in this issue we follow up by covering the integration of gallium nitride (GaN)-based optoelectronic devices (light-emitting diodes, photodiodes and waveguides) on silicon. Target applications include smart transmitters/receivers for wireless visible light communication (see pages 74–77).

Also, on page 38 we report that University of Illinois at Urbana Champaign (UIUC) has developed the growth by industry-standard metal-organic chemical vapor deposition (MOCVD) of cubic-phase GaN rather than the usual hexagonal-phase GaN — via a hexagonal-to-cubic phase transformation on nano-patterned silicon (100). This enables the use of CMOS-compatible substrates to manufacture brighter and more efficient green LEDs that can also be integrated with sensing and communications networking devices in smart solid-state lighting.

One of the pioneers of hybrid integration of III-V optoelectronic devices with silicon is John Bowers, professor of electrical and computer engineering and of materials at University of California Santa Barbara (UCSB), who is to receive the 2017 IEEE Photonics Award (see page 45). Bowers was also a co-founder of the Santa Barbara-based fabless firm Aurrion, which is being acquired by Silicon Valley-based Juniper Networks (also page 45). Aurrion has developed a hybrid silicon photonics platform that heterogeneously integrates indium phosphide (InP) optoelectronic materials, and Juniper aims to combine this with its optical network products.

Bowers is a director for the West Coast center of AIM Photonics (American Institute for Manufacturing Photonics), a federally funded consortium set up to boost photonics manufacturing in the USA. AIM has just announced that, after only one year of operation, its integrated silicon photonics process design kit (PDK) is now available to member organizations (page 44).

Associated with AIM is the work of member University of Rochester, which has won a four-year, $2m grant from the US National Science Foundation for the project 'EFRI ACQUIRE: A Scalable Integrated Quantum Photonic Interconnect' that aims to reduce the complexity and increase the capacity of quantum information processing (for secure communication, metrology, sensing and advanced computing) by using chip-scale integrated SiC quantum photonic processors (see page 43).

Most recently, on 17 August at the 2016 Intel Developer Forum in San Francisco, Intel announced commercial availability of its first Silicon Photonics 100G optical transceiver products, specifically a PSM4 (Parallel Single Mode fiber 4-lane) QSFP28 module that can transmit at 100Gb/s across 2km (targeting fast data-center connectivity) and a CWDM4 (coarse wavelength division multiplexing 4-lane) QSFP28 module (targeting optical interconnects for data communications applications). The products follow long-term R&D on what was the first 'hybrid silicon laser' (integrating an InP-based laser active layer onto a silicon waveguide and laser cavity), led by John Bowers at UCSB, making the IEEE Photonics Award timely. See next issue for details.

Mark Telford, Editor

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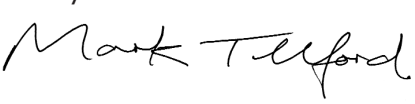

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***Semiconductor Today* covers the R&D and manufacturing of compound semiconductor and advanced silicon materials and devices** (e.g. GaAs, InP and SiGe wafers, chips and modules for microelectronic and optoelectronic devices such as RFICs, lasers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

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

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HVM: High Volume Manufacturing

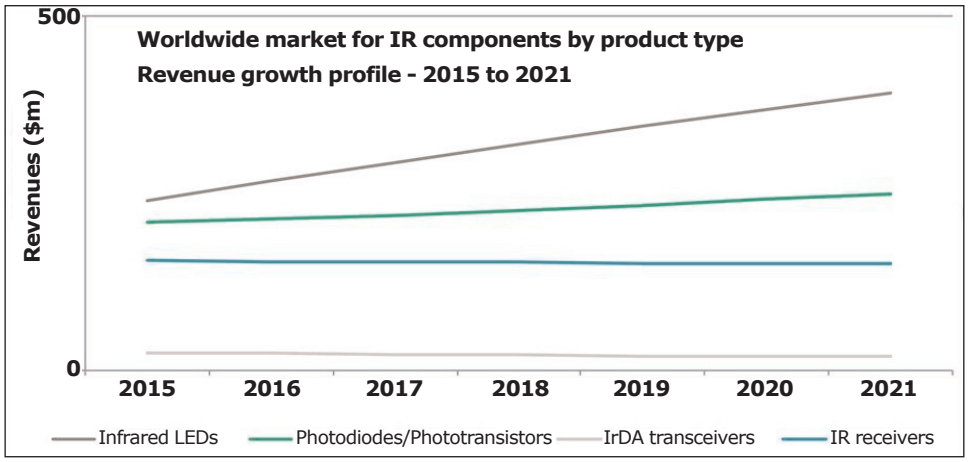
Infrared LED revenue growing faster than overall IR components

IR LEDs growing at 8.4% CAGR to 2021

Increased adoption of biometrics security in mobile phones, close-circuit television and other consumer applications spurred revenue growth in the global market for infrared LEDs from $201.5m in 2014 to $241.4m in 2015, according to Jamie Fox, principal analyst, LEDs and Lighting, at IHS Markit. While infrared LEDs grew 19.8% year-on-year in 2015, the overall infrared components market fell by 9%. Germany's Osram Opto Semiconductors, Taiwan's Everlight Electronics and US-based Vishay were the leading suppliers.

The forecast compound annual growth rate (CAGR) of 8.4% for infrared LEDs from 2015 to 2021 compares favorably to overall growth in total infrared component of 4.2%. The total market also includes slower-growth categories like photodiodes and phototransistors, Infrared Data Association (IrDA) transceivers and infrared receivers.

Infrared LEDs have traditionally been used in industrial light curtains, smoke detectors and other low-growth, mature applications.



However, upcoming and recent growth is primarily caused by increasing use in closed-circuit television (CCTV) cameras and biosecurity in devices such as smartphones, tablets, laptop PCs and video-game consoles.

Another growing market for infrared LEDs is in touch-screens in point-of-sale terminals and ATM machines, where infrared LEDs are used along the sides of the display, so that touch can be detected by the interruption of an infrared signal across the screen rather than the actual direct impact of touching the screen. Capacitive touch-screens (as used in consumer devices) are not as appropriate for these applications, because the constant use wears out the screens to the point where they become inactive, causing higher maintenance. Also, seamless smooth screens without raised edges are less important in these types of commercial applications than they are in consumer consumer devices, notes the report.

https://technology.ihs.com/553294/optoelectronic-components-report-2016

Nichia ranked top-revenue packaged LED supplier, with 12.9% market share, followed by Osram and Lumileds

According to the new 2016 edition of the IHS Markit's 'Packaged LED Report' (its annual revenue-share ranking of the top LED suppliers in backlighting, automotive, lighting and other applications), Nichia led in both lighting and mobile applications for 2015, with 12.9% share of the total packaged LED market. Nichia was followed by Osram and Lumileds with a combined share of 14.7%.

"It's not a surprise that Nichia led in more than one application," comments Alice Tao, senior analyst (LEDs and lighting) for IHS Markit. "In 2015, Nichia overtook Cree, which led the lighting category in 2014," she adds. "Nichia was also very strong in mobile phone LEDs, since the company is a major supplier for Apple's iPhone."

Samsung was the leading supplier in backlighting, which includes LEDs used in TVs, monitors, notebook PCs and tablet PCs. Nichia followed in second position and LG Innotek ranked third.

Osram has been the leading supplier of automotive LEDs for many years. Its market share was 35% in 2015 for LEDs used in the total automotive market and 40% for those used in the automotive exterior market. It also led in the 'other' application category, which includes LEDs used for industrial, medical, security, projection, signage and off-specification applications.

https://technology.ihs.com/579867/packaged-leds-report-2016

COB LED market in APAC to grow at 34.79% CAGR to 2020, driven by general lighting

...but use of different packaging technologies by manufacturers decreases assembly throughput, affecting growth

The chip-on-board (COB) LED market in the Asia-Pacific (APAC) region will increase at a compound annual growth rate (CAGR) of 34.79% over 2016–2020, forecasts Technavio's report 'Chip-on-Board LED Market in APAC 2016–2020', which segments the market into the applications of automotive lighting, back-lighting, and general lighting.

The growth of manufacturing facilities in China will be a key trend for market growth, says the report. Subsidies for LED makers offered by the government led to the expansion of manufacturing capacity. The increasing use of domestically made chips has further decreased the overall cost of LED manufacturing. This will foster the growth of Chinese LED makers, as the market is highly price sensitive, notes Technavio.

According to the report, a key driver of market growth will be the drop in the average selling price (ASP) of LEDs due to decreasing manufacturing costs. This is attributed to the use of larger wafers and automation in manufacturing.

However, limitations associated with packaging will be a major challenge to market growth, states the report. Lower prices, high light attenuation, and higher thermal resistance offered by aluminum make it the second most-reliable material for packaging. In addition, the use of different packaging technologies by different manufacturers decreases throughput in the assembly and manufacturing of COB LEDs, affecting market growth, concludes the report.

Key manufacturers covered by the report include Citizen, Cree, Lumileds, Nichia, Osram, Samsung, and Seoul Semiconductor.

www.technavio.com/report/apac-embedded-systems-chip-board-led-market

GaN device supply chain robust despite consolidation

Even with the well-publicized consolidation of RF Micro Devices and TriQuint Semiconductor, Infineon's acquisition of International Rectifier (IR) and most-recently Wolfspeed, and NXP Semiconductors' acquisition of Freescale Semiconductor, the gallium nitride (GaN) device supply chain is growing and diversifying, according to a report by Strategy Analytics that lists 37 companies manufacturing GaN devices for RF and power electronics applications.

"While RF GaN revenue is concentrated with Sumitomo Electric Device Innovations (SEDI), Wolfspeed (now part of Infineon) and Qorvo, the entire supply chain is bustling with activity," says Eric Higham, director of Strategy Analytics' Advanced Semiconductor Applications service (ASA). "GaN performance enables a lot of new capabilities in high-power electronics applications and we expect to see more activity from new and established players as GaN gains traction in these applications," he adds.

"In the RF market, we expect defense applications of GaN to see strong growth, so this will boost this portion of the supply chain," says Asif Anwar, director of the firm's Advanced Defense Systems service.

www.strategyanalytics.com/access-services/components/advanced-semiconductors/reports/report-detail/2015-snapshot-of-gan-supply-chain-companies

Qorvo's quarterly revenue grows by a more-than-expected 15%

North Carolina GaAs capacity being consolidated into Oregon and GaN to Texas, making way for SAW filters

For fiscal first-quarter 2017 (to 2 July 2016), 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 $697.6m, up 15% on $607.1m last quarter and up 4% on $672.7m a year ago. This is well above the $650m guidance, reflecting strength in the firm's Mobile Product segment in China, a large customer smartphone ramp, and growth in broad markets in the Infrastructure & Defense Products (IDP) segment.

Qorvo had three 10% customers: the largest (representing the collective demand from multiple subcontractors for this end customer) at about 29% of revenue (down from 33% last quarter), plus China-based telecoms equipment maker Huawei Technologies Co Ltd (a customer for both Mobile Products and Infrastructure & Defense Products) and South Korea's Samsung.

Mobile Products revenue was $547m, down slightly on $551m a year ago but up 18% on $465m last quarter. Mobile Products supported multiple performance-tier and premium-tier smartphones with a product portfolio including highly integrated high-, mid- and low-band solutions, envelope tracking (ET) power management integrated circuits (PMICs), filters, switches, low-noise amplifiers (LNAs) and antenna control solutions. Also, Qorvo benefited in China from a strong market and the migration from three-mode to full-mode smartphones for domestic and export markets.

Qorvo production-released its next-generation bulk acoustic wave (BAW) filter process, and Mobile Products expanded customer engagements with its ultra-high-performance BAW-based quadplexers and hexaplexers. "We saw strong demand for our recently launched quadplexers, and for our second-generation RF Flex modules, which launched last year," notes president & CEO Robert A. Bruggeworth.

In Wi-Fi, for handsets, Qorvo saw 13% growth sequentially, as it ramped its highly integrated RF Fusion for mobile Wi-Fi. Outside of handsets, Mobile Products grew 30% on last quarter.

Infrastructure & Defense Products (IDP) revenue was $151m, up 6% on $142m last quarter and up 24% on $122m a year ago. Bruggeworth cites another strong quarter for design wins. In particular, IDP continued to support the roll-out of next-generation wireless infrastructure with key 5G and massive MIMO design wins. Qorvo also expanded its presence in the (IoT) Internet of Things) market with the acquisition (announced in April) of low-power short-range RF device maker GreenPeak Technologies of Utrecht, The Netherlands (expected to be accretive by the end of 2016).

In transport, Qorvo began the production ramp of a quad linear 400G optical driver for a tier-1 telecom equipment provider. The firm also reached record revenue levels for its CATV hybrid products, driven by the industry leaders. Both support the build-out of infrastructure to keep pace with the ever increasing demand for data. Defense business is up 30% year-on-year, driven mostly by domestic active electronically scanned array (AESA) radar programs, and the proliferation of gallium nitride (GaN), especially for international markets.

"IDP continues to reposition its product portfolio to support high-growth markets, and today they are highly diversified business in a $3.8bn serviceable market," comments Bruggeworth. IDP forecasts that the markets it serves will rise at a compound annual growth rate (CAGR) of 17%, nearly doubling its market by 2020 to $7bn. "In our infrastructure unit, we continue to see a stabilization in the China base-station market and strong customer activity, especially in GaN," says Bruggeworth. "We enjoyed robust demand for our 3.5GHz GaN power amplifiers (PAs) during the quarter and we supplied duplexers, LNAs and PAs for small-cell solutions at multiple base-station OEM customers."

On a non-GAAP basis, gross margin was 48.2%, down from 50% last quarter (and 51.5% a year ago) and below the expected 50%. This was due mainly to a shift in product mix to lower-margin products, reflecting low-band PAD (power amplifier duplexers) business exceeding expectations with higher-than-expected costs since there is significant outsourced filter content. In addition, early yields on high-volume quadplexers for China were below plan.

Operating expenses were $168.6m, up from $142.9m last quarter due mainly to higher R&D expenses, increased variable compensation expense, and the addition of GreenPeak. The higher R&D expense reflects increased investment in high-performance filter designers, SAW and BAW process engineers, and associated material costs for prototypes.

Operating income was $167.6m (operating margin of 24% of sales), up from $160.6m last quarter. Net income rose from $142.6m ($1.04 per diluted share) last quarter to $143.1m ($1.08 per diluted share, above the expected $1.05).

Cash flow from operations fell from $160.5m last quarter to $59m.

Meanwhile, capital expenditure has risen from $84.4m last quarter to $130m, primarily to address growing demand for premium filters. Hence, during the quarter, cash and short-term investments fell from $613m to $447m.

During the June quarter, Qorvo completed its $500m accelerated share repurchase (ASR), retiring an additional 400,000 shares, with $250m remaining available under the firm's $1bn share repurchase program authorized last November. Qorvo has repurchased $1.3bn of shares in the last five quarters.

Across all of Mobile Products, customer order activity strengthened throughout the June quarter with many orders placed well within lead times. Through the month of July, order activity in Mobile remained very strong. "It's clear to us the demand for broadband data continues to increase, with the effect amplified for RF suppliers as content per device experience," says Bruggeworth.

"In the June quarter, Qorvo saw customer order activity accelerate as the quarter progressed," notes Bruggeworth. "In the September quarter, we continue to see strong demand in support of this year's most popular devices, and we are rapidly expanding our capabilities to develop new highly integrated solutions for large customer opportunities launching in 2017 and 2018."

For the September 2016 quarter (including about $6-7m from GreenPeak), Qorvo expects revenue to grow to $820–850m, reflecting strong broad-based demand (although most of the growth is coming from Mobile). Gross margin should fall to about 47% (and remain near the Q2 level through the rest of the year based on the low-band product mix and while the firm's fab conversions are underway). Diluted earnings per share (EPS) should be $1.35–1.45.

In the September quarter, Qorvo expects its OpEx to trend down through second-half 2016, reaching the goal of about 20% of sales and sustaining that performance through the December quarter as some spending falls off and productivity programs continue. Full-year fiscal 2017 CapEx should be about 15% of sales.

"Qorvo today is the number-one or number-two player in the majority of our growth markets, and we are investing to extend our leadership," says Bruggeworth. "We are building a technology moat to maintain leadership where we are number one, and where we are number two, we are investing to advance from a challenger to the leader," he adds.

Two major initiatives are underway: (1) leveraging BAW filter assets; and (2) establishing filter independence. "We expect these initiatives to support margin expansion early next year, as new customer programs ramp," says Bruggeworth.

"Our BAW products are closing in on state-of-the-art performance and we're on a measured pace to add capacity needed to meet expected customer demand for premium filters," says chief financial officer Mark J. Murphy. "A large number of productivity projects are underway including conversion to 8" BAW wafers in our Texas fab and 6" SAW on our Florida fab, conversion of our North Carolina fab to TC-SAW and SAW (starting with 6" wafers), consolidation of our GaAs capacity into Oregon, migration of GaN from North Carolina to Texas, and an additional Mobile Products assembly & test capacity in China," he adds. "We expect these new product capabilities, capacity additions, and productivity initiatives to help us sustain above-market growth and drive margin expansion."

CapEx should remain elevated as Qorvo aligns capacity additions with stronger customer demand for premium filters and integrated modules.

"Upon transition to more integrated modules with Qorvo-produced filters and completion of our fab conversions, we expect gross margin to expand," says Murphy.

On the design front, Qorvo's GaN PAs were selected by a major infrastructure provider for a massive MIMO active antenna system. Two global wireless infrastructure manufacturers selected the firm's 28GHz 5G base-station GaN PAs and a major infrastructure provider selected its 2.6GHz PA, LNA and switch for pre-5G MIMO deployment. In connectivity, Qorvo saw strong momentum in CPE Wi-Fi, particularly 5GHz.

"The expanding market requirements for carrier aggregation and 5G among others will favor our unique competitive strengths, and we expect this to support strong longer-term dynamics and improving visibility into our growth drivers," says Bruggeworth. "Only Qorvo delivers a comprehensive portfolio of filters, switches, amplifiers, PMICs, LNAs and tuners with the scale, integration capabilities and system-level expertise to supply an expanding variety of highly integrated solutions," he claims.

www.qorvo.com

All proposals approved at Qorvo stockholders' annual meeting

Qorvo, says that all agenda items were approved at its 2016 Annual Meeting of Stockholders.

The proposals were as follows:
(1) election of 10 directors to serve a one-year term;
(2) approval, on an advisory basis, of the compensation of the firm's named executive officers;
(3) reapproval of the company's cash bonus plan, including the material terms of the performance goals; and
(4) ratification of the appointment of KPMG LLP as Qorvo's independent registered public accounting firm for the fiscal year ending 1 April 2017.

Skyworks' revenue falls less than expected, despite largest customer's inventory adjustment

For fiscal third-quarter 2016 (to 1 July), Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) has reported revenue of $751.7m, slightly exceeding the $750m guidance but down 3% on $775.1m last quarter and 7.2% on $810m a year ago, impacted as expected by a one-time inventory adjustment at a large customer in Asia (driving up Skyworks inventory from $323.9m last quarter to $437.6m). Excluding Skyworks' largest customer, revenue is up 10–12% year-on-year.

Of total revenue, integrated mobile systems (IMS) comprised 55%, broad markets 29%, and power amplifiers (PAs) 16%.

"We delivered above-guidance results in the quarter, driven by increasing global demand for high-speed connectivity coupled with strong operational execution," says president & CEO Liam K. Griffin.

On a non-GAAP basis, gross margin was 50.9%, slightly below the 51% guidance (despite the higher revenue level and broad markets doing better) but up from 50.8% last quarter and 49% a year ago.

Operating expenses were $107.6m (below the expected $108.5m). This was up on $101.3m a year ago but cut from last quarter's $108.6m.

Operating income has fallen further, from $295.4m (operating margin of 36.5%) a year ago and $285m (operating margin of 36.8%) last quarter to $274.7m (operating margin of 36.5%). Likewise, net income has fallen from $262.5m ($1.34 per diluted share) a year ago and $242.3m ($1.25 per diluted share) last quarter to $238.1m ($1.24 per diluted share, although $0.03 over the $1.21 guidance).

Cash flow from operations was $141m (down further, from $154.5m last quarter and $222m a year ago). Though still down on $108m a year ago, capital expenditure (CapEx) has rebounded from $37m last quarter to $57m, with depreciation of $54.6m. During the quarter, Skyworks returned over $240m of cash to shareholders via dividends and the repurchase of 3 million shares of common stock. Hence, overall, cash and cash equivalents fell from $1177m to $973.7m.

"Our highly integrated solutions are enabling a broad array of applications, ranging from streaming media to e-commerce to cloud-based services," says Griffin. "Specifically, we are capturing performance-driven content gains within the world's premium mobile platforms while expanding our customer and end-market reach across the Internet of Things."

"We continued to gain broad market traction," notes Griffin. Business highlights of the quarter included:

- supporting Huawei's P9 smartphone platform (incorporating 10 unique devices including SkyOne systems across low, mid and high bands);
- launched advanced carrier aggregation capabilities across a suite of premium and value tier smartphone OEM accounts (including Samsung, Motorola as well as Oppo, Vivo and ZTE);
- ramping SkyBlue technology (enabling enhanced power management and LED flash drivers);
- commencing volume production of proprietary diversity receive solutions;
- expanding the antenna tuning portfolio (enabling higher data rates and smaller footprints);
- securing telematics design wins at Continental for 4G LTE automotive systems;
- capturing digital attenuator and multimode repeater design wins at Audi;
- releasing Bluetooth Low Energy long-range modules for industrial applications;
- enabling connectivity within leading always-listening virtual assistant platforms;
- supporting the world's first head cam with LTE connectivity and 4K streaming video;
- powering enterprise radios for the Google 3.5GHz-band ecosystem; and
- surpassing 2 billion cumulative shipments of filters from the Panasonic joint venture.

"These major wins and others demonstrate our expanding customer and end-market reach across both mobile platforms and the Internet of Things," says Griffin. "Accordingly, we are planning for sustained market outperformance with operating leverage and strong cash flow generation," he adds.

"Based on our broad market traction and new program ramps as well as analog and mixed-signal content gains, we expect a strong second half of 2016 with further operational improvements," says chief financial officer Donald W. Palette. For fiscal Q4/2016, Skyworks expects revenue to be up 10–11% sequentially to $831m. Gross margin should be 51%, up from 50% a year previously (even with a lower revenue base) but roughly flat quarter-to-quarter (despite revenue rising). Both R&D and SG&A expenses should be level sequentially. Diluted earnings per share should rise to $1.43.

"The double-digit revenue growth we expect in Q4, followed by continued growth into our first fiscal quarter, will reduce inventory," says Palette. "We have level loaded our factories and positioned ourselves well to address a series of new filter-rich program ramps with leading customers," he adds. By the March-quarter 2017, Skyworks should see a return to year-on-year growth.

"Given the confidence in our business model and plans to enhance cash returns to our shareholders, we are separately announcing that our board of directors has authorized an 8% dividend increase and a new $400m stock repurchase program," notes Palette.

www.skyworksinc.com

Skyworks acquires remaining stake in filter joint venture with Panasonic

Skyworks Solutions Inc of Woburn, MA, USA (which makes analog and mixed-signal semiconductors) says that, for $76.5m, it has acquired the remaining 34% stake that it did not already own in the filter joint venture it created with Japan's Panasonic in 2014. The acquisition is not expected to impact Skyworks' consolidated financial statements, as operations have been consolidated with Skyworks' financial statements since the date of the initial joint venture.

Skyworks says that at the core of the joint venture was Panasonic's engineering and process talent, expertise in filter design and leading-edge products, as well as 412 fundamental filter patents and patent applications for surface acoustic wave (SAW) and temperature-compensated (TC) SAW devices. In August 2015, Skyworks expanded its production capacity with the addition of a 405,000ft^2 facility in Osaka to help meet the growing demand for highly integrated solutions leveraging filter technology. To date, total production has exceeded more than 2 billion filters.

"With this acquisition, Skyworks has strengthened its leadership position as one of the world's largest providers of high performance, integrated-filter solutions," reckons Skyworks' president & CEO Liam K. Griffin. "Given the proliferation of frequency bands, the addition of LTE capabilities and market demand for always-on connectivity, the need for filters has never been higher," he adds. "Our strategic investment uniquely enables us to deliver end-to-end solutions for some of the fastest-growing and most demanding applications in the world requiring high-performance filter technology. Together with external partners, we are successfully addressing the low-, mid- and high-band performance requirements across premium smartphones and IoT applications."

According to a recent report from Research and Markets, the global radio frequency filter market is expected to grow at a compound annual growth rate (CAGR) of 15% during 2016–2020, and the rise in the number of frequency bands, modulation schemes and power amplifier modes to support increased mobile data traffic is resulting in high RF front-end complexity.

www.skyworksinc.com

Skyworks launches Wi-Fi, Bluetooth, ZigBee RF switches

Skyworks has launched two new Wi-Fi switches suitable for WLAN networks, repeaters, ISM-band radios, Bluetooth systems, smartphones, and connectivity modules.

The SKY13585-679LF is a SPDT (single-pole double-throw) switch intended for 1–6GHz applications, maintaining low insertion loss and high isolation for all switching paths. The SKY13586-678LF is a SP3T (single-pole triple-throw) antenna switch for 2.4GHz Wi-Fi applications.

The new devices offer wide 3–5V supply range and are compatible with 1.8V or 3.3V control logic. They require fewer control signals from industry-standard SP2T and SP3T solutions and include integrated DC blocking capacitors, so no external DC blocking capacitors are required. They also feature what is said to be high-linearity performance and low insertion loss, making them suitable for transmit/receive applications.

The switches are available in ultra-miniature 1x1 and 1.1 x 1.1 packages (6-or 8-pin), saving application board space and cost for OEMs.

www.skyworksinc.com/products_switches.aspx

Skyworks launches RF switches for connected home applications

Skyworks has launched two RF switches suitable for the Internet of Things (IoT) applications including the connected home.

In addition to the connected home, the SKY13587-378LF, which is a gallium arsenide (GaAs) pseudomorphic high-electron-mobility transistor (pHEMT) single-pole dual-throw (SPDT) switch, can be used for transmit and receive switching in industrial, lighting and smart energy applications, as well as 802.11a/b/g/n WLAN networks that operate at 2.4GHz and 5.8GHz. The SKY13588-460LF is a CMOS silicon-on-insulator (SOI) single-pole triple-throw (SP3T) switch made for antenna selection in Wi-Fi applications in IoT systems.

The new switches have an operating temperature range up to 105°C, making them suitable for applications that require extended temperature. They also boast high isolation and low insertion loss, which is best for low-power transmit/receive applications. Their positive voltage control provides low current and optimal efficiency for battery-operated IoT applications, says Skyworks. Their broadband frequency ranges from 20MHz to 6.0GHz (SKY13587-378LF) to 0.1 to 6.0GHz (SKY13588-460LF).

These devices are available in compact MLPD/QFN packages (6-or 12-pin), saving application board space and design cost for OEMs.

www.skyworksinc.com/products_IoT.aspx

Aemulus and Peregrine partner to develop microwave frequency tester

Peregrine Semiconductor Corp of San Diego, CA, USA — a fabless provider of radio-frequency integrated circuits (RFICs) based on silicon-on-insulator (SOI) — has announced a strategic partnership with automated test equipment (ATE) firm Aemulus Corp of Penang, Malaysia to develop a new microwave frequency tester. Building on Aemulus' Amoeba AMB7600 RF tester, the next-generation test solution will extend its support into microwave frequency bands and enable more complex testing.

"This Aemulus microwave tester is the latest project in a series of successful collaborations with Peregrine," notes Aemulus' CEO Sang Beng Ng. "This new tester will not only contribute to growth in test & measurement, but I foresee many opportunities flowing in from other markets with high-frequency demands, such as automotive, radar and 5G wireless," he adds.

"With this strategic partnership, we look forward to duplicating the success of previous collaborative projects."

For the new tester, the Amoeba AMB7600 will be upgraded with key peripheral modules to expand into microwave bands X, Ku and Ka. The AMB7600 is claimed to be the first true multi-site, multi-instance RF tester, and it supports RF, digital and analog testing. While the AMB7600 addresses RF front-end devices, the new tester will enable more complex testing, such as the rigorous testing needs of radar products and mixers. Currently in design development, the new tester will be integrated into Peregrine's test infrastructure in fall 2016 and will have full implementation by spring 2017.

"As the market demand for high-frequency products increases, Peregrine has responded with a robust high-frequency product portfolio and has set new records for SOI at microwave frequencies," claims Carl Tulberg, principal engineer, NPI operations at Peregrine. "But this innovation must be supported by a sophisticated test infrastructure and that boils down to the right test equipment," he adds. "This Aemulus partnership aligns with our product roadmap and ensures we meet our microwave test equipment needs today and in the future. It also highlights Peregrine's focus and investment in high-frequency product development."

Peregrine's high-frequency portfolio includes RF switches, an image-reject mixer and monolithic phase and amplitude controllers (MPACs). The firm says it is its UltraCMOS technology platform that enables it to reach these high frequencies without compromising performance or reliability.

www.aemulus.com

Peregrine appoints general manager of High Performance Analog

Peregrine has promoted Takaki Murata to VP & general manager of its high-performance analog (HPA) business unit.

"Peregrine Semiconductor was acquired by Murata in December of 2014, and they have proven to be a powerful and supportive parent company," notes CEO Jim Cable. "Takaki has been preparing for this promotion for the last year and a half, as he served on the executive staff of our HPA business," he adds. "The timing of this promotion reflects the success of our integration and the logical next step to further our assimilation into the Murata family of companies."

Takaki has a Ph.D. in electrical engineering and 12 years of experience at Murata, in a range of different assignments including: LTCC material development, SAW (surface acoustoc wave) filter development, antenna sales engineering, RF front-end sales engineering, corporate accounting and inductor business strategic planning. Since early 2015, he has been VP of business development inside HPA.

"Murata is looking to Peregrine to provide semiconductor innovation to be applied to the Murata advantage in our growth markets of power, automotive, healthcare and 5G," says Norio Nakajima, executive VP communication and sensor business unit, and energy business group of Murata Manufacturing Co. "We have heavily invested in Peregrine because we see their technological advantage as critical to many of our new and growth initiatives," he adds. "Takaki is ideally suited to his new position because of his technological expertise and his deep and long history with Murata Manufacturing."

Since its purchase by Murata in December 2014, Peregrine has increased staffing by 40%. "The continued investment in Peregrine by Murata is an indicator of the significance that it places on our technology and innovation," says Cable.

The HPA business unit serves over 4000 customers in end markets ranging from wireless infrastructure and wired broadband to test & measurement, automotive and aerospace. Recently, it launched its first product in the power/energy market. Products include RF switches, digital step attenuators (DSAs), digitally tunable capacitors (DTCs), tuning control switches, power limiters, phase-locked loops (PLLs), mixers, pre-scalers, DC–DC converters, monolithic phase and amplitude controllers (MPACs) and what is claimed to be the fastest GaN FET driver available.

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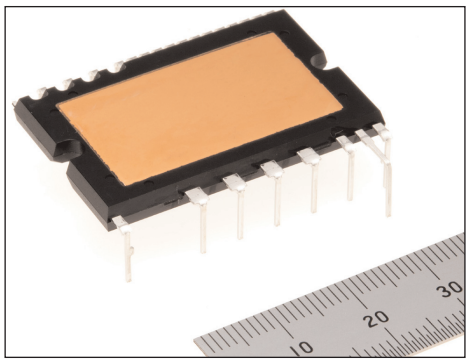
Mitsubishi Electric launches super-mini full-SiC DIPIPM for air conditioners

Tokyo-based Mitsubishi Electric Corp has launched the new PSF15S92F6 15A/600V transfer-mold power semiconductor model in its lineup of super-mini dual-in-line package intelligent power modules (DIPIPM), with embedded silicon carbide metal-oxide-semiconductor field-effect transistors (SiC-MOSFETs).

The module includes a three-phase inverter bridge with built-in SiC-MOSFET, HVIC, LVIC and bootstrap diode chips. Other functions include short-circuit protection (using an external shunt resistor), control power supply under-voltage protection (Fo output on N-side protection), and an analog temperature voltage output function.

The new module features low power consumption, optimized for home appliance applications such as high-grade energy-efficient air conditioners. The SiC-MOSFET reduces power consumption by about 70% compared with Mitsubishi Electric's existing super-mini DIPIPM, contributing to an overall reduction in air conditioner power consumption.



Mitsubishi Electric's new PSF15S92F6 15A/600V transfer-mold super-mini DIPIPM module.

The module also allows a simplified inverter system design. The footprint (24.0mm x 38.0mm x 3.5mm) and pin configurations are compatible with Mitsubishi Electric's existing super-mini DIPIPM Ver.6 (PSSxxS92x6series,etc). Also, designed with a high threshold voltage, SiC-MOSFET does not require a negative bias circuit, allowing simplification of the system design. Finally, there are fewer external components due to the use of an embedded bootstrap diode with a current-limiting resistor.

Mitsubishi Electric commercialized its first DIPIPM transfer-mold intelligent power module in 1997, the beginning of its ongoing effort targeting miniaturization and energy saving in inverter systems. Development of the new DIPIPM was partially supported by Japan's New Energy and Industrial Technology Development Organization (NEDO). The new PSF15S92F6 module is compliant with the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) directive 2011/65/EU.

www.MitsubishiElectric.com

EPC publishes reliability report after 8 million GaN device hours of stress testing

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA — which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications — has announced its Phase Eight Reliability Report, showing the results of the rigorous set of JEDEC-based qualification stress tests that eGaN FETs and integrated circuits undertake prior to being considered qualified products.

Product-specific detailed stress test results for over 8 million actual device hours are provided, showing zero failures. In addition to product qualification stress testing, due diligence is necessary in other areas of reliability such as field experience, failures over device operational lifetime, and board level reliability, says EPC. More specifically, the three sections of tests covered in the Phase Eight Reliability Report are:
I: Field Reliability Experience (examining field failures, assembly failures, applications failures, and intrinsic die qualification);
II: Early Life Failure and Wear-out Capability (early life failure rate, and electro-migration);
III: Board Level Reliability and Thermo-mechanical Capability (intermittent operating life, temperature cycling, and board-level reliability).

EPC says that the report, coupled with the field reliability of eGaN FETs and ICs given in the Phase Seven Reliability Report — which documented the accumulation of over 17 billion device operation hours combined with a very low failure rate below 1 FIT (failures per billion hours) — demonstrates that the stress-based qualification testing is capable of ensuring reliability in customer applications. The cumulative reliability information shows that eGaN FETs and ICs have solid reliability and are able to operate with very low probability of failures within reasonable lifetimes of end products manufactured today, adds the firm.

"Demonstration of the reliability of new technology is a major undertaking and one that EPC takes very seriously," comments EPC's CEO & co-founder Dr Alex Lidow. "The tests described in this report, along with the reported results, show that EPC gallium nitride products have the requisite reliability to displace silicon as the technology of choice for semiconductors."

www.epc-co.com

Hexagonal boron nitride enables cost-effective, compact solid-state detection of neutron signals

Record-efficiency semiconductor thermal neutron detector could replace helium gas for nuclear weapon detection

A group of Texas Tech University researchers led by professors Hongxing Jiang and Jingyu Lin has developed hexagonal boron nitride semiconductor as a possible low-cost alternative to helium gas detectors in neutron detection ('Realization of highly efficient hexagonal boron nitride neutron detectors' by A. Maity, T.C. Doan, J. Li, J.Y. Lin and H.X. Jiang, Applied Physics Letters 109, 072101 (2016)).

To prevent terrorists from smuggling nuclear weapons into its ports, the US Security and Accountability for Every Port Act mandates that all overseas cargo containers be scanned for possible nuclear materials or weapons by using detectors containing helium-3 gas, as detecting neutron signals is an effective method to identify nuclear weapons and special nuclear materials. However, while helium-3 gas works well for neutron detection, it is extremely rare on Earth. Demand for helium-3 gas detectors has nearly depleted the supply, most of which was generated during the period of nuclear weapons production over the past 50 years. It is not easy to reproduce, and the scarcity of helium-3 gas has caused its cost to rise recently, making it impossible to deploy enough neutron detectors to fulfill the requirement to scan all incoming overseas cargo containers. Helium-4 is a more abundant form of helium gas, which is much less expensive, but it cannot be used for neutron detection because it does not interact with neutrons.

The Texas Tech group's alternative concept was first proposed to the US Department of Homeland Security's Domestic Nuclear Detection Office and received funding from its Academic Research Initiative program six years ago.

By using a 43μm-thick hexagonal boron-10 enriched nitride layer (h-10BN), the group created a thermal neutron detector with 51.4% detection efficiency, which is a record for semiconductor thermal neutron detectors. "Higher detection efficiency is anticipated by further increasing the material thickness and improving materials quality," says professor Jiang of the Nanophotonics Center and Electrical & Computer Engineering at Texas Tech University's Whitacre College of Engineering.

"Our approach of using hexagonal boron nitride semiconductors for neutron detection centers on the fact that its boron-10 isotope has a very large interaction probability with thermal neutrons," Jiang says. "This makes it possible to create high-efficiency neutron detectors with relatively thin hexagonal boron nitride layers. And the very large energy bandgap of this semiconductor (6.5eV) gives these detectors inherently low leakage current densities," he adds.

Large energy bandgap gives these detectors inherently low leakage current densities

"Compared to helium gas detectors, boron nitride technology improves the performance of neutron detectors in terms of efficiency, sensitivity, ruggedness, versatile form factor, compactness, lightweight, no pressurization… and it's inexpensive," Jiang continues. "Beyond special nuclear materials and weapons detection, solid-state neutron detectors also have medical, health, military, environment and industrial applications," he adds. "The material also has applications in deep-ultraviolet photonics and two-dimensional heterostructures. With the successful demonstration of high-efficiency neutron detectors, we expect it to perform well for other future applications."

The main innovation behind this new type of neutron detector was developing hexagonal boron nitride with epitaxial layers of sufficient thickness — which previously did not exist, say the researchers. "It took our group six years to find ways to produce this new material with a sufficient thickness and crystalline quality for neutron detection," Jiang notes. Based on their experience working with III-nitride wide-bandgap semiconductors, the group knew at the outset that producing a material with high crystalline quality would be difficult. "It's surprising to us that the detector performs so well, despite the fact that there is still a little room for improvement in terms of material quality," he said.

One of the most important impacts of the group's work is that "this new material and its potential should begin to be recognized by the semiconductor materials and radiation detection communities," Jiang believes.

Now that the group has solved the problem of producing hexagonal boron nitride with sufficient thickness, as well as crystalline quality, to enable the demonstration of neutron detectors with high efficiency, the next step is to demonstrate high sensitivity of large-size detectors. "These devices must be capable of detecting nuclear weapons from distances tens of meters away, which requires large-size detectors," Jiang says. "There are technical challenges to overcome, but we're working toward this goal."

http://scitation.aip.org/content/aip/journal/apl/109/7/10.1063/1.4960522

www2.ece.ttu.edu/nanophotonics

Dialog enters GaN market with integrated devices targeting fast-charging power adapters

UK-based fabless IC firm using TSMC's 650V GaN-on-Si process

Dialog Semiconductor plc of London, UK, a fabless provider of highly integrated power management, AC/DC power conversion, solid-state lighting (SSL) and Bluetooth low-energy technology, has announced its first gallium nitride (GaN) power IC product, using the 650V GaN-on-silicon process technology of Taiwan Semiconductor Manufacturing Corp (TSMC, the world's biggest silicon wafer foundry).

Together with Dialog's patented digital Rapid Charge power conversion controllers, the SmartGan DA8801 can enable more efficient, smaller and higher-power-density adapters compared with existing traditional silicon field-effect transistor (FET)-based designs. Dialog is initially targeting its GaN solutions at the fast-charging smartphone and computing adapter segment, where it already enjoys more than 70% market share with its power conversion controllers.

"The exceptional performance of GaN transistors allows customers to deliver more efficient and compact power adapter designs that meet

today's market demands," comments Mark Tyndall, senior VP corporate development & strategy. "Following our success in BCD [bipolar-CMOS-DMOS]-based power management ICs (PMICs), as an early GaN innovator, Dialog once again leads the commercialization of a new power technology into high-volume consumer applications," he adds.

The DA8801 half-bridge integrates building blocks such as gate drives and level-shifting circuits with 650V power switches to deliver an optimized solution that reduces power losses by up to 50%, with up to 94% power efficiency, says Dialog. The firm adds that the product allows seamless implementation of GaN, avoiding the complex circuitry that is needed to drive discrete GaN power switches.

The new technology also allows a reduction in the size of power electronics by up to 50%, enabling an existing typical 45W adapter design to fit into a 25W or smaller form factor. This reduction in size will enable true universal chargers for mobile devices, Dialog reckons.

"As Dialog's strategic foundry partner for power management ICs for many years, we are delighted to have expanded our relationship to collaborate closely in bringing our GaN process to the mainstream consumer market for high-volume applications," says Maria Marced, president of TSMC Europe. "Dialog's first GaN product delivers on the promise of GaN while bringing the integration to a higher level."

The DA8801 will be available in sample quantities in Q4/2016.

www.dialog-semiconductor.com

Advantech's new generation of GaN solid-state power amplifiers powers live Ultra HD TV transmission over satellite

Advantech Wireless Inc of Montreal, Canada (which manufactures satellite, RF equipment and microwave systems) has launched a new generation of gallium nitride (GaN)-based solid-state power amplifiers (SSPAs) with a number of improvements to empower live Ultra HD TV transmission over satellite by providing what is claimed to be higher performance and reliability, the smallest form factor, and the lowest power consumption.

The units are designed for 4K/8K Ultra HD transmission broadcasting and are DVB-S2X ready, providing a 70% increase in linear transmit power, high linearity and reliability with a fraction of the size, weight and power.

"Our new generation of GaN-based SSPAs delivers the best solution for DSNG applications in terms of performance, quality and overall cost of ownership," claims VP business development Cristi Damian. "The SapphireBlu Series of GaN-based SSPAs have enabled Ultra HD TV transmissions for some of the largest and most popular sporting events," he adds. "Due to the combination of our Ku-band Ultra-Linear GaN-based SSPA system with Advantech Wireless' 13m A-Line Antenna deployed in a major DTH uplink system in Latin America, millions of viewers worldwide have been able to follow the live transmissions of international sporting events."

Advantech Wireless exhibited at the SET Expo 2016 broadcast and new media technology trade show & conference in Sao Paulo, Brazil (30 August to 1 September).

www.advantechwireless.com
www.setexpo.com.br

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GaN Systems' co-founders to retire

GaN Systems Inc of Ottawa, Ontario, Canada, a fabless developer of gallium nitride (GaN)-based power switching semiconductors for power conversion and control applications, says that, ten years after launching the firm, its two Ottawa-based co-founders president Girvan Patterson and chief technology officer John Roberts have announced their retirement.

Having achieved their goal of building GaN Systems into a manufacturer of GaN power transistors and supplier to more than 500 customers, serial entrepreneurs Patterson and Roberts will leave their operating roles. Patterson will retain a position on GaN Systems' board of directors, while Roberts will remain available to the company as an emeritus contributor.

Prior to starting GaN Systems, both Roberts and Patterson had extensive experience in the semiconductor industry, each with careers launching new companies. Roberts was founder & president of two Ottawa-based semiconductor companies: Calmos (later Tundra) Semiconductor and SiGe Semiconductor. Patterson founded graphics workstation producer Orcatech and co-founded Plaintree Systems, a pioneer in Ethernet switching. Together, Patterson and Roberts have taken a dozen companies either to an IPO or acquisition.

Patterson and Roberts.

"I am honored to have presided over a company that has delivered a core technology for achieving the energy efficiency the world needs, by making electronic systems more efficient, lighter and compact," says Patterson. "Saving a data center millions of dollars in energy costs or enabling hybrid vehicles to dramatically increase miles per gallon fuel efficiency is very satisfying as well as very important in today's world," he adds. "I am immensely grateful to our early investors who had sufficient faith in us to allow us to lead the company to this stage… It is time to transition leadership to the team that will take revenue to $100m."

"It is very satisfying to see our customers' products — batteries charging in minutes instead of hours, Internet server racks with more Terabytes per second of data, cars with extended range, and motors with tiny embedded electronics — all because of our transistors," says Roberts. "I look forward to watching GaN Systems team continue to bring efficiencies to power system designers."

"Founders Girvan Patterson and John Roberts both are visionary leaders who together have successfully navigated the development of GaN Systems' product development, manufacturing and quality processes," comments CEO Jim Witham. "They built a robust product portfolio, established the supply chain, and signed on a world-class global distribution and support channel," he adds. "Under their stewardship, for the first time wide-bandgap power devices have enabled power systems with vastly superior performance and lower cost than was possible with silicon."

www.gansystems.com

Raytheon shows US Army GaN-based AESA radar targeted at Lower Tier Air and Missile Defense Sensor

Raytheon Company of Waltham, MA, USA has given the US Army a look into the future of missile defense technology, as the firm provided its comprehensive vision for the next generation of air and missile defense radar. The information was supplied to the Army as part of its process to define the requirements for a future Lower Tier Air and Missile Defense Sensor (LTAMDS).

"Raytheon's solution for the LTAMDS is based on the more than $200m that the company has invested in gallium nitride (GaN)-powered active electronically scanned array (AESA) technology," says Ralph Acaba, VP of Integrated Air and Missile Defense at Raytheon's Integrated Defense Systems business. "Raytheon showed it can quickly and affordably design, build, test and field a GaN-based AESA radar capable of defeating all threats when we exhibited a potential LTAMDS solution at the winter AUSA tradeshow this past March."

Raytheon's GaN-based AESA LTAMDS radar is designed to serve as a sensor on the Integrated Air and Missile Defense Battle Command System network. It will be fully interoperable with NATO, and also retains backwards compatibility with both the current Patriot system and any future system upgrades fielded by any of the 13 nations that currently own Patriot.

"Others may draw on lesson learned from the terminated MEADS air and missile defense project or repeatedly re-baselined naval radars; Raytheon's LTAMDS solution builds on successful programs such as the US Navy's Next Generation Jammer and the Air and Missile Defense Radar," says Doug Burgess, director of Integrated Air and Missile Defense AESA programs. "Our response, and our AESA GaN radar rollout at AUSA, show there doesn't need to be a wait of a decade or longer to get the sensor of the future. It will be available much, much sooner."

www.raytheon.com

Imperial College London wins GaN Systems Geoff Haynes Future Power Challenge

In a ceremony at the UK Engineering & Physical Sciences Research Council (EPSRC) National Centre for Power Electronics Annual Conference 2016 in Nottingham, UK, a post-graduate team from Imperial College London received the £2000 prize for winning the first annual GaN Systems Geoff Haynes Future Power Challenge.

Sponsored by GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications), the competition was open to all UK power electronics postgraduate students who submitted research papers or posters that contributed to accelerating the use of GaN transistors in future power conversion or control applications.

Professor Mark Johnson of the University of Nottingham and professor Barrie Mecrow of Newcastle University judged the competition at the annual summer school event organized by the PhD students of the 10 universities that form the EPSRC National Centre for Power Electronics.

The summer school is a student-led event intended to increase communication and co-operation between the research teams and to provide an opportunity for the students to meet with prospective employers and research partners. Entries covered subjects as diverse as the design of a novel compact motor with embedded filter windings, through a reliability study and optimized PWM (pulse width modulation) control strategy for an A-NPC (active neutral-point-clamped) converter.

Ph.D. students George Kkelis and Juan Arteaga together with research assistants Sam Aldhaher and David Yates of Imperial College London's Department of Electrical and Electronic Engineering, supervised by Dr Paul Mitcheson, first presented their work at the IEEE Wireless Power Transfer Conference in May. The team developed two inverter prototypes, each based on a Class EF topology using GaN Systems' GS66504B switches. Their new design maintains zero-voltage switching and delivers a constant-output AC current regardless of the load resistance value. The design allows a Class E or Class EF inverter to operate efficiently for any load. This was shown to significantly relax the requirement for accurate alignment of transmit and receive coils in a wireless power application.

The annual GaN Systems Geoff Haynes Future Power Challenge was established in recognition of Geoff Haynes' critical role in establishing GaN Systems, and championing the use of gallium nitride for power applications. Geoff Haynes retired last year as vice president of GaN Systems but continues to drive the application of the technology by engaging with the research activities of the engineers of the future.

GaN Systems' president & co-founder Girvan Patterson underlined the importance of supporting the research initiatives between industry and academia to speed the adoption of disruptive technologies and inspire a new generation of engineers.

www.gansystems.com
www.powerelectronics.ac.uk

Fairview launches portfolio of gallium nitride solid-state power amplifiers offering high power and gain across up to 7.5GHz

Fairview Microwave Inc of Allen, TX, USA, which supplies on-demand microwave and RF components, has launched a new line of gallium nitride (GaN) solid-state amplifiers, offering designers what is claimed to be a unique solution of off-the-shelf, in-stock components that typically require months of lead time to acquire.

The rugged connectorized amplifier designs have high output load impedance, offering easier impedance matching over wider bandwidths using lower-loss components. The high thermal conductivity of GaN helps to dissipate heat more effectively, resulting in amplifier designs with much higher output power levels over broadband and narrowband frequencies. Common applications include commercial and military radar, jamming systems, medical imaging, communications, and electronic warfare.

Fairview's newest range of GaN RF amplifiers includes models with very high gain levels from 43dB to 60dB across mostly broad frequency bands ranging from 30MHz to 7.5GHz. Saturated output power levels range from 10W to 100W with up to 35% power-added efficiency (PAE). All of the high-power GaN amplifiers have single voltage supplies that are internally regulated. The 50Ω input/output-matched designs are adaptable to a range of power and modulation requirements. The GaN solid-state power amplifiers also show harmonic response of –15dBc to –20dBc, under worst-case conditions. The new GaN amplifiers are designed to withstand environmental conditions such as humidity, altitude, shock and vibration. Some models are also equipped with integrated heat-sinks and cooling fans. Most designs are EAR99.

www.fairviewmicrowave.com/rf-products/gan-power-amplifiers.html

EpiGaN nominated for EU Innovation Radar Prize

EpiGaN nv of Hasselt, near Antwerp, Belgium, which supplies commercial-grade 150mm- and 200mm-diameter gallium nitride on silicon (GaN-on-Si) epitaxial wafers for 600V high-electron-mobility transistor (HEMT) power semiconductors, has been shortlisted along with 10 European firms participating in European Union (EU)-funded projects such as Horizon 2020 to compete for the EU Innovation Radar Prize 2016 in the category 'Industrial and Enabling Tech'. Public voting for the winner closes on 31 August. The 16 finalists chosen will present their achievements at the ICT Proposers Day in Bratislava, Slovakia on 26 September.

Incorporated in 2010, EpiGaN was founded by chief executive officer Dr Marianne Germain, chief technology officer Dr Joff Derluyn and chief operating officer Dr Stefan Degroote as a spin-off of nanoelectronics research center Imec of Leuven, Belgium. The founders jointly developed GaN-on-Si technology at Imec, part of which has been licensed to EpiGaN.

In 2011, EpiGaN was joined by start-up investment firms Robert Bosch Venture Capital, Capricorn CleanTech Fund and LRM to enable the installation of its wafer production facility. In June, Beijing/Brussels-based Euro-Asia private equity fund A Capital joined the initial investors to fund expansion of EpiGaN's sales and support base to Asian markets. EpiGaN is now undertaking volume production and wafer characterization at its Research Campus Hasselt in the Eindhoven–Leuven–Aachen high-tech triangle. In January, the firm signed a global representation agreement for its 150mm and 200mm GaN-on-Si power semiconductor product solutions with silicon substrate maker SunEdison Semiconductor of St. Peters, MO, USA.

EpiGaN offers GaN-on-Si and GaN-on-SiC material solutions aimed at the next generation of efficient power electronics, RF power and sensor devices and systems. Allowing drastic savings in energy loss as well as more compact and lighter power conversion systems such as power supplies, GaN technology is also in demand for its superior performance in wireless communications.

The Innovation Radar was established recently as a data-driven initiative by the EU Commission to identify high-potential European digital innovations and the key drivers behind them participating in its Seventh Framework Program (FP7), Competitiveness and Innovation Framework Programme (CIP), and Horizon 2020 projects. The EU Innovation Radar supports and guides digital innovators in assessing and highlighting their innovation and economic potential in the global market. EpiGaN says that it has been nominated because of its development of large-diameter GaN-on-Si epiwafers that enable a new generation of power electronics with much higher conversion efficiencies.

EpiGaN says that it is developing and manufacturing AlGaN/GaN structures on 200mm silicon substrates at the 600V node to enable its customers to position themselves in rapidly growing market segments, addressing the power switching market, including power supplies, solar inverters, power supplies for data centers and, in future, electric vehicles.

https://ec.europa.eu/digital-single-market/en/innovators/epigan-innovation-radar
www.epigan.com

AKHAN completes executive line-up by adding chief technology officer and chief financial officer

AKHAN Semiconductor Inc of Gurnee, IL, USA, which specializes in the fabrication and application of nanocrystalline (NCD)-based materials & devices for semiconductor and electronic applications, has completed hiring to its C-Suite positions with two new executives — Bill Alberth as chief technology officer and Kristie King as chief financial officer — joining existing chief executive officer & founder Adam Khan and chief operating officer Carl Shurboff.

Alberth has nearly 30 years of experience in the mobile device and wireless technology sector. Before joining AKHAN, he spent 25 years with Motorola Mobile Devices along with Shurboff, overseeing the architecture and commercialization of wireless LTE, CDMA, UMTS, WIFI, Bluetooth and NFC products. In 2012, he founded Innovations Technologies Consulting Inc, where he has served as president.

King has over 20 years of senior leadership experience with Motorola Mobility Inc and also Motorola Solutions Inc. She has worked with several startups and Fortune 100 companies, and has used her financial modeling skills, financial system design expertise, contract negotiation and financial management leadership to achieve these companies' business goals. King is also currently on faculty at Lake Forest Graduate School of Management, where she designed and teaches the Entrepreneurial Finance course.

"Each with a proven track record of success in technology commercialization and research-to-product deployment, their respective skills, talent, and expertise will be invaluable in growing and maintaining our global lead in diamond semiconductor," believes Khan.

www.akhantech.com

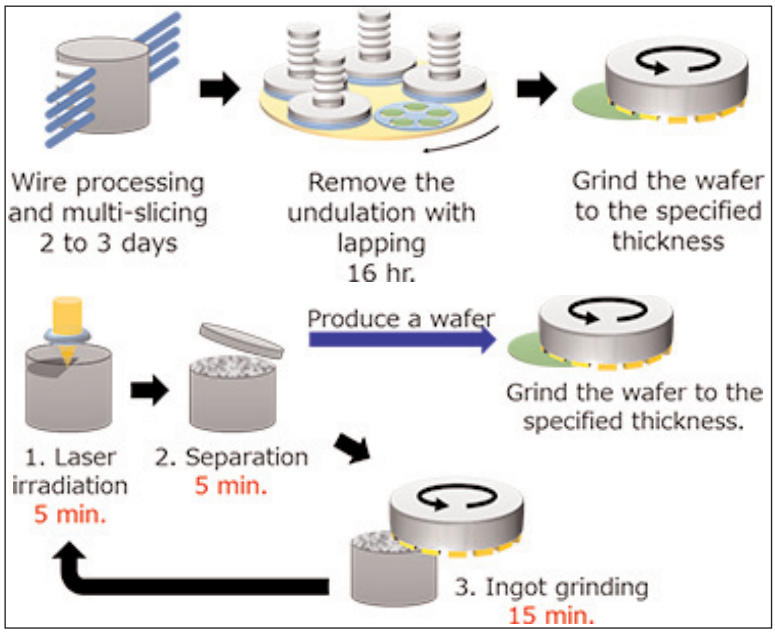
Disco develops laser ingot slicing method to speed SiC wafer production and cut material loss

Tokyo-based equipment maker Disco Corp has developed the KABRA (Key Amorphous-Black Repetitive Absorption) laser ingot slicing method. Implementing the process is said to enable high-speed production of silicon carbide (SiC) wafers, increase the number of wafers produced from a single ingot, and dramatically improve productivity.

Existing methods for slicing wafers from a silicon carbide ingot mainly use multiple diamond wire saws for mass-producing wafers because the processing time is long due to the high rigidity of SiC. The number of wafers produced from a single ingot is also small due to the large amount of material lost in the slicing sections. This has been a major factor that increases the cost of producing SiC power devices, hindering their introduction to the market and the widespread use of SiC power devices, says Disco.

The KABRA process forms a flat light-absorbing separation layer at a specified depth through irradiation with a continuous, vertical laser from the upper surface of the SiC. Conventional laser processing is not suitable for slicing, says Disco, because the modified layer formed by laser irradiation, in principle, extends in the direction of the laser incident — see Figure 1(a). However, Disco's new laser slicing method focuses on two facts: (1) SiC can be decomposed by focused continuous laser irradiation and separated into amorphous silicon (Si) and amorphous carbon (C) in an amorphous state; and (2) the light absorption coefficient is about 100,000 times larger than that of SiC.

As a result, Disco forms KABRA layers inside the ingot both vertically and in the direction of the laser incidence, establishing what is claimed to be the optimal laser slicing method — see Figure 1(b). In addition, the patent-pending process can be applied to various types of SiC ingots, including single-crystal (4H, 6H, and semi-insulating) and multi-crystal ingots.



One of the major characteristics is that the process can be applied to monocrystal ingots, regardless of the off-angle of the crystal c-axis.

Disco says that other advantages of the process include the following:

1. Processing time much reduced

Existing processes require about 2 hours to slice a wafer from a 4"-diameter SiC ingot, and 2–3 days for one ingot (when producing a specified thickness of 350μm from a 4"-diameter 20mm-thick SiC ingot). In contrast, the KABRA process can greatly reduce the processing time, it is claimed, requiring only 25 minutes to slice a wafer (about 18 hours for one ingot) in total processing time (including laser irradiation, separation, and ingot grinding). In addition, the process only takes about 30 minutes to slice a wafer from a 6"-diameter SiC ingot, even though the existing process requires over 3 hours.

2. Lapping process is no longer required

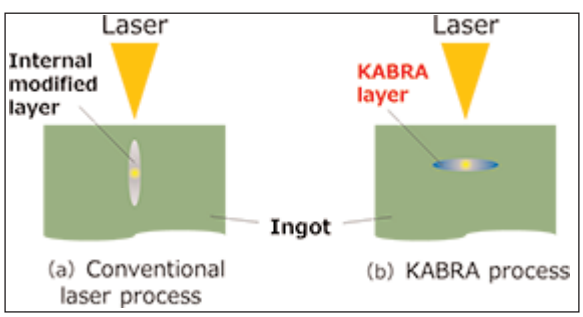
For wire processing, a lapping process is required to remove about 50μm of undulations generated on the surface of a processed wafer. However, the KABRA process does not require lapping because the wafer undulation after separation can be controlled (Figure 2), making it possible to greatly reduce the initial costs and running costs.

3. Number of wafers produced increases by 1.5x

Although wire processing produces about 200μm of material loss per wafer at the slicing sections (kerf loss), the KABRA process essentially has no material loss. In addition, the removal amount of the KABRA layer after separation can be suppressed to about 100μm. This increases the number of wafers produced from a single ingot by about 1.5x that of the existing process.

Disco is now accepting requests for test cuts, and plans a chargeable processing service. The firm will also give academic conference presentations at The Japan Society for Precision Engineering Autumn Meeting/The Japan Society of Applied Physics Autumn Meeting in September, and will exhibit KABRA equipment for the first time at the SEMICON Japan trade show (14–16 December).

www.disco.co.jp



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DISCOVER PROGRESS

AXT's second-quarter revenue up 9.6%, driving higher-than-expected profit

Fiber-optics communications continues to drive InP growth, but VCSELs expected to boost GaAs

For second-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 $20.5m, down slightly on $21m a year ago but up 9.6% on $18.7m last quarter, and at the high end of the expected $19.5–20.5m.

Of total revenue, 65% came from Asia Pacific, 22% from Europe, and 13% from North America.

Two customers generated more than 10% of revenue, and the top five generated 42% of total revenue (down from 45% three quarters ago), reflecting diversification of both products and customers.

"Q2 was another strong quarter for InP sales," notes CEO Morris Young. "Our indium phosphide revenue have grown at an average rate of more than 50% annually for the last two years [to about 30% of total revenue]." Fiber-optics communications continues to be the leading application.

Regarding GaAs, AXT saw some sequential growth in revenue from semi-insulating substrate, which have reached a relatively stable quarterly level of contribution. Semiconducting gallium arsenide also grew modestly. "The majority of our revenue continues to be driven by demand for higher-end LED applications such as backlighting, signage and automotive," says Young.

Regarding raw materials, AXT saw no substantial changes to the pricing or demand environment for its key material in Q2. "However, several China-based gallium suppliers, including two of our own joint venture companies, are in the process of scaling back production to align with market demand. In addition, others [in China] may be shutting down altogether," says Young. "Further market stabilization and eventual rebound in raw material pricing may come as a result of this decrease in volume production and as excess inventory is being consumed," he adds.

About two years ago AXT began implementing programs to reduce manufacturing costs. More recently, it has focused on increasing yield for both ingots and wafering process. "Single-crystal growth and the resultant wafer creation are highly technical and we have strengthened our proprietary process technology during this quarter," notes Young. "Over time, all these programs have begun to contribute meaningfully to our gross margin performance."

Gross margin has risen further, from a low of 20.9% a year ago and 28.1% last quarter to 29.4%. This was due to increased production volume, a favorable mix (namely, increased sales of indium phosphide substrates and other materials for high-end applications), progress in manufacturing efficiency, and yield improvements.

Operating expenses were $5.1m, level with a year ago but up from $4.8m last quarter due mainly to a one-time restructuring charge of $226,000 related to a staff reduction at one of AXT's gallium-producing joint ventures in China.

Net profit was $1.15m ($0.03 per diluted share, about $0.01 above the guidance range of breakeven to $0.02 per share), up from $42,000 last quarter and just breakeven a year ago.

Depreciation and amortization were $1.2m. Capital expenditure (CapEx) rose again, from $0.8m last quarter to $1m. With AXT generating positive cash flow during the quarter, cash, cash equivalents and investments hence rebounded by $1.6m from $43.3m to $44.9m.

"AXT remains focused on maximizing opportunities in strategic emerging areas, such as indium phosphide substrates, where we are solidly positioned with the expertise, technology and manu- ►

Relocation of Beijing manufacturing operations could be postponed

"We have recently learned that a master development plan of the area where our manufacturing facility is located has not yet been formally approved by the China Central Government and the timeline for relocating our gallium arsenide wafer production operations has not yet been determined by the China Central Government," notes AXT's chief financial officer Gary Fischer. "We believe the Central Government will undertake a comprehensive review of the master development plan, which will add time to the process. There are a number of factors that the Beijing City Government could consider that could extend the timeline for our relocation. We believe that we satisfy these factors and, accordingly, we may have some flexibility when we work with the government towards a resolution," he adds. "In addition, the Beijing City Government's Economic Development Bureau requested that we consider maintaining our indium phosphide production operations at our current site, along with our China headquarters and our R&D center."

www.axt.com

facturing capability to support further growth," says Young.

For third-quarter 2016, AXT expects revenue of $20.5–21.5m (with InP again driving growth) and net profit of $0.03–0.05 per share.

"We are closely monitoring semiconducting gallium arsenide applications requiring very low-defect-density material [low etch pit density (EPD) for vertical-cavity surface-emitting lasers (VCSELs)]," says Young. This emerging technology is gaining momentum in applications such as 3D sensing. "The mobile phone and tablet market will likely to be among the earliest adopters. But the technology is also very well suited for other areas such as smart TV, high-speed communications and high-power material processing," he adds. "The very low-EPD requirement for VCSEL devices provides a great opportunity for AXT as our VGF technology and proprietary processes allow us to offer industry-leading specifications," Young believes. "Similarly to indium phosphide, these requirements create a meaningful significant barrier to entry. Our belief is that we could see meaningful contribution from VCSEL applications sometime next year. It will benefit the topline but also contribute towards the higher gross margins," he adds. "There is plenty of room for further improvement [in gross margin]. We expect to see sustainable benefit and continue to study additional areas in which we feel we may drive further improvements," concludes Young.

www.axt.com

Tektronix launches modular, fully integrated Keithley 4200A-SCS parameter analyser with IV/CV switch module

Test, measurement and monitoring equipment supplier Tektronix Inc of Beaverton, OR, USA has introduced the customizable and fully integrated Keithley 4200A-SCS parameter analyzer that aims to accelerate semiconductor device, materials and process insights by reducing characterization complexity for new or sporadic users, simplifying test setup, and delivering clear, precise results.

Building on the Keithley 4200-SCS parameter analyzer, the 4200A-SCS features a new graphical user interface and a range of self-learning tools such as expert instructional videos embedded into the instrument. The result is a reduction of up to 50% in test setup times and significantly easier and more intuitive operation. Usability is particularly important for applications such as semiconductor device research, device failure analysis or reliability testing where instruments are a shared resource among multiple users, notes the firm.

"Parameter analysis is critical to characterizing new semiconductor devices, materials or testing the reliability of devices before commercial use. However, researchers may only need to perform these tests sporadically, making it hard for them to become experts at using parametric testing instrumentation,"

says Mike Flaherty, general manager, Keithley product line. "That's why we went to great lengths to make the 4200A-SCS exceptionally easy to set up and easy to learn how to operate, even for users with no prior experience with a parameter analyzer."

Knowing that various measurements add additional complexity to semiconductor research, Tektronix is also introducing the Keithley 4200A-CVIV four-channel IV/CV switch module. For use with the 4200A-SCS mainframe, the module provides on-the-fly switching between SMU (I–V) and capacitance–voltage (C–V) measurements, allowing users to move C–V measurements to any device terminal without lifting prober needles or moving cables.

With a new widescreen high-definition display, the 4200A-SCS offers more screen real-estate for interactive testing and experimentation. The display is coupled with a completely new graphical user interface that delivers the intuitive operation sporadic users need while still offering the advanced features required by expert users, says the firm. The new user interface includes expert videos that capture the knowledge of Keithley application engineers from around the world, reducing the user's learning curve and helping them troubleshoot when unexpected results occur while building confidence in the results they are seeing.

Like the instrument it replaces, the 4200A-SCS is a modular, fully integrated parameter analyzer that performs electrical characterization of materials, semiconductor devices and processes. Consisting of source measure units (SMUs) for I–V characterization, a capacitance–voltage module for AC impedance measurements, and an ultra-fast pulse measure unit that performs pulsed I–V, waveform capture and transient I–V measurements, the 4200A-SCS provides the critical parameters needed for materials research, semiconductor device design, development or production.

The Keithley 4200A-SCS parameter analyzer and 4200A-CVIV switching module are available now. Pricing starts at €38,890/£22,400.

www.tek.com/keithley-4200a-scs-parameter-analyzer

Veeco grows gross margin despite revenue falling 9% in second-quarter 2016 to $75.3m

Consolidation of three plants into MOCVD facility to save $20m annually

For second-quarter 2016, epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA has reported revenue of $75.3m, down 8.6% on $78m last quarter and 42.7% on $131.4m a year ago, consistent with expectations for a soft LED industry environments in first-half 2016.

Of Veeco's 'foundational business' (which has provided relatively stable base business for multiple quarters), the Scientific & Industrial segment comprised 26% of total revenue (supported by MBE systems for advanced research) and the Data Storage segment comprised 18% (totaling $34m, up from $32m last quarter).

The Advanced Packaging, MEMS & RF segment fell back from a record 30% of total revenue last quarter to 23%.

The Lighting, Display & Power Electronics segment — primarily metal-organic chemical vapor deposition (MOCVD) systems — has rebounded from 29% of total revenue last quarter to 33%, driven by an increase in sales to Chinese LED makers.

"Over the past several quarters, LED manufacturers have been plagued by overcapacity conditions and intense price pressures," notes chairman & CEO John R. Peeler. "The first half of 2016 played out as expected with weak LED industry conditions weighing on our MOCVD business," he adds. "More recently, the pace of LED bulb price declines has slowed, which eases some of the financial pressures chip suppliers have faced… We're now seeing signs that the industry conditions are improving across the supply chain," Peeler continues. "We're also seeing customers decommission or replace their older tool-sets and transition production to newer, more cost-effective platforms which can improve their profitability."

On a geographic basis, China rebounded from 11% to 33% of total revenue, driven primarily by increased demand for MOCVD systems. The USA comprised 27% of total sales, supported by investments from mobile RF device makers. Europe, the Middle-East and Africa (EMEA) and the rest of the world each comprised 20% of revenue.

On a non-GAAP basis, gross margin has risen further, from 37.9% a year ago and 41.7% last quarter to 42.4% (the highest level in four years), exceeding the guidance range (of 39–41%) for the second consecutive quarter due to better product mix and certain one-time adjustments.

Operating expenses (OpEx) totaled $38m, flat quarter-over-quarter.

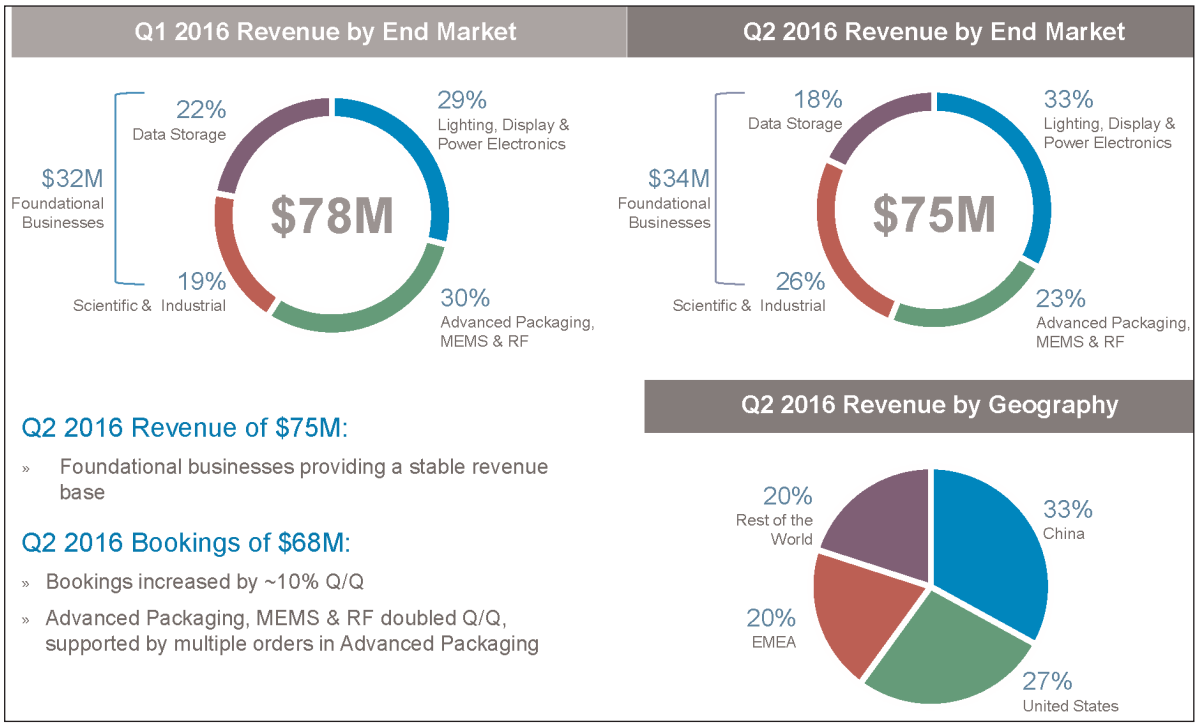
Net loss has risen from $5.7m ($0.15 per share) last quarter to $7.6m ($0.19 per diluted share), compared with a profit of $8.4m ($0.20 per diluted share) a year ago. Adjusted EBITDA has worsened from –$2.1m last quarter to –$2.8m, compared with +$12.8m a year ago.

Capital expenditure rose further, from $4m last quarter to $5m, as Veeco continues to invest in engineering programs and equipment to support development activities associated with the Power Electronics and Advanced Packaging markets.

During the quarter, cash and short-term investments fell by $18m, from $349m to $331m, due mainly to the dual effect of low business volumes driving losses in the past combined with an inventory build to prepare for a projected ramp in shipments.

"Veeco closed out a difficult first half of 2016 delivering second quarter results which were in line with our expectations and underscore our focus on operational execution," comments Peeler.

"We have taken decisive steps aimed at improving our through-



cycle profitability by reducing fixed costs and streamlining our operations," Peeler says. "This plan will enable us to lower our quarterly adjusted EBITDA breakeven level to between $75 and $80m in revenue [of which about 60% should be MOCVD-related], without compromising our ability to capitalize on growth opportunities," he adds.

The restructuring plan involves the consolidation of three manufacturing operations and streamlining of field and administrative functions.

"We currently manufacture ion beam [etch], optical and certain MOCVD products in separate facilities located in the State of New York," notes chief financial officer Sam Maheshwari. "We are consolidating these manufacturing activities into our New Jersey [MOCVD] facility by Q1 of next year. The consolidation would help us manage volume variability across product lines, while maintaining the ability to scale through our outsourced manufacturing partners," he adds.

"Second, we are reducing certain head-count to create a more efficient field infrastructure and streamline administrative function," continues Maheshwari. "Third, in the R&D area, expenses will decline towards the end of this year as certain development programs are completed. However, we will continue to fund R&D programs that position the company for future growth," he adds.

The plan is expected to be substantially completed by the end of 2016 and to result in annualized savings of about $20m, starting in first-quarter 2017. About 60% of these savings are in OpEx and 40% is from cost of goods sold.

As a result of these initiatives, in Q2/2016 Veeco recorded a pre-tax charge of about $16m ($2m cash and $14m non-cash), primarily due to facility- and equipment-related impairment, as well as severance charges.

During Q2/2016, order bookings were $68m, up 10% on $62m in Q1, driven primarily by Advanced Packaging, MEMS and RF orders doubling (supported by multiple orders for Veeco's PSP products). Orders from Lighting, Display and Power Electronics remain soft and were relatively flat on Q1.

Order backlog was $144m, down 15% on $169m in Q1. However, this was largely due to being adjusted downwards by about $17m following a partial order cancellation from one customer that was previously booked in early year 2015.

For third-quarter 2016, Veeco expects revenue of $70–85m. Gross margin should fall to 39–41%. Net loss is expected to be $10–4m ($0.26–0.10 per share). Adjusted EBITDA loss should be in the range of $6m to breakeven.

"Over the past couple of months, MOCVD utilization rates appear to have stabilized and modestly improved, and this suggests supply and demand are moving closer to equilibrium," says Peeler. Most recently, for the Lighting, Display and Power Electronics segment, orders in July were greater than in the whole of Q2/2016. "Multiple LED manufacturers have indicated plans to add MOCVD capacity over the next 12 months. It remains to be seen whether these investments are intended as positioning for market share gains or to address future demand. In either case, Veeco is well positioned to capture the resulting opportunities with our EPIK platform."

"Looking ahead, we see positive indications that should lead to a pick-up in demand for our MOCVD equipment," says Peeler. "Based on our current visibility and improved outlook, fourth quarter revenues are trending higher than Q3 at this time," adds Maheshwari. "We remain committed to our non-GAAP gross margin target of 40% or higher."

www.veeco.com

Epistar orders Veeco EPIK 700 MOCVD systems

Epistar Corp of Hsinchu Science-based Industrial Park, Taiwan (the world's largest manufacturer of LED epiwafers and chips) has ordered multiple Veeco TurboDisc EPIK700 gallium nitride (GaN) metal-organic chemical vapor deposition (MOCVD) systems for the production of LEDs. The systems will be used to meet demand for various applications.

"The improved demand of solid-state lighting combined with the need to compete in a competitive market dictates we choose the most productive and most cost-efficient MOCVD platform in the industry," states Epistar's president Dr MJ Jou. "Veeco has been our supplier of choice dating back to their innovative K465i system," he notes. "After adopting their latest EPIK platform, we have achieved superior yield results and lowered manufacturing costs. The addition of these new EPIK MOCVD systems will help advance our production goals and improve our product competitiveness," he believes.

Based on Veeco's proven TurboDisc technology and the proprietary Uniform FlowFlange, the EPIK 700 MOCVD system enables users to achieve improved cost per wafer savings compared with previous MOCVD systems through improved wafer uniformity, reduced operating expenses and increased productivity.

"A leader such as Epistar ramping production to meet demand of LEDs is a positive sign for the industry as a whole," believes James T. Jenson, senior VP, Veeco MOCVD operations, noting that the market seems to be turning upward again. "We look forward to supporting Epistar's future MOCVD requirements as they continue their growth plans," he adds.

www.epistar.com.tw
www.veeco.com

Aixtron's increased orders in second quarter herald recovery in second-half 2016

For first-half 2016, deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany has reported revenue of €55.5m, down 31% on first-half 2015's €80.7m, reflecting the ongoing weak demand environment in the firm's core market of gallium nitride (GaN) LED applications as well as silicon applications. Of total revenue, optoelectronics comprised 35% (up from just 14% a year ago), silicon 30%, LEDs just 20% and power electronics 10%.

Equipment sales comprised 66% of revenue (€36.6m) and sales of spare parts and services the remaining 34%.

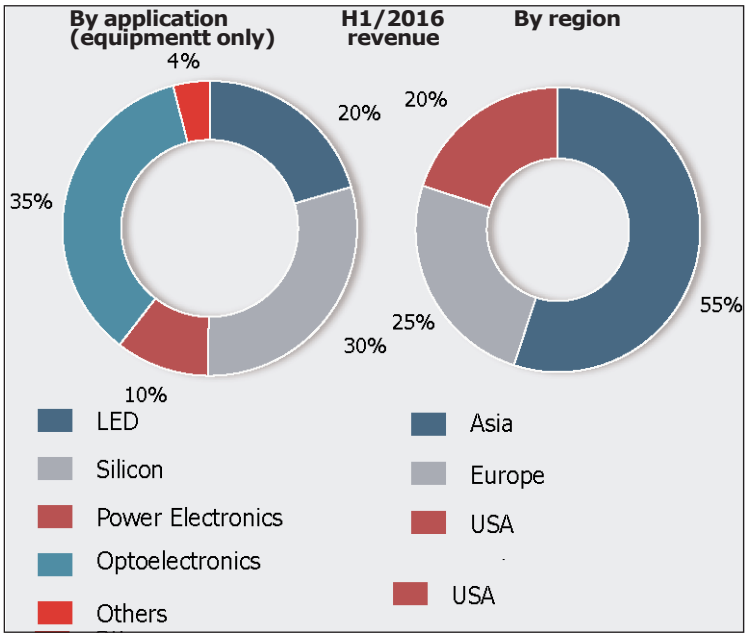
On a regional basis, 55% of revenue came from Asia (down from 70% last quarter and 79% a year ago), Europe 25% (roughly doubling from 13% last quarter and 11% a year ago), and the USA 20% (up from 17% last quarter and 10% a year ago).

However, for second-quarter 2016 revenue was €34.1m, rebounding by 59% from Q1's low of €21.4m, though still almost halving from Q4/2015's €62.5m and down 16% on €40.4m a year ago.

Despite revenue falling year-on-year, gross margin has improved from 15% in first-half 2015 to 18% in first-half 2016, with quarterly gross margin rising from just 9% in Q2/2015 and 15% in Q1/2016 to 20% in Q2/2016, due mainly to better utilization of production capacities from higher volumes.

Operating expenses have been cut by 8% from €39.1m in first-half 2015 to €35.9m in first-half 2016 (rising only slightly from €17.8m in Q1 to €18m in Q2, despite the increased revenue). The additional costs from PlasmaSi Inc of Fremont, CA, USA (acquired in Q2/2015) and the comparative negative currency effect in Q1 were offset by higher productivity, limiting discretionary spending, and a contractual settlement.

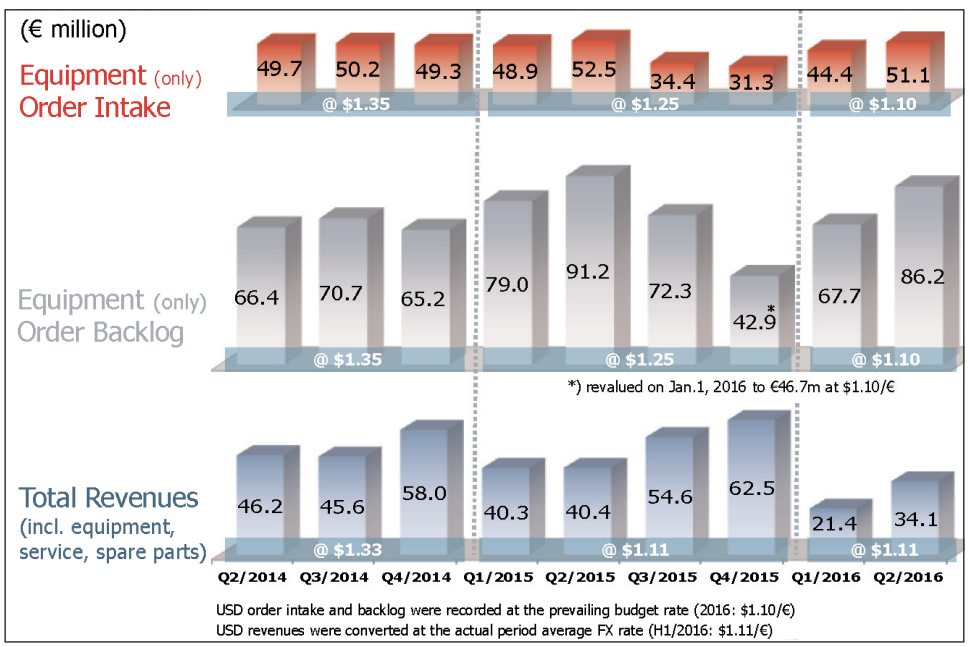
The development of revenues and earnings was in line with expectations while manufacturers remain cautious concerning capacity expansion, says Aixtron.



Earnings before interest, tax, depreciation and amortization (EBITDA) has improved slightly from –€21.8m in first-half 2015 to –€20m in second-half 2016 (improving from –€15.3m in Q2/2015 and –€11.7m in Q1/2016 to -€8.2m in Q2/2016).

Capital expenditure (CapEx) has been slashed from €7.4m in first-half 2015 to €1.7m in first-half 2016 (€0.9m in Q1; €0.8m in Q2). This has therefore slightly mitigated the increase in free cash outflow, from –€12.3m in first-half 2015 to –€41m in first-half 2016 (–€20.3m in Q1;–€20.7m in Q2). This is due largely to higher inventories in preparation for stronger planned shipments in second-half 2016 as well as a the second instalment of the agreed return of advance payments to San'an Optoelectronics Co Ltd (China's largest LED maker) plus an agreed milestone payment in Q1/2016 for the acquisition of PlasmaSi.

Cash and cash equivalents have hence fallen further, from €209.4m at the end of December 2015 to €181.9m at the end of March and €161.3m at the end of June (compared with more than €300m



at the end of 2013).

Although total order intake in first-half 2016 fell by 6% year-on-year from €101.4m in first-half 2015 to €95.5m in first-half 2016, it improved by 15% sequentially from €44.4m in Q2 to €51.1m in Q2. The development in revenues and order intake in Q2/2016 was mainly driven by demand for MOCVD production systems for opto-electronics and power electronics as well as for the silicon industry.

Equipment order backlog at the end of June was €86.2m, down slightly from €91.2m a year previously but up 27% sequentially from €67.7m at the end of March. This supports management's expectation of significant revenue growth for second-half 2016 compared with first-half 2016.

"Despite the weak development of revenues in the first half, we reiterated our 2016 full-year revenue guidance [of €170–200m, given in February 2016, compared with full-year 2015's €197.8m] due to a solid order momentum which is set to continue into Q3/2016," says president & CEO Martin Goetzeler. Full-year 2016 order intake is expected to be €180–200m (up from €167.1m in full-year 2015).

Before transaction-related impacts, the EBITDA, EBIT, net result and free cash flow are expected to improve slightly for full-year 2016 compared with 2015 but to remain negative as revenue volumes still remain too low to enable full financing of all technology roadmaps in the development pipeline. "It is clear that continued net losses cannot be acceptable going forward," comments Goetzeler.

Aixtron has also issued the reasoned opinion from its Executive and Supervisory Boards in which they recommend that shareholders accept the €670m (€6 per ordinary share) takeover offer by Grand Chip Investment GmbH (GCI), an indirect subsidiary of Fujian Grand Chip Investment Fund LP (FGC), made in late May for all outstanding Aixtron shares. The GCI offer and the planned transaction is deemed positive as it could provide Aixtron with the relevant support to successfully develop all targeted technologies to market maturity and to better access growth markets as underlined by the following examples:

- GCI has committed to support Aixtron to continue developing existing product lines, for its customers' benefit and to maintain the existing global set up;
- GCI has also committed that the IP portfolio is to remain with and be used solely by Aixtron while protecting sensitive and confidential customer information;
- GCI has committed to support a regional expansion (especially in China), which would allow better exploitation of the most significant growth opportunities;
- the fairness opinion of J.P. Morgan supports that GCI's takeover offer reflects a fair and adequate offer price; and
- alternative scenarios for Aixtron would either be very risky or would result in a smaller Aixtron with reduced growth potential.

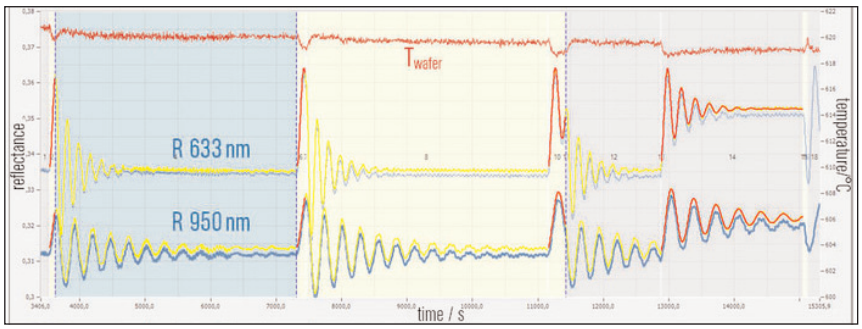
Closing of the transaction is expected in second-half 2016.

www.aixtron.com

LayTec adds nanoscale SPC for quaternary films to EpiNet 2016 analysis software

In its April and June newsletters, in-situ metrology system maker LayTec AG of Berlin, Germany reported on x-ray diffraction (XRD)-gauged nk database improvements for InGaAsP (indium gallium arsenide phosphide) and InGaAlAs (indium gallium aluminium arsenide) on indium phosphide (InP) and for ternary/quaternary materials on gallium arsenide (GaAs). The next release of LayTec's control and analysis software EpiNet 2016 (scheduled for fourth-quarter 2016) will offer completely new analysis features for customers interested in high-accuracy statistical process control (SPC) of related device growth processes.

The figure gives an example: the thickness of very thin InGaAsP layers in a device stack grown on InP(001) in an Aixtron Planetary Reactor is determined by a well selected set of automated analysis operations.



Screenshot of EpiNet 2016: data analysis of an InGaAsP/InP device structure on InP(001): the thickness of the three very thin InGaAsP layers in steps 2, 6, 10 is: 28.5nm, 48.7nm and 100.3nm, respectively. The table in the lower part of the figure gives the sequence of analysis functions for routine and automated SPC of this device growth process. T=temperature, R=reflectance.

First, several InP layers are utilized for permanent in-situ high-accuracy re-calibration of all reflectance channels (yellow lines) in long-lasting epi runs. Second, the lattice matching of the quaternary layers is verified by wafer bow analysis (not shown). Third, the composition of the quaternary material is determined at the thick InGaAsP layer in step #14. Finally, based on this information, the thicknesses of the thin InGaAsP layers in steps #2, #6 and #10 are accurately measured by double-wavelength thickness analysis.

To better understand growth processes, LayTec also offers related training courses for process engineers and quality managers.

www.laytec.de/epinet

LayTec's 21st in-situ seminar at ICMOVPE-XVIII conference

At LayTec's 21st in-situ seminar on 11 July in conjunction with the 18th International Conference on Metal Organic Vapor Phase Epitaxy (ICMOVPE-XVIII) in San Diego, CA, USA, more than 80 researchers and engineers discussed the latest research results and learned about new in-situ metrology developments.

Dan Koleske of the USA's Sandia National Laboratories presented in-situ results of aluminium nitride (AlN)/sapphire growth measured by an EpiCurveTT tool on his Taiyo Nippon Sanso SR4000 reactor.

Gary Tompa of Structured Materials Industries Inc (SMI) of Piscataway, NJ, USA focused on the integration and utilization of an EpiTT tool in SMI's Ga_2O_3 MOCVD system.

Hilde Hardtdegen of Research Center Jülich in Germany reported on finding narrow growth temperature windows for novel $Ge_1Sb_2Te_4$ 2D materials by combining reflectance and temperature sensing of an EpiR TT tool on her Aixtron AIX 200 MOCVD reactor.

Finally, LayTec's Oliver Schulz gave an overview of the latest modular adaptations of the new Gen3 product lines to AIX CRIUS, AIX 6x2" and Veeco K700 MOCVD reactors.

In-situ lattice-match sensing with XRD resolution

At ICMOVPE XVIII, LayTec presented the talk 'MOCVD of InGaAsP/InP-based device structures: full replacement of ex-situ process calibration by advanced in-situ metrology'. The work follows collaboration between the team of Tony SpringThorpe at the National Research Council (NRC) of Canada, Christoph Hums and co-workers at Fraunhofer HHI (Heinrich Hertz Institute) in Berlin, Germany, and LayTec.

During lattice-matched growth of InGaAs on InP in an Aixtron CRIUS reactor, the high-resolution wafer bow sensing (EpiCurveTT Gen3 with ARS module) reached a resolution of 0.2km^{-1}. Two effects that contribute to the wafer bow were carefully separated: the lattice mismatch between layer and substrate and the vertical temperature gradient across the wafer resulting from temperature difference between the wafer pocket and showerhead.

As a result, the lattice match of InGaAs to InP could be tuned in-situ with ±50ppm resolution — an accuracy that formerly could be achieved only by ex-situ x-ray diffraction (XRD), notes LayTec.

www.hhi.fraunhofer.de
www.nrc-cnrc.gc.ca/eng

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Plasma-Therm receives orders for etch and deposition systems from imec

Plasma process equipment maker Plasma-Therm LLC of St Petersburg, FL, USA has received orders from imec of Leuven, Belgium for two Advanced Vacuum Apex SLR plasma processing systems that will provide etch and deposition capabilities to be used in nano-electronics R&D.

One system will be configured with an inductively coupled plasma (ICP) source. The other system will be configured configured for high-density plasma chemical vapor deposition (HDP-CVD). Apex SLR systems incorporate a field-proven, high-density plasma source that was developed by Advanced Vacuum's parent company Plasma-Therm for its widely used Shuttlelock line of plasma tools.

"Plasma-Therm has a long history supporting R&D institutions, and this order continues that tradition," says Dr David Lishan, Plasma-Therm's director, technical marketing. "Leading R&D organizations rely on Plasma-Therm technology for developing new processes and creating smaller, faster, and more efficient devices," he adds.

"These Apex SLR systems were selected by imec's scientists to help develop industry-relevant technology solutions," Lishan continues. Recent imec innovations include disposable photonics biosensors, flexible electronics, hyperspectral imaging devices, and 3D device integration (advanced packaging) processes.

Advanced Vacuum's Apex SLR is a highly versatile, small-footprint plasma processing system. Apex SLR ICP is capable of etching a wide range of materials used in semiconductor devices and nano-technology, while the Apex SLR HDP-CVD enables relatively low-temperature plasma deposition of high-quality thin films. These films can include optical coatings, semiconductor device passivation layers, and other materials used in nanoelectronic fabrication and other applications with limited processing thermal budget.

www.Advanced-Vacuum.com
www.plasmatherm.com
www.imec.be

Seoul National University employs Advanced Vacuum plasma systems in nanotechnology research

South Korea's Seoul National University has integrated two Advanced Vacuum plasma processing systems from equipment maker Plasma-Therm LLC of St Petersburg, FL, USA into its nanotechnology fabrication lab, which supports multiple users engaged in wide-ranging nano-technology research.

Lab researchers recently installed two Apex SLR systems incorporating Plasma-Therm's inductively coupled plasma (ICP) source technology. One system is configured for dry etching, and the second system is configured for high-density plasma chemical vapor deposition (HDPCVD).

Jong-Seung Park, team manager/fab operations at Seoul National University, said the university's cleanroom facility serves many users that are employing the Apex SLR systems' etch and deposition capabilities. "Both systems operate as we expected and deliver reproducible results over the last more than 16 months."

Advanced Vacuum's Apex SLR system

The Apex SLR ICP system utilizes chlorine-based chemistries for etching various materials, with an emphasis on aluminium interconnects, says Park. The Apex SLR HDPCVD system has been employed for a wide range of silicon oxide and silicon nitride deposition processes, such as trench or gap filling for device fabrication.

Apex SLR systems are suitable for both corporate R&D and academic research, comments Dr David Lishan, director, technical marketing for Plasma-Therm. "The Apex SLR, with its very strong and successful processing history, excellent uniformity and reproducibility, has proven highly productive in research environments," Lishan adds. "The ability for facilities like SNU's to task Apex SLR systems and quickly achieve process specs for multiple users are big reasons for selection of Apex SLR over products that are less capable and more expensive."

Advanced Vacuum Apex SLR systems are versatile, small-footprint, field-proven tools for all plasma processing applications. The Apex SLR ICP is capable of etching a wide range of materials for semiconductor devices and other types of nanotechnology. The Apex SLR HDPCVD performs deposition of high-quality thin films at relatively low temperatures for applications such as optical coatings, semiconductor device passivation layers, and other nano-electronic fabrication processes with limited thermal budgets.

www.Advanced-Vacuum.com
www.useoul.edu

Samco opens new office in Malaysia

On 10 August, semiconductor process equipment maker Samco Inc of Kyoto, Japan opened its Malaysia branch office in Petaling Jaya, a suburb of Kuala Lumpur.

"With our new office conveniently located near Kuala Lumpur, we expect to better serve Malaysia's research universities and manufacturers," says chairman, president & CEO Osamu Tsuji. "Four company representatives will be assigned to this new location, where they will actively provide production-type systems and services, consisting of the three major technologies Samco specializes in." These include: thin-film deposition with plasma-enhanced chemical vapor deposition (PECVD) and atomic layer deposition (ALD) systems; microfabrication with inductively coupled plasma (ICP) etching, reactive ion etching (RIE) and deep reactive ion etch (DRIE) systems; and surface treatment with plasma cleaning and ultraviolet (UV) ozone cleaning systems.

"Samco has been continually enhancing its sales presence and service capability in Southeast Asia since the establishment of Samco's Singapore office 20 years ago," says Tsuji. "The region has seen an increased number of semiconductor and electronic component manufacturers in recent years, which initially led to the creation of the company's former Vietnam service office in Ho Chi Minh during 2012."

However, there was still a considerable physical distance between the Vietnam office and the Europe-based device manufacturers that have accumulated in Malaysia (mainly in Penang, Kuala Lumpur and Malacca), as well as the research institutions of some of Samco's important customers, says Tsuji. "Bridging that distance was one reason Samco decided to replace its Vietnam office with our new location in Malaysia."

These efforts to strengthen the company's presence in Southeast Asia include samco-ucp, which was established in Liechenstein after the acquisition of plasma cleaner systems maker UCP in May 2014, and now serves as Samco's main European office. "Some of samco-ucp's chief customers are concentrated in Southeast Asia," notes Tsuji. "Our Malaysia office will also be used as a sales and service base for samco-ucp's main product, production-type plasma cleaners that operate with a remote plasma source."

Currently, the company's annual sales in the region are nearly $2m, which is expected to rise to $5m after three years. "With the combined sales revenue from both companies, we plan to increase Samco's annual revenue in Malaysia to $10m," concludes Tsuji.

www.samcointl.com

Rubicon's revenue falls to $3.5m in Q2/2016

For second-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 $3.5m, down on $4.3m last quarter (due to a temporary reduction of wafer orders) and less than half of the $7.1m a year ago.

The quarter-to-quarter decline was due to revenue from wafer sales falling from $2.35m last quarter to $1.83m (although this is still up on $1.74m a year ago). This was mostly due to polished wafers falling to $0.49m compared with $0.83m last quarter and $0.84m a year ago. While still growing from $0.9m a year ago, revenue from patterned sapphire substrates (PSS) fell back slightly from $1.5m last quarter to $1.34m.

R&D revenue was steady at about $0.1m (down slightly on $0.14m a year ago). Optical revenue of $0.9m was down on $1.4m last quarter and $1.2m a year ago.

Revenue from core sales has rebounded from $0.44m last quarter to $0.69m, although this is down on $4m a year ago. All of this $0.69m was 4" cores (rebounding from $0.44m last quarter but down from $1.24m a year ago), as 2" cores fell further from $2.62m a year ago and just $2000 last quarter to zero, while 6" cores ($0.17m a year ago) remained zero.

Operating expenses have risen from $2.7m last quarter to $4.1m, with general & administrative expenses growing from $1.8m to $2.7m.

Although better than $8.6m ($0.33 per share) a year ago, net loss has worsened from $7.3m ($0.28 per share) last quarter to $8.2m ($0.31 per share). However, this was impacted by about $0.04 per share through increased proxy solicitation costs related to the contested director election.

Net cash used in operating activities has risen further, from $5.1m a year ago and $5.7m last quarter to $6.6m, impacted by building a higher consignment inventory for a key wafer customer in response to higher-volume orders for third-quarter 2016. In addition, timing of receivables collections and payment on the settlement of securities litigation affected cash flow. During the quarter, cash and short-term investments hence fell further, from $25m last quarter to $18m.

Also during the quarter, Rubicon took additional actions to reduce operating costs which it anticipates will positively impact cash flow.

The firm continues to work on re-focusing its business on the optical sapphire market. Further progress was made on its two new technologies: LANCE large window growth and SapphirEX coating technologies (patents pending), which are expected to allow the company to introduce new products into the optical sapphire market. Rubicon also continues to work with developers of other new applications for sapphire outside of the traditional LED and mobile device markets.

"Given the excess capacity of sapphire serving the LED substrate and mobile device markets, we are placing more emphasis on the optical and industrial sapphire markets, where we feel we have a greater competitive advantage," says CEO Bill Weissman. "In addition, the company is reviewing a variety of alternatives, with a goal of providing greater value to our stockholders."

www.rubicon-es2.com

Nanophoton launches Raman wafer analyzer

At the International Conference on Crystal Growth & Epitaxy (ICCGE-18) in Nagoya, Japan (7–12 August), Osaka-based analytical and imaging instrument maker Nanophoton Corp launched the RAMANdrive wafer analyzer for semiconductor applications.

With sub-micron resolution, RAMANdrive provides stress, polytype, defect distribution etc in three dimensions using Nanophoton's most powerful Raman imaging technology. The dedicated 300mm stage was developed for accurate and safe analysis of the whole wafer, while the Raman Imaging System provides high-performance data.

Raman imaging provides comprehensive data about stress, polytype, impurity or contamination non-destructively in all three dimensions, notes president/CEO Michael Verst. "In combination with our dedicated 300mm wafer stage, I strongly believe that our RAMANdrive will be a powerful tool especially for QA/QC as well as development work. It will substantially improve the yield ratio, but also accelerate the development of new materials etc," he adds. "Nanophoton invested a substantial amount of efforts in the development, and during all the time we worked closely with related experts to meet the requirements of our customers in the semiconductor industry."

The unique features of RAMANdrive include the following:

1. The unique Nanophoton Stage Navigation System features what is said to be easy and fast operation by implementing data from the regular inspection system and using it to move the wafer safely and with high accuracy to all positions of interest for detailed analysis.
2. RAMANdrive uses high-quality dark-field microscopy to localize and identify particles even smaller than 100nm. Analysis is done by high-performance Raman spectroscopy and provides detailed analysis of the composition of the material.
3. High-quality confocal optics gives RAMANdrive high-performance 3D Raman imaging capability. Stress distribution and polytype distribution can be clearly visualized in 3D with submicron resolution.

www.nanophoton.jp


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AquiSense acquired by UV-C LED maker Nikkiso

AquiSense Technologies LLC of Erlanger, KY, USA (which designs and manufactures water, air and surface disinfection systems based on UV-C LEDs) has been acquired in a cash deal by UV-C LED maker Nikkiso America Inc of San Diego, CA, USA (the US arm of Tokyo-based Nikkiso Co Ltd).

With over a half century of product development, Nikkiso has provided original technologies to a range of industries, including medical, aviation, life sciences and microelectronics. AquiSense and Nikkiso share a common aim to provide life-saving disinfection products employing UV-C LEDs.

The acquisition is intended to allow Nikkiso and AquiSense to accelerate market commercialization of disinfection products worldwide. "We have been excited to see the innovative solutions at AquiSense enter a number of high-value markets and look forward to supporting those efforts," says Dennis Martin, CEO of Nikkiso America.

"We have worked closely with a number of suppliers to integrate the best UV-C LEDs, and Nikkiso have consistently delivered strong product," comments AquiSense's CEO Oliver Lawal, who will continue in his role, together with Jennifer Pagan as chief technology officer and all other employees.

www.aquisense.com
www.NikkisoUVLED.com

Seoul Viosys files mosquito trap patent lawsuit

South Korean UV LED and blue LED chip maker Seoul Viosys Co Ltd has filed a lawsuit with the Federal District Court of Southern New York accusing P3 International (a US-based manufacturer of home electronics products that sells its products via large retail shops such as WalMart) of infringing its patented MosClean UV LED mosquito trap technology.

At the end of June, Seoul Viosys won a patent lawsuit filed against UV LED curing system maker Salon Supply LLC and made the firm suspend sales of the infringing product in addition to receiving compensation and a royalty for use of the patent.

The patent at issue in the latest lawsuit against P3 covers technologies for manufacturing the UV LED mosquito trap, such as packaging UV LED chips optimized to lure Zika virus mosquitoes, and manufacturing the insect trap engine.

The Zika virus, which is spread through mosquitoes, is found to be the main cause of microcephaly in new born babies. However, over 80% of infected patients do not know that they are infected and it can be transmitted through sexual relations.

Seoul Viosys began to develop the UV LED mosquito trap under the guidance of professor Lee, Dongkyu, an authority in Korea on mosquitoes, by focusing on the premise that mosquitoes are lured to UV rays. After much R&D, Seoul Viosys' violeds technology was finally commercialized as MosClean, which is the best at luring mosquitoes using violeds technology.

According to Seoul Viosys, performance tests conducted in the USA, Vietnam, Indonesia and Korea show that Mosclean is four times more effective in catching mosquitoes than the standard mosquito trap. In addition, Dr Philip Koehler of the University of Florida, an authority on entomology in the USA, proved that it can lure 13 times more Zika virus mosquitoes and seven times more malaria mosquitoes than the standard traps of the US CDC.

This technology has the ability to capture up to 13 times more Adedes aegypti (Zika) and nine times more Anopheles sierroides (or the stained wing mosquito) than standard traps, so Seoul Viosys says that, increasingly, companies are stealing its patented technologies. Hence, to protect and expand violeds technology, Seoul Viosys plans to continue filing lawsuits against infringing companies.

Seoul Viosys was established in 2002 as Seoul Optodevice (a subsidiary of South Korean LED maker Seoul Semiconductor Co Ltd) based on a technical cooperation with Japan's Nitride Semiconductor Co Ltd (the first firm to develop long-wavelength UV LEDs, emitting at 360–400nm, in 2001). It is said to be the first firm specializing in UV LEDs (spanning epitaxy, chip, package and module manufacturing) and the first to develop short-wavelength UV LEDs. Seoul Optodevice was renamed Seoul Viosys in 2013 to denote its expansion from a visible LED and UV LED chip maker to a UV LED system provider.

In 2005 the firm made an equity investment in Sensor Electronic Technology Inc (SETi) of Columbia, SC, USA, and subsequently produced its first 254–340nm UV-C and UV-B (deep UV) LEDs. Seoul Viosys has since maintained close technical cooperation with SETi for over 10 years to commercialize UV LED chips with wavelengths below 350nm.

"We have put a lot of energy into R&D for the development of UV LED technologies for the past 15 years," comments Seoul Viosys' president Kang TaeWoong. "For the mass production of UV LED devices, we received approval from the US Department of Defense and Foreigner Investment Committee, and increased production facilities in SETi, which is our subsidiary in the USA, to expand product production," he adds. "Just as Nichia is the representative company of white and blue LED production, we will be the company representing UV LED," he believes. "We will put more effort into protecting violed patented technologies and applied products, and will expand the products at a reasonable price."

www.seoulviosys.com

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UIUC uses MOCVD growth of cubic GaN on silicon to boost efficiency and brightness of green LEDs

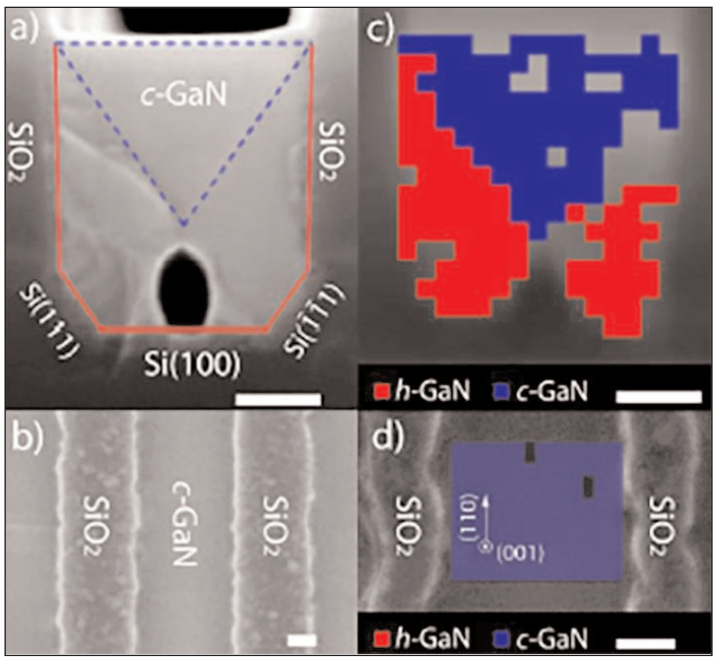
Hexagonal-to-cubic phase transition enables growth on CMOS-compatible substrate

Researchers at the University of Illinois at Urbana Champaign (UIUC) say that they have developed a new method for making brighter and more efficient green LEDs (R. Liu and C. Bayram, 'Maximizing cubic phase gallium nitride surface coverage on nano-patterned silicon (100)', Appl. Phys. Lett. 109, 042103 (2016)). Using the industry-standard metal-organic chemical vapor deposition (MOCVD) semiconductor growth technique, they have created gallium nitride (GaN) cubic crystals grown on a silicon substrate that are capable of producing powerful green light for solid-state lighting.

The work paves the way for novel green-wavelength emitters that can target advanced solid-state lighting on a scalable CMOS-silicon platform by exploiting cubic gallium nitride, says Can Bayram, assistant professor of electrical and computer engineering (who first began investigating this material several years ago while at IBM T.J. Watson Research Center).

"The union of solid-state lighting with sensing (e.g. detection) and networking (e.g. communication) to enable smart (i.e. responsive and adaptive) visible lighting, is further poised to revolutionize how we utilize light," says Bayram. "CMOS-compatible LEDs can facilitate fast, efficient, low-power and multi-functional technology solutions with less of a footprint and at an ever more affordable device price point for these applications."

Typically, GaN forms in one of two crystal structures: hexagonal or cubic. Hexagonal GaN is thermodynamically stable and is by far the more conventional form. However, it is prone to polarization, where an internal electric field separates the negatively charged electrons and positively charged holes, preventing them from combining (diminishing the light output efficiency).



A new method of cubic phase synthesis: hexagonal-to-cubic phase transformation. The scale bars represent 100nm in all images. (a) Cross-sectional and (b) top-view SEM images of cubic GaN grown on U-grooved Si(100). (c) Cross-sectional and (d) top-view EBSD images of cubic GaN grown on U-grooved Si(100), showing cubic GaN in blue, and hexagonal GaN in red.

Until now, the only way researchers were able to make cubic GaN was to use molecular beam epitaxy (MBE), which is an expensive and slow crystal growth technique compared with the more widely used MOCVD.

Bayram and his graduate student Richard Liu made the cubic GaN by using lithography and isotropic etching to create a U-shaped groove on Si (100). This non-conducting layer essentially served as a boundary that shapes the hexagonal material into cubic form.

"Our cubic GaN does not have an internal electric field that separates the charge carriers — the holes and electrons," says Liu. "So, they can overlap and, when that happens, the electrons and holes combine faster to produce light."

Ultimately, Bayram and Liu believe that their cubic GaN method may lead to LEDs free from the phenomenon of droop (whereby the light-emission efficiency of green, blue or ultra-violet LEDs declines as more current is injected) that has plagued the LED industry.

"Our work suggests polarization plays an important role in the droop, pushing the electrons and holes away from each other, particularly under low-injection-current densities," says Liu.

Having better performing green LEDs could open up new avenues for LEDs in general solid-state lighting, it is reckoned, e.g. providing energy savings by generating white light through a color mixing approach. Other applications include ultra-parallel LED connectivity through phosphor-free green LEDs, underwater communications, and biotechnology such as optogenetics and migraine treatment.

In addition, cubic GaN could eventually be used to replace silicon in power electronic devices, and could replace mercury lamps to make ultra-violet LEDs that disinfect water, it is reckoned.

http://scitation.aip.org/content/aip/journal/apl/109/4/10.1063/1.4960005

http://mntl.illinois.edu

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Cree's growth in commercial lighting offsets slowdown in consumer lighting prior to launch of next-gen bulb

For full-year fiscal 2016 (ended 26 June), Cree Inc of Durham, NC, USA has reported revenue of $1.62bn, down slightly on $1.63bn for fiscal 2015, as growth in commercial lighting and stable LED revenue was offset by lower consumer lighting sales (as Cree shifted its product focus to premium bulbs) as well as the slowdown in the Wolfspeed Power & RF business (due mainly to customer delays for RF products).

Revenue for Lighting Products (LED lighting systems and bulbs) fell by 2% from $906.5m to $889.1m (55% of total revenue). Revenue for LED Products (LED components, LED chips & silicon carbide materials) rose by 1% from $602m to $610.8m (38% of revenue) or flat year-on-year excluding upfront license fees of $8m. Power & RF Product revenue fell by 6% from $123.9m to $116.7m (remaining 7% of total revenue).

However, for fiscal fourth-quarter 2016, Cree's revenue was $388.4m, up 2% on $382.2m a year ago and 6% on $366.9m last quarter, as commercial lighting regained momentum (launching nine new products or significant upgrades). Specifically, Lighting Product revenue was $198.4m (51% of total revenue), down 13% on $229.1m (60% of revenue) a year ago but up 5.7% on $187.7m last quarter. The double-digit growth in commercial lighting (as customer service improved significantly) offset the slowdown in consumer lighting as Cree reduced retail inventory (prior to launching its next-generation bulb in late fiscal Q1/2017). LED Product revenue was $159.1m (41% of total revenue), up 6% on $150.2m last quarter and up 30% on $122.2m (32% of revenue) a year ago, benefiting from upfront LED-related IP license fees being recognized during the quarter. Power & RF Product revenue was $30.9m (8% of total revenue), roughly level with $30.8m a year ago but up 7% on $29m last quarter (and in line with targets).

On a non-GAAP basis, quarterly gross margin has grown further, from 20.9% a year ago and 30.6% last quarter to 30.8%. Specifically, LED Product gross margin has rebounded from just 7% a year ago and 34.7% last quarter to 35.1%. Lighting Product gross margin of 25.8% is up on 24.8% a year ago but down from 26% last quarter, due to lower consumer margins related to product transition costs. Power & RF Product gross margin has fallen further, from 52.5% a year ago and 46.4% last quarter to 45%.

For full-year fiscal 2016, Lighting Product gross margin has risen from 26% to 27.2%, due primarily to factory cost reductions. LED Product margin rose from 31.7% to 34.8%, as Cree restructured the business. Power & RF Product margin fell from 54.7% to 48.1%, due to costs associated with new product ramp ups and changes in product mix. Overall gross margin has risen from 29.8% for 2015 to 31.1% for 2016.

Quarterly operating expenses were $98.5m, cut from $108m a year ago but up on $96.5m last quarter.

For fiscal Q4, operating income was $21.5m (operating margin of 5.5% of revenue), up from $16.5m (4.5% margin) last quarter and a loss of $28.4m (–7.4% margin) a year ago. Full-year operating income has risen from $66.1m (4% margin) for fiscal 2015 to $101.7m (6.3% margin) for 2016, driven by improved margins in Lighting and LEDs combined with lower OpEx that more than offset lower Power & RF margin.

Likewise, net income was $18.9m ($0.19 per diluted share), up from $16.9m ($0.17 per diluted share) last quarter and net loss of $20.7m ($0.19 per diluted share) a year ago. Full-year net income rose from $70.5m ($0.63 per diluted share) for fiscal 2015 to $87.9m ($0.86 per diluted share) for fiscal 2016.

Cash generated from operations fell from $87.6m last quarter to $64.6m. In addition to patent spending of about $3.4m (down from the usual $5m), spending on property, plant & equipment (PP&E) has more than halved from $47.9m last quarter to $20.3m, slashing total capital expenditure from $53m to $23.7m (down from $34.7m a year ago). Free cash flow was hence $40.8m, up from $34.7m a year ago and versus –$6.3m last quarter. During the quarter, cash and investments fell by $15m to $605m.

"Fiscal 2016 was a year of progress towards our goal to build a more focused and valuable LED lighting technology company," says chairman & CEO Chuck Swoboda. "We successfully restructured the LED business, improved commercial lighting fundamentals, refocused our consumer business on premium LED bulbs, and unlocked significant value with the agreement to sell Wolfspeed [to Infineon Technologies of Munich, Germany for $850m]."

For fiscal first-quarter 2017 (ending 25 September 2016), Cree targets consolidated revenue (including both continued and discontinued Wolfspeed operations) of $356–378m. Net income is expected to fall to $10–16m ($0.10–0.16 per diluted share).

For continuing operations specifically, revenue is expected to fall to $310–330m, as Lighting backlog is tracking behind fiscal Q4/2016. "Q1 Lighting revenue is targeted to be 5–10% lower sequentially as we continue to rebuild the commercial project pipeline that was disrupted in fiscal Q3," says chief financial officer Michael McDevitt. LED revenue will be in a similar range (excluding the upfront license fees recognized in fiscal Q4). Gross margin should rise. OpEx will be similar to fiscal Q4. Target net income is $6–11m ($0.06–0.11 per diluted share).

For Wolfspeed, the targets are revenue of $46–48m (similar to fiscal Q4), and net income of $4–5m ($0.04–0.05 per diluted share).

www.cree.com

Cree receives favorable initial determination in ITC case against Feit Electric and Unity Opto Technology

On 29 July, LED chip, lamp and lighting fixture maker Cree Inc of Durham, NC, USA received notice of the initial determination issued in the US International Trade Commission (ITC) investigation no. 337-TA-947 ('Certain Light-Emitting Diode Products and Components Thereof') in favor of litigant Cree vs respondents Feit Electric Company Inc of Pico Rivera, CA, USA and its Asian supplier Unity Opto Technology Co Ltd on violations of trade laws for both patent infringement and false advertising.

The decision by the ITC administrative law judge (ALJ) includes the following findings:

- A violation of section 337 of the Tariff Act by lighting company Feit and Unity due to infringement of US Patent Nos. 8,596,819 (LED Lighting Product Efficiency), 8,628,214 (LED Lighting Product Efficiency), 7,976,187 (Omni-directional LED Lighting Product), and 8,766,298 (LED Component Structure).
- A violation due to the false and misleading advertisement by Feit and Unity of certain products as bearing the ENERGY STAR logo when they failed to meet ENERGY STAR standards and/or requirements.

"We are pleased that the judge's decision reaffirms Cree's breakthroughs on more efficient and omni-directional LED lighting products," says Cree's general counsel Brad Kohn. "We hope this decision results in an exclusion order and a cease and desist order that would protect both consumers and Cree by preventing the importation of products that improperly use Cree's patented technology, falsely claim to meet ENERGY STAR requirements, or both."

In response, Feit notes the ITC ruled that one patent asserted by Cree was not infringed. Also, it believes that the adverse findings in the initial determination are based on multiple errors that will be corrected in the forthcoming review phase of the investigation. The firm hence intends to pursue all other remedies as may be available to overturn the initial determination.

"We are fully committed to the quality of our products and to meeting ENERGY STAR certification requirements," says president Aaron Feit. "We do not believe that the initial determination as presently issued will have any adverse effect on our company and we are committed to bringing innovative energy-saving LED lighting to the market," he adds. "We believe that Cree's actions are detrimental to the adoption of energy efficient lighting."

The ITC's final determination in the investigation is currently expected by 29 November.

www.feit.com
www.creebulb.com

MHB-B high-power LED to lower system cost for high-performance

Cree has launched the XLamp MHB-B LED, a high-power LED that enables a more effective way to deliver lower system costs for high-lumen, high-efficiency applications designed to meet the new DesignLights Consortium (DLC) 4.0 Premium requirements.

Leveraging key elements of Cree's SC5 Technology Platform, the ceramic MHB-B LEDs combine high light output, high efficacy and high reliability to enable high-lumen LED designs that are not possible with mid-power LEDs, the firm says. The MHB-B LED delivers up to 931lm at 85°C and 13% higher LPW (lumens per Watt) than the MHB-A LED in the same 5mm x 5mm package, allowing lighting manufacturers to quickly increase performance for existing MHB designs without any additional investment.

"We evaluated many low-cost LED options but found that they require very large PCBs and optics and do not provide good lifetimes," comments Frank Chen, VP fixture department, at Shenghui/Sengled. "We selected the MHB-B LED because its leading light output, efficacy and reliability will allow us to meet increasing industry requirements such as the DLC 4.0 Premium category at the lowest system cost."

The MHB-B LED enables designs that use significantly lighter and smaller heat-sinks than designs based on mid-power LEDs, says Cree. For example, a high-bay reference design built with MHB-B LEDs delivers 24,000 lumens and more than 130 LPW system efficacy at 44% less weight and 36% smaller diameter than comparable high bays based on mid-power LEDs. Built on Cree's high-power ceramic technology, the MHB-B LEDs have LM-80 data available immediately, delivering reported L90 lifetime projections of 60,000 hours at 105°C. The reference design demonstrates a cost-effective way to meet all of the DLC 4.0 Premium requirements for high-bay luminaires, says Cree.

"The new MHB-B LED allows lighting manufacturers to achieve best system value for all high-lumen applications including high-bay, roadway and other outdoor lighting without compromising performance or lifetime," claims Dave Emerson, VP & general manager for Cree LEDs.

Featuring Cree's EasyWhite technology, the XLamp MHB-B LEDs are available in color temperatures of 2700–6500K with high color rendering index (CRI) and multiple voltage options. Product samples are available now, and production quantities are available with standard lead times.

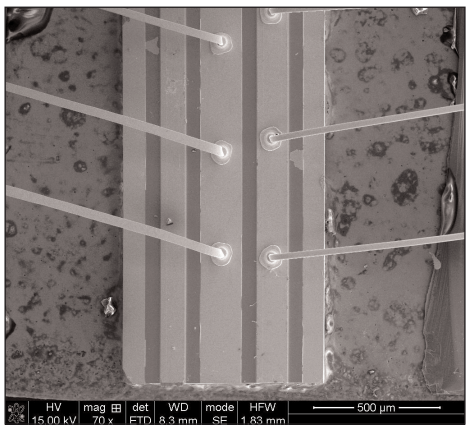
www.cree.com/xlamp/mh

Terahertz quantum cascade laser output power in cw mode almost doubled to 0.23W

Target of 1W to enable applications in spectroscopy, medical imaging and remote sensing

By optimizing the material growth and manufacturing process, researchers at the China Academy of Engineering Physics' Research Center of Laser Fusion and the Institute of Applied Physics and Computational Mathematics in Beijing have nearly doubled the continuous-wave (cw) output power of terahertz quantum cascade lasers (QCLs) from the previous record of 138mW to a new record of 230mW (Xuemin Wang et al, AIP Advances 6, 075210 (2016)). Boosting the continuous-wave output power is an important step toward increasing the range of practical applications, which include medical imaging and airport security.

Sitting between microwaves and infrared light on the electromagnetic spectrum, terahertz radiation is relatively low energy and can penetrate materials such as clothing, wood, plastic and ceramics. Its unique qualities make it an attractive candidate for imaging, but the ability to produce and control terahertz waves has lagged behind technology for radio, microwave and visible light.



Scanning electron microscope image of terahertz quantum cascade laser. (Credit: Wang, et al/AIP Advances.)

Recently, researchers have made rapid progress on technology to produce terahertz QCLs. The thin layers of material in a quantum cascade laser give it the valuable property of tunability, so the laser can be designed to emit at a chosen wavelength. The output power is also relatively high compared to other terahertz sources, notes the paper's first author Xuemin Wang of the Research Center of Laser Fusion at the China Academy of Engineering Physics.

In the new terahertz QCL, the optimal 2.9mm-long device operating at a frequency of 3.11THz has a low threshold current density of 270A/cm^2 at a temperature of ~15K. The maximum operating temperature was ~65K in cw mode

The research team is now focusing on future improvements to boost terahertz QCLs output power in cw mode to more than 1W (a level that has previously been reached in terahertz QCLs operating in pulsed-wave mode). "In engineering, biomechanics and medical science, the applications require continuous-wave mode," Wang says, adding that scientists and engineers could use the new laser as a flexible source of terahertz radiation in applications including spectroscopy, medical imaging, and remote sensing. In particular, the new terahertz QCL can be used in air, which is a challenge for lower-powered lasers since particles in the air can scatter or absorb the laser light before it reaches its target.

http://scitation.aip.org/content/aip/journal/adva/6/7/10.1063/1.4959195

NSF grants $2m to project to fabricate chip-scale integrated SiC quantum photonic processors

University of Rochester-led team targets interconnects for secure communication, metrology, sensing and advanced computing

Under a four-year, $2m grant from the US National Science Foundation (NSF), Qiang Lin, assistant professor of electrical and computer engineering in the University of Rochester's Hajim School of Engineering & Applied Sciences, will lead a photonics system integration research project 'EFRI ACQUIRE: A Scalable Integrated Quantum Photonic Interconnect' that aims to ultimately reduce the complexity and increase the capacity of quantum information processing for secure communication, metrology, sensing and advanced computing.

Funding comes from NSF Emerging Frontiers in Research and Innovation (EFRI), the signature program for the Office of Emerging Frontiers and Multidisciplinary Activities (EFMA) within the Directorate of Engineering.

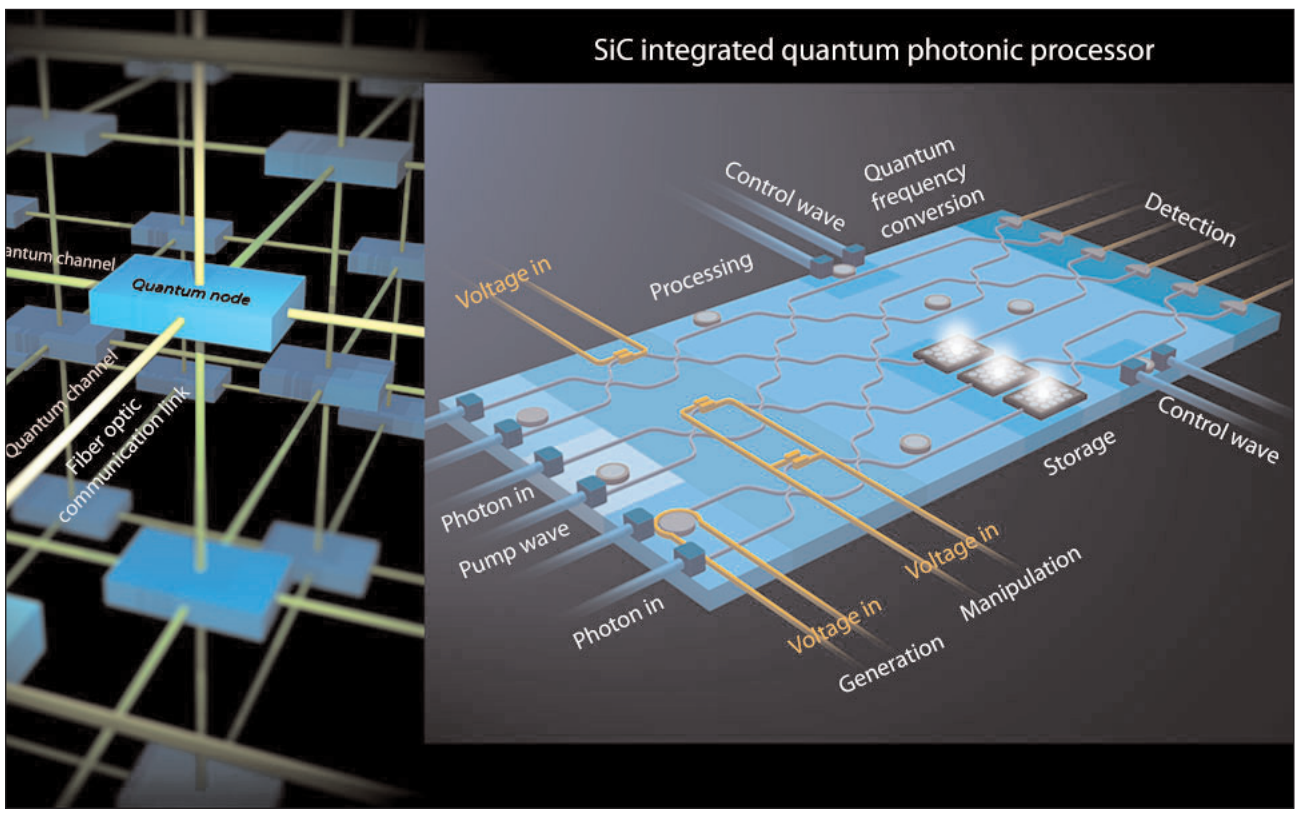
"Our team will build chip-scale integrated silicon carbide quantum photonic processors for high-fidelity and energy-efficient quantum information processing, which interface seamlessly with fiber-optic links for secure communication and distribution of quantum information," says Lin, principal investigator of the project and director of the university's Laboratory for Quantum, Nonlinear and Mechanical Photonics, which studies the fundamental physics of light and its applications, including secure communication and advanced computing. "We have a very strong, multidisciplinary, multi-university team of experts for this project, coming together in a shared vision," says Lin.

Co-principal investigators are John Howell (professor of physics and optics), David Awschalom of the University of Chicago, Philip Feng of Case Western Reserve University, and Jurgen Michel of Massachusetts Institute of Technology (MIT) — all global experts in chip-scale integrated SiC quantum photonic processors. Members of the National Institute of Standards and Technology (NIST) Thomas Gerrits, Sae Woo Nam and Richard Mirin are also collaborating on the project.

The research is expected to result in a new class of device technologies with previously inaccessible attributes and merits that may eventually have a profound commercial impact on the industrial sector. SiC combines excellent linear optical, nonlinear optical, point defect, electrical, mechanical and thermal characteristics into a single material with mature wafer processing and device fabrication capability, hence representing a promising material system for integrated quantum photonics.

Such research also feeds into work of the AIM Photonics (American Institute for Manufacturing Photonics) consortium of the US Department of Defense (DoD), of which the University of Rochester is a partner.

www.nsf.gov/eng/efma
www.rochester.edu



Artist's conception of quantum node lattice with detailed inset of SiC integrated photonic processor within one of the quantum nodes. (University of Rochester).

AIM Photonics releases integrated silicon photonics PDK

End-October application deadline for 2017 multi-project wafer runs

The US Department of Defense (DoD) consortium AIM Photonics (American Institute for Manufacturing Photonics) says that, after just one year of operation, its integrated silicon photonics process design kit (PDK) is now available to all those organizations that have executed membership agreements.

The milestone has resulted from a project led by SUNY Polytechnic Institute, encompassing a significant effort by Analog Photonics, to create a library of photonic components designed to work within the SUNY Poly silicon photonics process. The PDK will enable AIM Photonics members to access leading-edge silicon photonics technology to generate their own piece of real estate on the up-coming multi-project wafer (MPW) run.

"We look forward to providing many other groundbreaking photonics capabilities to the broader photonics community in the coming months and years, thereby fulfilling our charter as a member of the National Network for Manufacturing Innovation," says Dr Michael Liehr, AIM Photonics' CEO and SUNY Poly's executive VP of Innovation and Technology.

AIM Photonics says that the PDK and the MPW capability are tangible examples of the benefits afforded to its members. Members are provided access to cutting-edge research and state-of-the-art fabrication, packaging, design and testing capabilities and enjoy the significant cost savings associated with consortium activities.

In addition to the typical custom layout information needed to create custom photonic devices, the PDK also includes intellectual property in the high-performance library of fundamental silicon photonic passive and active devices developed by Analog Photonics LLC.

"These library components can be quickly instantiated at a schematic level to create sophisticated system-level designs in a short amount of time," says Analog Photonics' CEO Mike Watts. "The capabilities of this library will enable next-generation photonic circuits to be developed quickly and reliably," he believes.

"This kind of system-level design methodology is beginning to be supported by leading electronic-photonic design automation (EPDA) companies and is critical for enabling large-scale integrated photonic designs with lower cost and schedule," says Brett Attaway, AIM Photonics' director of EPDA. "We could not have completed this initial release of the PDK without the strong support of our world-leading AIM member EPDA companies," he adds. "It's extremely important that we enable the next generation of integrated photonic design methodologies, and our EPDA member companies are enabling us to do that and help grow the industry with this PDK release."

Future releases of the PDK are planned over the next several years with improved validation data, models and new components added to the library.

AIM Photonics is planning to have several MPW fab runs in 2017, depending on demand, which may include up to three MPWs for the full silicon photonics process, and two MPWs with a reduced process for passive-only devices and three MPWs for interposers as demand requires. The first full silicon and interposer MPW runs in 2017 will start towards the end of the first quarter.

To ensure space for all interested parties, AIM Photonics is currently accepting reservations for these MPW runs. Those interested in participating in any of the 2017 MPW silicon photonics runs should e-mail Chandra Cotter at CCotter@aimphotonics.com by 31 October in order to guarantee a place. Interested parties can also sign up for the 2017 runs by visiting the consortium's website.

PDK and MPW fab access occurs solely through a MPW aggregator. The MOSIS Service has been chosen as the AIM Photonics MPW aggregator.

www.aimphotonics.com/multiproject-wafer-mpw
www.mosis.com/vendors/view/AIM

Juniper to acquire silicon photonics firm Aurrion

According to a blog by founder Pradeep Sindhu, optical network product provider Juniper Networks Inc of Sunnyvale, CA, USA has entered into an agreement to acquire the fabless, privately held firm Aurrion of Santa Barbara, CA, USA.

Co-founded in 2008 with Dr Alexander Fang (chief executive officer) and University of California at Santa Barbara (UCSB) professor John Bowers (chairman of the board), Aurrion has developed a hybrid silicon photonics platform that heterogeneously integrates indium phosphide (InP) optoelectronic materials .

Sindhu says that, over the past almost two decades, Juniper has dramatically reduced the cost-per-bit-per-second of the electronics portion of networking systems, but the optoelectronics portion has not followed a similar cost curve. Historically, the optoelectronics portion represented significantly less than half the cost of a networking system, especially for optoelectronics designed for short to medium distances. This has since completely reversed, so that the optoelectronics portion now represents significantly more than half the cost. But the explosive growth of video streaming, social networking and other bandwidth-intensive applications such as traffic between data centers means that there is ever increasing demand for greater bandwidth at decreasing cost and increasing flexibility.

Aurrion has developed technology that combines the economies of scale pioneered by the silicon industry with the unique properties of light to carry information over long distances at significantly lower cost. The end result, says Sindhu, is dramatically lower cost-per-bit-per-second for networking systems, higher capacities for networking interfaces, and greater flexibility in how bandwidth carried on light is processed inside the electronic portions of networking systems.

"Aurrion's breakthrough technology will result in fundamental and permanent improvements in cost-per-bit-per-second, power-per-bit-per-second, bandwidth density, and flexibility of networking systems," expects Sindhu. "If we couple this new technology with Juniper's history of bringing innovative networking products to market, we believe we can make significant improvements to the foundations of all of our networking products within a relatively short time," he adds. "This acquisition will strengthen Juniper's ability to bring the most advanced and most cost-effective network products to market more quickly."

www.aurrion.com
www.juniper.net

John Bowers receives 2017 IEEE Photonics Award

John Bowers, a professor of electrical and computer engineering and of materials at University of California Santa Barbara (UCSB), has been selected to receive the 2017 Institute of Electrical and Electronics Engineers (IEEE) Photonics Award. He is the first faculty member from UCSB to receive the honor, which recognizes his "pioneering research in silicon photonics, including hybrid silicon lasers, photonic integrated circuits (PICs) and ultra-low-loss waveguides".

"Silicon photonics has the potential to revolutionize photonics and electronics by enabling low-cost, high-volume manufacturing of optical interconnects with a path toward embedding high-capacity fiber optics on circuit boards and eventually on electronic chips," says Bowers, who holds the Fred Kavli Chair in Nanotechnology at UCSB and is director of the campus' Institute for Energy Efficiency. Bowers has focused his expertise on silicon photonics and optoelectronics, with the goals of developing energy-efficient technology for the next generation of optical networks.

"The IEEE Photonics Award is the most prestigious recognition of contributions to the field of photonics and optics," notes Rod Alferness, dean of the College of Engineering (who received a Photonics Award in 2005, before coming to UCSB). "John Bowers' work in integrated silicon photonics is leading the way to the future of electronics and telecommunications," he comments.

As bandwidth demand rises due to the proliferation of computers, mobile devices, smart technology and apps, so will the strain on existing communications infrastructure, notes UCSB. Steps have been taken over the last couple of decades to provide the speed, capacity and processing necessary to manage the data generated every day in the form of optic and photonic technology, using light to transmit information.

But with new technology comes greater demand. Mobile devices are on the rise, along with data-intensive apps, as well as the Internet of Things (IoT). To satisfy both capacity and performance requirements, optics and photonics must be more deeply integrated into electronics and telecoms systems. However, fiber optics uses indium phosphide (InP) wafers and foundries, which is incompatible with electronics' silicon wafers and foundries.

The answer lies in integrating optics and electronics on the same chip so that the electrical signal is converted into an optical one without equalization, says UCSB. This is a process in which Bowers has been investigating heavily both in his research and also as director for the West Coast center for AIM Photonics, a federally funded manufacturing consortium established to boost photonics manufacturing and create skilled, high-tech jobs in the USA.

https://labs.chem.ucsb.edu/bowers

POET reports further step towards commercializing integrated optoelectronics technology platform

Functional HFETs demoed on same proprietary epi and using same integrated process sequence used to demo high-performance detectors

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 — says that it has taken another significant step toward its goal of developing a fully integrated commercial optoelectronic technology platform.

The specific milestone achieved is the first demonstration of functional heterojunction field-effect transistors (HFETs) down to 250nm effective gate lengths on the same proprietary epitaxy and utilizing the same integrated process sequence that was previously used to demonstrate high-performance detectors. This milestone is the latest in POET's initiative to integrate a detector, HFET and laser together into a single chip, the three key components of POET's current market target of an active optical cable.

"Two of the three critical individual pieces of an integrated optoelectronic product are now in place and undergoing their respective optimization cycles," says chief operating officer Dr Subhash Deshmukh. "As reported earlier, we have encountered delays in completing the VCSEL [vertical-cavity surface-emitting laser] milestone. The VCSEL continues to be our focus, even while we simultaneously make progress on other aspects of the technology," he adds. "The characterization that has been done to date on the VCSEL points to required optimization of a few layers in a very complex and unique epitaxial stack and fine tuning of the resonant cavity mode. The new and optimized epitaxial structure is expected to be delivered to the foundry for processing over the next couple of months," Deshmukh continues.

"We have not uncovered any fundamental show-stoppers. We are charting new territory here and, as pointed out at the recent town hall meeting and at the annual meeting of shareholders, technical issues are commonly encountered throughout the R&D process and we are systematically understanding and addressing these issues."

To enable electrical pumping of the VCSEL, the team has had to re-design some aspects of the epitaxial stack

POET has already demonstrated electrical functionality of the VCSEL with desired thyristor characteristics and demonstrated lasing modes through optical pumping of the VCSEL cavity (i.e. light emission was detected on the epitaxial wafer surface). However, in order to enable electrical pumping of the VCSEL, the team has had to re-design some aspects of the epitaxial stack. VCSEL functionality was previously verified in a lab setting and the functionality of that original laser has been re-tested and reconfirmed.

POET reaffirms its confidence in its roadmap and progress in the lab-to-fab-to-commercialization of monolithic optoelectronic products. "We will provide the next update around the earnings call, which we intend to schedule for early fourth-quarter 2016," says CEO Dr Suresh Venkatesan.

www.poet-technologies.com

POET increases shares reserved for issue under stock option plan

At POET's annual general meeting (AGM) of shareholders on 7 July the following items were approved:

- the number of directors was set at seven;
- all seven directors were re-elected as proposed (with each director receiving over 95% of the votes cast);
- certified public accountant Marcum LLP of New Haven, CT, USA was reappointed as auditors for the ensuing year; and
- the firm's stock option plan (with all officers, directors and insiders abstaining from voting) was amended to increase the number of common shares reserved for issue to 44,352,885 (representing 20% of the 221,764,427 issued and outstanding common shares).

At the meeting of directors following the AGM, as part of the annual incentive stock option grant program, options were granted to the following groups of people to purchase up to a total of 3,900,000 common shares (representing about 1.76% of the outstanding shares): employees (400,000), management (1,550,000), directors (950,000) and CEO and chairman's discretionary pool (1,000,000).

The options are exercisable for 10 years at a price of $0.86 (the closing price of shares on 6 July). Of the options, 25% will vest on the first anniversary of the grant, and the balance will vest quarterly over a further three-year period thereafter.

The options were granted subject to provisions of the stock option plan and are subject to the TSX Venture Exchange policies and applicable securities laws.

SystemOnGlass firm ColorChip raises a further $20m

Privately held integrated optical communications component and sub-system developer ColorChip of Yokneam, Israel has raised $20m in new growth funding to ramp-up operations and drive an accelerated product roadmap. The funding adds to $25m raised in November 2015 (making $45m over the past year).

Funding comes from Gemini Israel Funds, BRM Group, IGP, Vintage, HGL Capital and Viola Credit. To date, the firm has raised $80m, with IGP, Gemini and BRM leading the previous funding rounds.

With Internet services becoming more data intensive due to streaming HD video, virtual reality, cloud computing, and Internet of Things (IoT) devices, there is a growing need for new technologies to help datacoms manage all the exponential growth in traffic, ColorChip says, claiming that its optical communication solutions are well placed to help solve the growing bandwidth demand.

"We have so much support and confidence from our investors and are going to utilize the funds to recruit additional employees as well as scale up our operations to better serve the growing demands of the datacom market," says CEO Yigal Ezra.

Founded in 2001 by Dr Shimon Eckhouse and professor Shlomo Rushin of the School of Engineering at Tel Aviv University, ColorChip provides dense, hyper-scale optical transceivers for telecom/datacom markets plus planar lightwave circuit (PLC) optical splitters for FTTx markets, after developing unique 'SystemOnGlass' hybrid optical integrated circuit technology.

SystemOnGlass comprises dense multi-lane photonic integrated circuits (PICs) that include both active optoelectronic components (InP lasers and photo-detectors) and passive optical components (PLCs).

The firm uses glass wafers to industrialize its optical devices, allowing what is said to be cost-effective, rapid and highly scalable production, and bringing efficiencies commonly only seen in silicon chip fabrication to optical communications.

ColorChip also claims to be unique in Israeli, since it not only develops its solutions but is also vertically integrated and manufactures its core technology in its own fabrication plant. The fab uses the firm's unique IP and is a key component of its core technology, allowing industrialized manufacturing of optical assemblies.

ColorChip targets the high-speed transceiver 40G/100G datacom market, which is predicted to reach $1.7bn by 2019. The firm is hence scaling up its operations, including hiring new employees in Israel, the USA, and remote site facilities.

http://color-chip.com

NeoPhotonics' Q2 revenue up 16% year-on-year to $99.1m, driven by 100G

Full-year growth outlook raised to 22–25% year on year, despite accelerating PON product decline

For second-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, level with last quarter but up 16.1% on $85.4m a year ago. This was driven by robust demand for 100G-and-above products but offset by revenue for passive optical network (PON) products for fiber-to-the-home (FTTH) in China declining faster than expected (by $4m, which had not been factored into the firm's outlook). "These two points mark some key transitions in our business and in the industry," says chairman, president & CEO Tim Jenks.

"We commented on last quarter's call that Q2 revenue would be generally in line with Q1 revenue as we worked through our capacity expansion plans and we absorbed deferred ASP [average selling price] declines," notes chief financial officer Ray Wallin. Without the impact of the unforecasted PON decline, revenue would have been above the high end of the $97–102m guidance range.

Of total revenue, Network Products and Solutions (lower-speed transceivers, <100Gb/s) fell slightly to 34%, while High Speed Products (100G-and-above) products rose further to a record 66% of revenue.

Of NeoPhotonics' top 10 customers, nine were sequentially up, reflecting continued strength for 100G products. There were two 10%-or-greater customers: US-based Ciena comprised 16% of total revenue (level with last quarter), and China's Huawei Technologies 45% (more in line with full-year 2015's 44% rather than last quarter's unusually high 54%).

Of total revenue (compared with last quarter), 60% came from China (down from 62%), 20% again came from the Americas, 5% again came from Japan, and 15% came from the rest of the world (up from 13%).

"Globally, we continue to see the overall environment for 100G-and-beyond products very robust across both telecom and data-center applications," notes Jenks. "In spite of PON market softness, we delivered solid financial results."

On a non-GAAP basis, gross margin is down from 32.8% last quarter to 29.3% (at the lower end of the 29–31% guidance range). This reflected a reduction of about one percentage point from taking additional reserves on certain end-of-life laser products, as well as PON under-recoveries and additional ramp-up costs.

Without the impact of the unforecasted PON decline, revenue would have been above the high end of the $97–102m guidance range. We are accelerating our high-speed product growth and we have announced the end of life of our declining and lower-margin PON products [to be phased out within a year]

Operating expenses (OpEx) were $21.8m, down from $23m last quarter but up from $21.1m a year ago. However, as a percentage of revenue, operating expenses have been cut further, from 24.8% a year ago and 23.2% last quarter to 22%. This is slightly below the guidance range due to lower-than-anticipated expenses for development materials and higher-than-expected recognition of non-recurring engineering (NRE) payments for certain developments, which benefited R&D expenses.

Net income was $6.87m ($0.15 per diluted share, at the top end of the $0.08-0.15 guidance range, reflecting focused expense control). This is up from $5.34m a year ago but down slightly from $6.95m last quarter. This represents the firm's eighth consecutive non-GAAP profitable quarter. Adjusted EBITDA (earnings before interest, taxes, depreciation and amortization) was $12m (12.1% of revenue), up from $11.4m a year ago but down slightly from $12.3m last quarter.

"We delivered strong free cash flow of $8m through efforts on managing operating expenses and working capital efficiencies, including strong collections and inventory management," notes Wallin. NeoPhotonics added about $13m in capital equipment. During the quarter, cash and cash equivalents, short-term investments and restricted cash rose by $9.7m from $103.8m to $113.5m.

"We are accelerating our high-speed product growth and we have announced the end of life of our declining and lower-margin PON products [to be phased out within a year]," states Jenks. For the last four quarters, PON revenue was $43.9m and gross margins were 15–20%. (Excluding PON, company revenue would have been $87.2m in Q1 and $91.3m in Q2/2016.)

For second-half 2016, NeoPhotonics expects PON revenue to be less than $10m (down from $19.8m in first-half 2016), with gross margin of 10–15%, following further declines of over $4m in both Q3 and then Q4.

Despite this, for third-quarter 2016 NeoPhotonics expects revenue to rise

by 1–7% sequentially to $100–106m, with gross margin of 29–31%. OpEx should rise to a more normal $23–25m (due to slightly higher R&D spending). The firm expects earnings per share of $0.09–0.17. Excluding PON, revenue should rise by 6–11% sequentially from Q2's $91.3m to $96–102m.

"We are experiencing an unprecedented level of demand for our 100G products, which we're seeing as a major and sustaining mid-term trend in China as well as in the West," notes Jenks. NeoPhotonics has hence raised and narrowed the range of its full-year 2016 revenue forecast from 20–25% to 22–25% growth (including the impact of the lower PON forecast).

NeoPhotonics has hence also increased its capital expenditure to support the growth of its production capabilities. "We have been increasing our 100G production capacities throughout the year, to a large extent to support the transition to pluggable modules, notably to DCO coherent pluggable modules in China," says Jenks. NeoPhotonics now expects $30–35m of capital spending in second-half 2016, aggregating to 12–13% of revenue for full-year 2016.

"While we've been adding capacity, we have been volume constrained by supply bottlenecks as we ramp our supply chain to support increasing volumes," notes Jenks. "This situation is now being resolved, so with solid bookings and forecasts through the end of the year and into 2017, we believe demand will continue to strengthen and this industry expansion will be directly reflected in our revenue growth as 100G deployments globally for both telecom and data-center applications are expanding, and are in sync," he adds. "In Q3 our investments in production, assembly & test operations are resulting in continued volume growth."

"With the capacity we have added and as we accelerate 100G shipments, we anticipate gross margins will expand by 2–3 percentage points in Q4," reckons Wallin. The gross margin forecast includes ongoing ramping costs as well as under-recovery due to PON revenue declines.

"In China, our 100G product demand in the second quarter was up substantially year over year, and we expect it to increase markedly over the next few quarters in support of the China deployment strength," says Jenks. "This will happen as Chinese carriers continue to build out backbone network capacity, continuing their nationwide network deployments, but also in anticipation of moving from 4G/LTE eventually to 5G wireless rollouts expected in a few years. This is a major trend and a driver for the medium term," he adds. "Nearer term, we anticipate awards for approximately another 30,000 100G ports for the second half of the year and into 2017... The total for next year is looking more like 60,000 ports, and essentially we will see a lot of this get filled by the DCO pluggable."

We have been increasing our 100G production capacities throughout the year, to a large extent to support the transition to pluggable modules, notably to DCO coherent pluggable modules in China

Pluggable DCO modules have rapidly emerged in China as the preferred approach for 100G coherent deployments. "We expect DCO modules to dominate in the China market and to be considerably higher in volume there than ACO modules for the foreseeable future," notes Jenks. "NeoPhotonics is seeing a significant benefit from this ascending industry trend as our compact ultra-narrow-linewidth tunable laser and our micro coherent receiver are specially designed for use in CFP and CFP2 modules, and we are designed in with several of the leading volume module vendors," he adds. "By the end of this year, we will have essentially tripled our capacity for these module component products versus the second half of last year, and we expect that about half of our added capacity will be devoted to supplying into CFP-DCO applications, and eventually to CFP2-DCO modules," Jenks continues.

Also, as 100G coherent transmission is the technology of choice for long-haul, metro and DCI connections, the use of contentionless switching architectures in coherent networks is expanding, and is critical for software-defined networks for content providers' data-centers, which is driving increases in our switching products. "Our multi-cast switch product expands NeoPhotonics' product line in the 100G metro ROADM [reconfigurable optical add-drop multiplexer] market, and shipments into the North American market continue to accelerate," notes Jenks. "Moreover, contentionless architectures are being trialed in several cities in China that could drive rapid volume increases in 2017 and beyond."

www.neophotonics.com

Oclaro grows for a fourth quarter, up 52% year-on-year

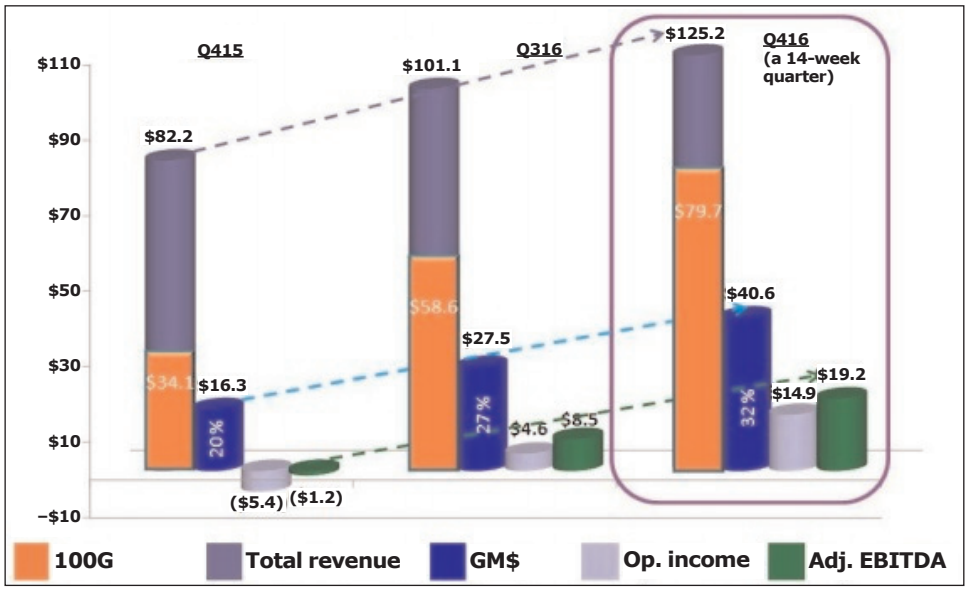
100G yields record margin & operating income, despite capacity constraints

For its fiscal fourth-quarter 2016 (to 2 July, a 14 week quarter), Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications) has reported revenue of $125.2m, up 24% on $101.1m last quarter and up 52% on $82.2m a year ago. (N.B. Scaling to a regular 13-week quarter equates to $116m.) This fourth consecutive quarter of 7%-or-greater growth took full-year fiscal 2016 revenue to $407.9m, up 20% on fiscal 2015's $341.3m.

By region for fiscal Q4, China comprised 44% of total revenue, the Americas 23%, Europe 16%, Southeast Asia 16% and Japan 2%. There were four 10%-or-more customers, contributing 25%, 12%, 10% and 10%, respectively.

For 40G-and-lower speeds revenue grew to $45.5m (36% of total sales, down from 59% a year ago). This is down 5% on $48.1m a year ago but up 7% on $42.5m last quarter, as growth in 10G sales more than compensated for the decline in the 40G legacy product. "Our 10G business has been stronger than we had initially anticipated," comments CEO Greg Dougherty.

Overall growth was fueled by another strong quarter for the entire 100G product portfolio to $79.7m (64% of total sales, up from 58% last quarter and 41% a year ago). This is up 36% on $58.6m last quarter and up 133% on just $34.1m a year ago (and comparable to Oclaro's total revenue then). Of the $21m increase from last quarter, there was a fairly equal contribution from client-side (datacom) modules, telco discrete products, and the new CFP2-ACO product line. "The demand for 100G-and-beyond product for long-haul metropolitan networks, data-center interconnection and high-end routing remains very strong worldwide," notes Dougherty. "Our strength in 100G-and-beyond is a testament to the strength of the Oclaro's indium phosphide (InP), high-speed DFB in tunable lasers, receivers and modulator chip technology, which differentiate us in the market that we serve. It also shows the value of being vertically integrated," he adds.



Line-side (telecom) revenue has risen further, to $59.7m (48% of total sales), up 25% on $47.7m last quarter and up 48% on $40.3m a year ago. "We again saw very good growth in our lithium niobate modulators and our tunable narrow-linewidth lasers used in 100G current systems for both long-haul and metro application," says Dougherty. "We also had a breakout quarter for our CFP2-ACO and are now running approximately three months ahead of the production ramp that we had projected," he adds. "We also had a very strong quarter for our line-side 10G tunable transceivers for metro access. The line-side (which traditionally contributed just a third of 100G revenue) is projected to reach 50% contribution in calendar second-half 2016 as CFP2-ACO sales increase further.

Client-side (datacom) revenue has also risen further, to $65.5m (52% of total sales), up 23% on $53.4m last quarter and up 56% on $41.9m a year ago. "We continue to see very strong demand worldwide for our 100G pluggable CFP and CFP2 product family," notes Dougherty. "We also had very strong demand for our QSFP28 product [based on the performance of our internal high-speed lasers] that are still in the early stages of revenues generation." Client-side sales were again supply constrained.

"The results we achieved in the fourth quarter represent an all-time Oclaro record for gross margin and operating income," says Dougherty.

On a non-GAAP basis, gross margin has grown further, from 19.9% a year ago and 27.2% last quarter to 32.4% (or 31.6% on a 13-week scale). This was driven mainly by the growth in 100G sales, the leveraging of manufacturing overhead, and improved factory efficiencies. Full-year gross margin has hence grown from 17.2% in fiscal 2015 to 29% in fiscal 2016.

Operating expenses rose from $22.9m last quarter to $25.7m, due mainly to year-end professional fees and the extra week of expenses in the 14-week quarter. However, OpEx fell as a percentage of sales from 22.6% last quarter to 20.6%. As Oclaro continues to grow its business, it expects OpEx to fall to 20–21% of sales.

Operating income was a record $14.9m (operating margin of 11.9% of sales), more than tripling

from $4.6m last quarter and compared with an operating loss of $5.4m a year ago. For full-year fiscal 2016, Oclaro achieved an annual operating income of $25.1m, compared with an operating loss of $38.4m in fiscal 2015.

Net income was $15.1m ($0.11 per diluted share), up from $2.9m ($0.03 per diluted share) last quarter and compared with a net loss of $6.6m ($0.06 per diluted share) a year ago. Full-year net income was $19.3m ($0.17 per diluted share), compared with a net loss of $40.8m ($0.38 per diluted share) in fiscal 2015.

Adjusted EBITDA was $19.2m, up from +$8.5m last quarter and compared with –$1.2m a year ago. Full-year adjusted EBITDA was +$40.9m for fiscal 2016, compared with –$20.9m in fiscal 2015.

Following investments of $15.1m in working capital and prepaid as well as capital expenditure (CapEx) of $14.5m to support expected future growth, cash, cash equivalents and restricted cash fell during the quarter from $106.8m to $96.6m. CapEx for full-year fiscal 2016 was $36m (within the $30–40m range provided at the beginning of the fiscal year), mostly for capacity expansion.

"Entering fiscal 2017, we are well positioned for ongoing revenue growth as our product mix continues to shift towards 100G for both our client- and line-side businesses," says Dougherty.

Driven by the continuing momentum in 100G, for fiscal first-quarter 2017 (a 13-week quarter ending 1 October 2016) Oclaro expects revenue to grow further to $126–134m. Gross margin should be 30–33%. Operating income should be $12–16m.

"Our growth will not be gated by demand but limited by what we are able to produce," says Dougherty. "We continue to run very tight on capacity for most of our 100G product as well as our tunable 10G offerings," he adds. "We continue to see strong demand for our mature 10G transceivers and tunable product driven by Chinese and European customers, as well as global demand for our newer 10G product such as the tunable SFP+. We are continuing to invest to increase our capacity and we'll see the impact starting later this calendar year [2016]," says Dougherty. "This demand should help to offset the expected reduction in our 40G line-side business, which will end in the March quarter (fiscal Q3/2017)," he adds. Oclaro expects revenue for its combined 40G-and-below portfolio to be in the mid-$30m range for the next two quarters, declining to around $30m per quarter in fiscal second-half 2017.

For full-year fiscal 2017, Oclaro expect revenue to grow by at least 30% over fiscal 2016. Targets include gross margin in the mid-30s%, operating margin in the mid-teens, and OpEx of 20–21% of sales. As it continues to invest in its 100G-and-beyond portfolio, Oclaro expects CapEx to rise to $55–65m, again mostly for capacity expansion.

www.oclaro.com

Oclaro eliminates $65m convertible debt

Oclaro has completed the exchanges for all $65m of its 6% convertible senior notes due 2020.

Between 8 and 18 August, Oclaro entered into privately negotiated agreements pursuant to which it (i) issued an aggregate of 34,659,972 shares of its common stock (par value $0.01 per share), and (ii) made a cash payment of $4.7m, in exchange for $65m worth of its 6.00% convertible senior notes due 2020. The shares were issued between 9 and 22 August. As a result of these transactions, Oclaro no longer has any convertible debt outstanding.

www.oclaro.com

AOI receives orders for 40G QSFP+ and 100G QSFP28 transceiver from new hyper-scale datacenter customer

Applied Optoelectronics Inc (AOI) of Sugar Land, near Houston, TX, USA, a manufacturer of broadband fiber-optic access network products (including components, modules and equipment) for the Internet datacenter, CATV broadband and fiber-to-the-home (FTTH) markets, says that, after an extensive period of product testing and qualification, it has received initial orders for its 40Gbps QSFP+ and 100Gbps QSFP28 optical transceiver modules from a new hyper-scale datacenter customer.

"The initial orders we have received, totaling more than 10,000 transceivers of various product types, are for delivery over the next couple of quarters, and represent a compelling opportunity to develop a long-term relationship with this new customer," says founder, president & CEO Dr Thompson Lin.

AOI's 40Gbps and 100Gbps optical transceivers are predominantly deployed in intra-datacenter applications and are used for high-speed switching and routing connectivity. Over the last four quarters, AOI has invested over $70m in production and R&D facilities to enable cost-effective, high-volume production for its datacenter and CATV broadband product lines, including in-house laser diode and light engine production.

www.ao-inc.com

Emcore's quarterly revenue grows to $22.4m

For fiscal third-quarter 2016 (to 30 June), Emcore Corp of Alhambra, CA, USA — which provides indium phosphide (InP)-based optical chips, components, subsystems and systems for the broadband and specialty fiber-optics markets — has reported revenue of $22.4m, up 3.9% on $21.5m last quarter and up 5.7% on $21.2m a year ago.

Regarding Satcom, Emcore saw the timing of a large system shipment pushed from fiscal Q3 to Q4, impacting Q3 revenue.

So, quarter-over-quarter growth was driven by cable TV revenue — which includes the R5 optical networking unit (ONU) product line — returning to strong revenue growth both year-over-year and sequentially (up by about 30%), rising from 60-65% last quarter of total revenue to 75–80%. "This strength and demand clearly demonstrates that the MSOs are making their planned shift to DOCSIS 3.1 fiber deployments," notes president & CEO Jeff Rittichier.

However, this growth was offset by revenue for chip-level device products falling by $1.8m from $4m last quarter (to 5–10% of total revenue) due to softness in the Gigabit passive optical network (GPON) market, resulting from a slowdown in purchasing from carriers within China and a result in inventory build-up in the supply chain. This has been caused by a delay in the release of a large tender for ONUs. The delay magnified the expected slowdown and was partially offset by growth in non-GPON business. "Despite the continued volatility in the GPON market, it remains incrementally beneficial to Emcore as it allows us to spread fixed manufacturing cost over a much larger number of devices, while laying the foundation for next-generation devices," 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-based products to the entire telecom industry, thereby optimizing our product mix between captive and merchant use and driving a higher blended margin for both our chip business and the company overall," says Rittichier.

On a non-GAAP basis, although down on 36.3% a year ago, gross margin has rebounded from 32.6% last quarter to 33.1%, driven by the improved efficiencies.

"Six sigma initiatives continue to be a contributing factor in driving operational improvements. Unfortunately these operational efficiencies were negatively impacted by lower chip pricing and lower material overhead absorption, partially related to the long-term inventory purchases," says chief financial officer Jikun Kim.

Total operating expense have fallen from $7.4m last quarter to $5.9m. The drop in sales, general & administrative (SG&A) expenses from $4.8m last quarter to $3.5m was driven by the $2.6m reimbursement of legal expenses related to the Sumitomo Electric Industries (SEI) arbitration agreement, offset by higher severance and other legal and equity compensation expenses. R&D investments fell by $0.2m from $2.6m last quarter to $2.4m due to normal variations in project expenses.

"Despite headwinds in the GPON market, we did a good job this quarter not only on top-line growth and product mix but through improved efficiencies in our manufacturing operations," says Rittichier. "We managed our operating expenses well and began the process of reducing our operations headcount as planned."

Pre-tax income from continuing operations was $0.6m, down on $2m a year ago but level with last quarter.

Capital expenditure (CapEx) was $1.8m (up from $1m last quarter) and depreciation was $615,000. During the quarter, cash and cash equivalents fell further, by $5.3m from $110m to $105m, driven mainly by increased inventory as well as accounts receivable offset by higher accounts payable balances.

On 29 July, Emcore paid a special dividend of $1.50 per share (totalling $39.2m) to shareholders of record as of 18 July (resulting in $85m of total cash returned to investors since June 2015).

Given the continued strength seen in cable TV and fiber-optic gyro markets, for fiscal fourth-quarter 2016 (ending 30 September), Emcore expects revenue to rise to $23-25m, with gross margin percentage in the mid-30s.

"Given our leadership position in the market and the significant investments we've made in CATV chip technology over the past few years, Emcore is enabling the shift to DOCSIS 3.1," says Rittichier. "Over the next year, as we roll out new products based on the LEML [linear externally modulated laser] and its derivatives, we expect those products will set the standard for both DOCSIS 3.1 and RF-over-glass [RFoG] deployments in downstream and the transmitter portions of the network," he adds. "Evidence of this can already be seen with our recently announced $4.7m purchase orders to supply R5 optical networking units to a major US supplier of network infrastructure for cable TV markets… these are expected to be shipped over the next quarter or two."

Emcore has now completed all its turnkey product transfers to external electronics manufacturing services (EMS) from its operation in Langfang City, Hebei, China, and is installing automated processes at its new Beijing facility. "One example of this is our new automated transmitter tuning process which has taken operator touch-time from 45 minutes per unit down to less than 5 minutes, improving both variable cost and return on assets," says Rittichier.

In total, the fiscal 2015 Greenbelt program identified $2.5m in cost savings that Emcore expects to realize in fiscal 2016. "We're expecting the fiscal 2016 Greenbelt program to create even more benefits for us in fiscal 2017," says Rittichier.

www.emcore.com

Infinera validates Intelligent Transport Network portfolio over Lumentum white-box optical line system

Infinera Corp of Sunnyvale, CA, USA, a vertically integrated manufacturer of digital optical transport networking systems incorporating its own indium phosphide-based photonic integrated circuits (PICs), says that its portfolio of dense wavelength division multiplexing (DWDM) platforms has been validated over the white-box optical line system of Lumentum Holdings Inc of Milpitas, CA, which makes optical and photonic products for optical networks and commercial lasers.

Infinera now offers customers an open optical networking solution validated by interoperability testing between Lumentum's white-box optical line system and Infinera's Intelligent Transport Networks.

The joint solution supports an ecosystem that enables open networks for data-center interconnect (DCI) and metro/edge WDM transport. Infinera and Lumentum say this marks the first multi-vendor driven demonstration of, and commitment to support, an open, interoperable and agile approach to the construction of transport networks. The combined power of Infinera's PIC-based platforms and Lumentum's white-box line system offers network operators a scalable, programmable and automated solution for provisioning bandwidth using open standardized interfaces.

Infinera and Lumentum are collaborating on open packet optical transport in the Telecom Infra Project (TIP) industry initiative co-founded by Facebook. TIP consists of multiple operators, infrastructure providers, system integrators and others collaborating to develop new technologies and approaches to deploy the telecom network infrastructure.

"Lumentum's award-winning optical white boxes are designed for simplicity and scalability, with open interfaces to enable software-defined networking (SDN)," says Lumentum's CEO Alan Lowe. "The demonstration of successful interoperability with Infinera validates the open system approach that should deliver the simplicity and service innovation many network operators desire."

The interoperability testing included Infinera's XTM Series, Cloud Xpress Family and DTN-X Family (including XTC and XT Series) platforms. The firms also conducted interoperability testing of Infinera's next-generation Infinite Capacity Engine pilot hardware. The platforms interoperated with the Lumentum white-box open line system including the 20-port Transport ROADM (reconfigurable optical add-drop multiplexer). The test cases covered point-to-point metro fiber links carrying multiple modulations including QPSK (quadrature phase shift keying), 8QAM (quadrature amplitude modulation) and 16QAM with PIC-based super-channels over the Lumentum open line system. The test was able to fill the fiber to full capacity at QPSK, 8QAM and 16QAM data rates via 19 super-channels injected into a single rack unit 20-port ROADM. A fully loaded solution achieves up to 24 terabits of fiber capacity using the Infinite Capacity Engine at 16QAM. Testing validated standard optical parameters including optical signal-to-noise ratio (OSNR) for seamless performance over metro distances.

www.infinera.com
www.lumentum.com/en/optical-communications/products
https://telecominfraproject.com

II-VI ramps volume production of LAN-WDM optics for 100Gb/s long- & extended-reach datacenter transceivers

II-VI Inc of Saxonburg, PA, USA is ramping up shipments of LAN-WDM optics to serve growth in 100GBASE-LR4 and -ER4 transceiver markets.

Data centers are scaling up to keep pace with fast-growing cloud services through increased interconnectivity of data-center computing resources and reduced overall signal latency. Transceivers operating at 100Gb/s are becoming the connectivity workhorse for spine-leaf network topologies. II-VI is therefore ramping up its production output to meet the increasing demand for micro-optics used in transceivers for intra-data-center connectivity.

The IEEE 802.3ba standard (which defines 100GBASE-LR4/ER4 transceivers) is based on LAN-WDM, a technology implemented using four optical channels on 800GHz frequency spacing, each transmitting at 25Gb/s. II-VI leverages its thin-film wavelength division multiplexing technology to build low-loss micro-optics assemblies that merge or multiplex these four optical channels at the transmitter end as they are launched into a single-mode fiber, then function in reverse at the receiver end.

"The role of micro-optics in optical networks continues to expand, this time in the rapidly growing and transforming data center," says Wade Tang, general manager, Advanced Components Division. "Our state-of-the-art thin-film filter fabrication facilities in Santa Rosa, California and Guangzhou, China have enabled our global leadership in this market, especially in the fiber-to-the-home market," he claims. "We have shipped over 200 million filters in the last three years. We are now extending that leadership to the high-bit-rate intra-data-center connectivity," Tang adds.

www.ii-vi-photonics.com

Spectrolab producing 30.7%-efficient space solar cell

Boeing subsidiary Spectrolab Inc of Sylmar, CA, USA, which manufactures multi-junction solar cells and panels for CPV (concentrated photovoltaic) and spacecraft power systems, says that it has begun manufacturing a higher-efficiency space solar cell, providing opportunities for the aerospace industry to develop lighter and less expensive spacecraft.

Due to Spectrolab's advances in manufacturing, the new XTJ Prime cell has achieved a solar energy conversion efficiency of 30.7% (higher than any other comparable model currently available, it is claimed). The first deliveries of the higher-efficiency XTJ Prime cells are expected later this year.

"As space has become more accessible to private companies and countries, competition to provide the highest-powered spacecraft at the lowest cost has intensified," noted Spectrolab's president Tony Mueller during a celebration of the 60th anniversary of Spectrolab being established. "The increased efficiency of the XTJ Prime solar cell drives a lower-dollar-per-watt solution, meaning spacecraft using this new cell will be lighter and less expensive to build and launch, and more powerful once in space," he added.

Spectrolab provides products to the commercial satellite industry, the US Department of Defense, the US National Aeronautics and Space Administration (NASA), and domestic and global aerospace companies. Earlier this year, its space solar cells helped to set a new record as NASA's interplanetary probe Juno traveled further from the sun than any other solar-powered spacecraft, reaching more than 517 million miles on its way to Jupiter.

www.spectrolab.com

Solar Frontier completes 30MW PV plant at Nagasaki Airport

At an opening ceremony attended by representatives of Nagasaki Prefecture, Tokyo-based Solar Frontier — the largest manufacturer of CIS (copper indium selenium) thin-film photovoltaic (PV) solar modules — and Chopro, a local liquefied petroleum gas (LPG) distributor and solar power producer, have announced the completion of a 30MW solar power plant located next to Nagasaki Airport in Japan.

As the biggest solar installation in Nagasaki Prefecture (and one of the biggest in Japan), the 'SOL de Omura Minojima Solar Power Plant' is expected to generate about 37 gigawatt-hours of electricity per year (equivalent to the annual power consumption of 7500 households in Japan).

Solar Frontier and Chopro jointly established the company Nagasaki Solar Energy to develop and manage the new power plant. Chiyoda Corporate provided engineering, procurement & construction (EPC) services, and the land for the project was leased by Nagasaki Prefecture. The project benefited from the support of regional companies, including a syndicate of local banks from the Kyushu region (led by Mizuho Bank) which provided non-recourse project financing. Electricity generated by the power plant is being sold to Kyushu Electric Power Company.

Representatives, including Solar Frontier's CEO Atsuhiko Hirano, in front of a monument symbolizing the project at Nagasaki Airport.

SOL de Omura Minojima's location next to Nagasaki Airport's 3000m runway and on an offshore island are said to have presented the development team with specific challenges. Solar Frontier's CIS solar panels offer anti-reflective properties so as not to affect aircraft operations. The power plant was designed in accordance with height and other regulatory restrictions due to airplanes landing and taking off. Also, a 10km submarine power cable was also laid in order to connect the power plant to the electric grid on mainland Kyushu. Construction of the solar power plant, which began in April 2015, was completed on schedule in July 2016.

www.solar-frontier.com

Stion's frameless CIGS PV modules power solar array on top of retailer's roof

Stion Energy Services (SES) — the turn-key project development arm of Stion Corp of San Jose, CA, USA, which makes CIGS (copper indium gallium selenium) photovoltaic modules — says that a 722kW solar array using frameless modules (which went into operation on 19 May) is now helping to cut electricity costs at the Eastland Plaza store in south Stockton, CA, of California-based grocery chain PAQ Inc (Food 4 Less).

Over a 25 year period, the PV system will offset more than $8.6m worth of electricity costs at what is PAQ's first store to go solar.

Stion's frameless module enables SES to further improve the power

Solar arrays on roof of PAQ's store.

generation capability of its systems. The frameless module weighs 10% less than Stion's framed modules and up to 25% less than crystalline modules and, due to its sleek design, enables Stion to ship 30% more modules per container. SES has also developed a proprietary adhesive solution that is said to enable robust and streamlined installation.

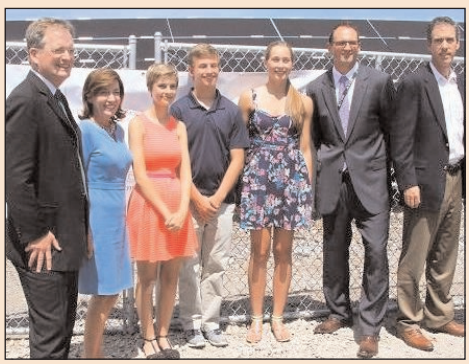
As what is claimed to be the only vertically integrated solar developer with 100% of its manufacturing in the USA, Stion Energy Services' exclusive use of Stion modules has enabled its engineers to identify which balance of system components work best with CIGS technology, compared with developers that use different modules, inverters and racking on all of their projects, says Stion Energy Services' director of engineering Kevin MacKamul, who has over 30 years of experience designing and installing commercial and utility solar projects.

www.stion.com

Stion partners with WGL, New Energy Equity and RER to power largest school project in New York State

Nanostructure-based CIGS (copper indium gallium sulphur diselenide) thin-film solar module maker Stion Corp of San Jose, CA, USA says that its solar panels are being used in a new solar electric array that is powering the Avon Central School District in Avon, NY. The 1.5MW array, which is the largest supplying electricity to a school district in the state of New York, will supply all of the school district's electricity needs and generate an additional $75,000 worth of annual electricity credits.

The project was co-developed by New Energy Equity of Annapolis, MD, and RER Energy Group of Reading, PA. RER has longstanding relationships with the Avon community and initiated the development, at which point New Energy Equity completed third-party financing and engineering, equipment selection, procurement, construction and management. WGL Holdings company WGL Energy Systems owns and operates the project and provides electricity to the school district. Partial funding for the project was provided by NY-Sun, Governor Cuomo's $1bn initiative to scale up solar energy in the state and develop a self-sustaining solar industry.



(From left to right) NYSERDA president John B. Rhodes, Lt. Gov Kathy Hochul, Avon Superintendent Aaron Johnson, and New Energy Equity's Ian Palmer stand with Avon, NY Students for the official ribbon cutting ceremony.

Stion's solar panels were manufactured in Hattiesburg, Mississippi, and include a 25-year warranty, which will enable the district to generate more than $1m in electricity credits over the lifetime of the panels.

"Stion's CIGS modules were selected because they outperform crystalline silicon modules in both warm and cold climates," comments New Energy Equity's CEO Ian Palmer.

"Stion's CIGS modules are the most stable energy producers available due to their industry-leading low temperature coefficient of -0.26%/°C," claims Stion's VP of sales Jim McGrath. "The glass-on-glass encapsulation prevents moisture ingress and delivers long-term power stability with no light-induced degradation (LID) or potential-induced degradation (PID)."

Additionally, the panels are frameless, which minimizes cleaning requirements, as dust, pollen, snow and other debris wash off the edge of the frameless module when it rains, rather than collecting on the edge. This enables the panels to maximize energy production relative to framed panels, the firm adds.

www.newenergyequity.com
www.rerenergygroup.com
www.stion.com

DESRI acquires First Solar's Rancho Seco Solar Project

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 its 11MW$_{AC}$ Rancho Seco Solar Project in Sacramento County, California (on the site of the decommissioned Rancho Seco Nuclear Generation Station), has been acquired by an affiliate of D.E. Shaw Renewable Investments L.L.C. (DESRI).

Rancho Seco is sited on 60 acres of property owned by the Sacramento Municipal Utility District (SMUD), which holds a 20-year power purchase agreement (PPA) for energy from the plant. Rancho Seco uses First Solar thin-film modules mounted on single-axis tracking tables. The project is expected to produce more than 23,000MWh per year.

Power from Rancho Seco is expected to provide energy for SMUD's commercial SolarShares program. Through the program, the Golden 1 Center (currently under construction for the Sacramento Kings basketball club) will obtain about 85% of its power from Rancho Seco, making it one of the greenest sports arenas in the world.

"We are pleased to buy another First Solar project," says Bryan Martin, CEO of DESRI. "First Solar brings a tremendous depth of technological expertise and we look forward to partnering with them on more opportunities in the future," he adds.

"DESRI's commitment to renewable solar energy represents a tremendous opportunity for a continued strategic partnership," says Brian Kunz, First Solar's VP of project development. "Earlier this year, an affiliate of DESRI acquired from First Solar the 31MW$_{AC}$ Portal Ridge solar project, currently in construction in Lancaster, California.

www.deshaw.com
www.firstsolar.com

First Solar connects 130MW of utility-scale solar power to grid in India

New Delhi-based subsidiary First Solar Power India Pvt Ltd has announced commercial operation of 80MW$_{AC}$ and 50MW$_{AC}$ capacity in Andhra Pradesh and Telangana, respectively. These projects are part of the 260MW$_{AC}$ project portfolio wholly owned by First Solar in India.

"After achieving a recent milestone of 1GW of PV solar capacity footprint in India, we are delighted to add 130MW$_{AC}$ of utility-scale solar power to the grid, growing our portfolio of operational solar assets to a cumulative capacity of 150MW$_{AC}$," says Sujoy Ghosh, First Solar's country head for India.

The 130MW$_{AC}$ plants collectively will produce enough energy to power about 227,500 average homes in India, and will displace over 204,000 metric tons of carbon dioxide per year. The project will be powered by more than 1.4 million First Solar modules. The modules have been independently tested to pass accelerated life and stress tests beyond industry standards. With what is claimed to be both a superior temperature coefficient and superior spectral response, they have been independently certified for reliable performance in high-temperature, high-humidity, extreme desert and coastal environments.

The electricity from the projects will be purchased by the Southern Power Distribution Company of Andhra Pradesh and The Telangana State Southern Power Distribution Company Limited under 25 year power purchase agreements.

www.firstsolar.com

First Solar books 121MW in PV module sales for utility-based community solar installations in USA

First Solar says that it has sales bookings of 121MW$_{DC}$ of thin-film modules which will be used in utility-based community solar installations in the USA. First Solar did not disclose the owner or offtaker of the projects, many of which are still in development and not yet announced by the owner.

"This scale of community solar implementation is extraordinary, and suggests the enormous potential for this market segment," says chief commercial officer Georges Antoun. "Small one-off installations cannot match the economies of scale realized by utility-scale portfolios that minimize development costs, transaction costs and building costs, while bringing end consumers the freedom to choose solar energy."

Antoun says the initiative is underway, with M+W Energy constructing several small, closely sited solar projects comprising about 41MW$_{DC}$ of energy. Additional generation facilities are expected to begin construction by the end of 2016.

Power generated by the solar plants will be purchased by a regional utility's consumers through a special community solar program that gives commercial and industrial operations, non-profits, educational institutions and residential customers access to renewable energy without needing to install and maintain solar panels on their rooftops, and with the confidence that these systems are operated and maintained with utility-scale infrastructure and reliability.

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Flexible ultra-thin gallium arsenide photovoltaic devices

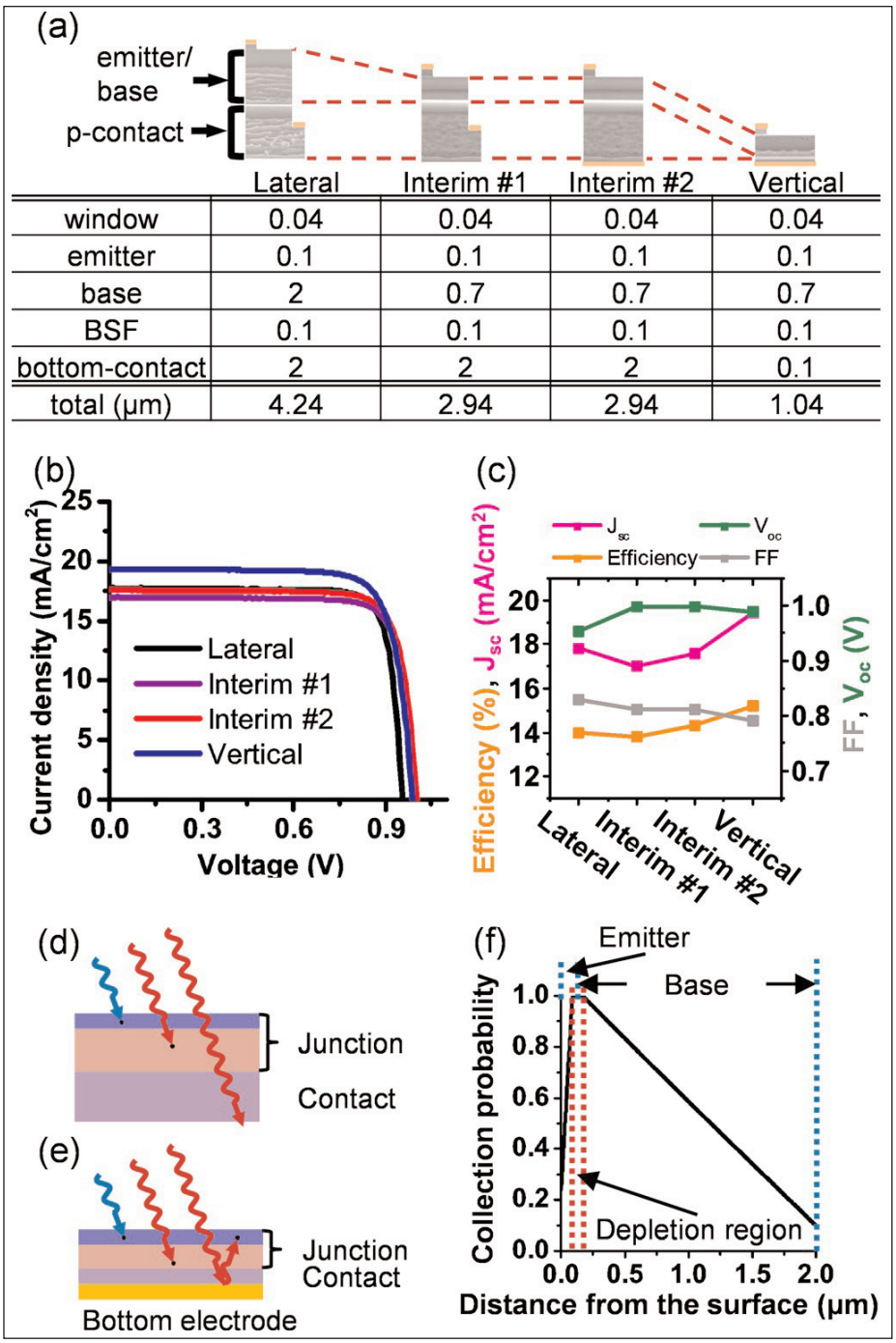
Researchers see application as electric power sources deployed on pairs of glasses and/or fabric.

Researchers based in South Korea have developed a transfer-printing process to produce flexible gallium arsenide (GaAs) photovoltaic devices on metal without an interlayer adhesive [Juho Kim et al, Appl. Phys. Lett., vol108, p253101, 2016]. The researchers believe that such flexible devices could find application as wearable electric power sources deployed on the frames of a pair of glasses and/or fabric. Other possible uses include space applications and concentrator photovoltaics.

The team from Gwangju Institute of Science and Technology (GIST), Korea Photonics Technology Institute (KOPTI) and Yeungnam University claim the yields for the process are close to 100%.

The solar cell material was grown using low-pressure metal-organic chemical vapor deposition (LP-MOCVD) at 700°C. Various structures were grown, including an ultra-thin one with a thickness of a quarter that of thickest (Figure 1). "Thinner compound semiconductor devices, in addition, use less material and time and thus less cost when the epitaxial structures are grown," the team comments. The layers were GaAs, variously doped, except for a 0.1μm aluminium gallium arsenide (n-$Al_{0.3}Ga_{0.7}As$) back-surface field (BSF) layer.

Microcells were defined by photolithography and top electrodes of titanium/gold were deposited. Wet chemical mesa etching created 760μmx760μm active areas. A photoresist (PR) layer protected the devices during separation from the substrate by wet chemical etching of a sacrificial layer. Also, SU8 epoxy layers were used to reinforce the photoresist protection in some cases to avoid cracking



	Lateral	Interim #1	Interim #2	Vertical
window	0.04	0.04	0.04	0.04
emitter	0.1	0.1	0.1	0.1
base	2	0.7	0.7	0.7
BSF	0.1	0.1	0.1	0.1
bottom-contact	2	2	2	0.1
total (μm)	4.24	2.94	2.94	1.04

Figure 1. (a) Different solar microcell structures. (b) Measured current density (J)–voltage (V) curves under AM 1.5G illumination. (c) Measured short-circuit current density (J_{sc}), open-circuit voltage (V_{oc}), fill factor (FF) and efficiency (η). (d) Photon dynamics in thick devices with most high-energy photons absorbed near surface, middle-energy photons absorbed at junction layer, and low-energy photons transmitted out of the microcell (a loss process). (e) Schematic of photon dynamics for ultra-thin device with bottom electrode reflecting non-absorbed photons. (f) Theoretical collection probability of GaAs solar cell.

where the microcells were ultra-thin.

The cells were transferred by film stamps constructed from polyimide (PI) and polydimethylsiloxane (PDMS). Before transfer, the bottom titanium/gold electrodes were deposited through a shadow mask that prevented metal being deposited on the sidewalls of the microcells, thus avoiding short circuiting between bottom and top contacts. The bottom electrode also constituted a light reflector in the ultra-thin cells, giving two passes for the photons to be absorbed.

The microcells were 'cold welded' onto metal electrodes on the receiver 12.5μm polyimide substrate by applying ~80kPa pressure at 170°C for 20 minutes (Figure 2). The photoresist protection helped avoid delamination when the film stamp was peeled away. The photoresist was removed with acetone.

The electrodes on the receiver substrate were 760μmx850μm rectangles. The microcells were encapsulated in 2μm SU8 epoxy and titanium/gold interconnects formed between the cells.

The ultra-thin sample had the highest J_{sc} of 19.4mA/cm^2, while maintaining V_{oc} near that of the thicker samples. The conversion efficiency of 15.2% for the ultra-thin device also exceeded that of the other structures.

The team attributes the improvements to the combined effects of the back reflector, and thinner base and bottom contact layers. The researchers add: "Most low-energy photons are absorbed at the junction (during the energy conversion process), but some of them are transmitted out of the junction (loss process). To reduce the loss, we can make the base thicker or re-route the photons to pass through the thinner junction using a back reflector."

The ultra-thin devices should also support more severe bending before breakage. The researchers found the ultra-thin arrays did not break after bending around 1mm-thick glass slides or the 1.4mm radius stem of a medical cleaning swab. Bending to 1.4mm radius and unbending up to a 1000 times gave no indication of degradation in the electrical performance, according to the team.

The researchers also interconnected seven cells in series with chromium/gold, giving a V_{oc} of 6.8V, almost 7x that for a single cell (7x0.99V = 6.93V). ■

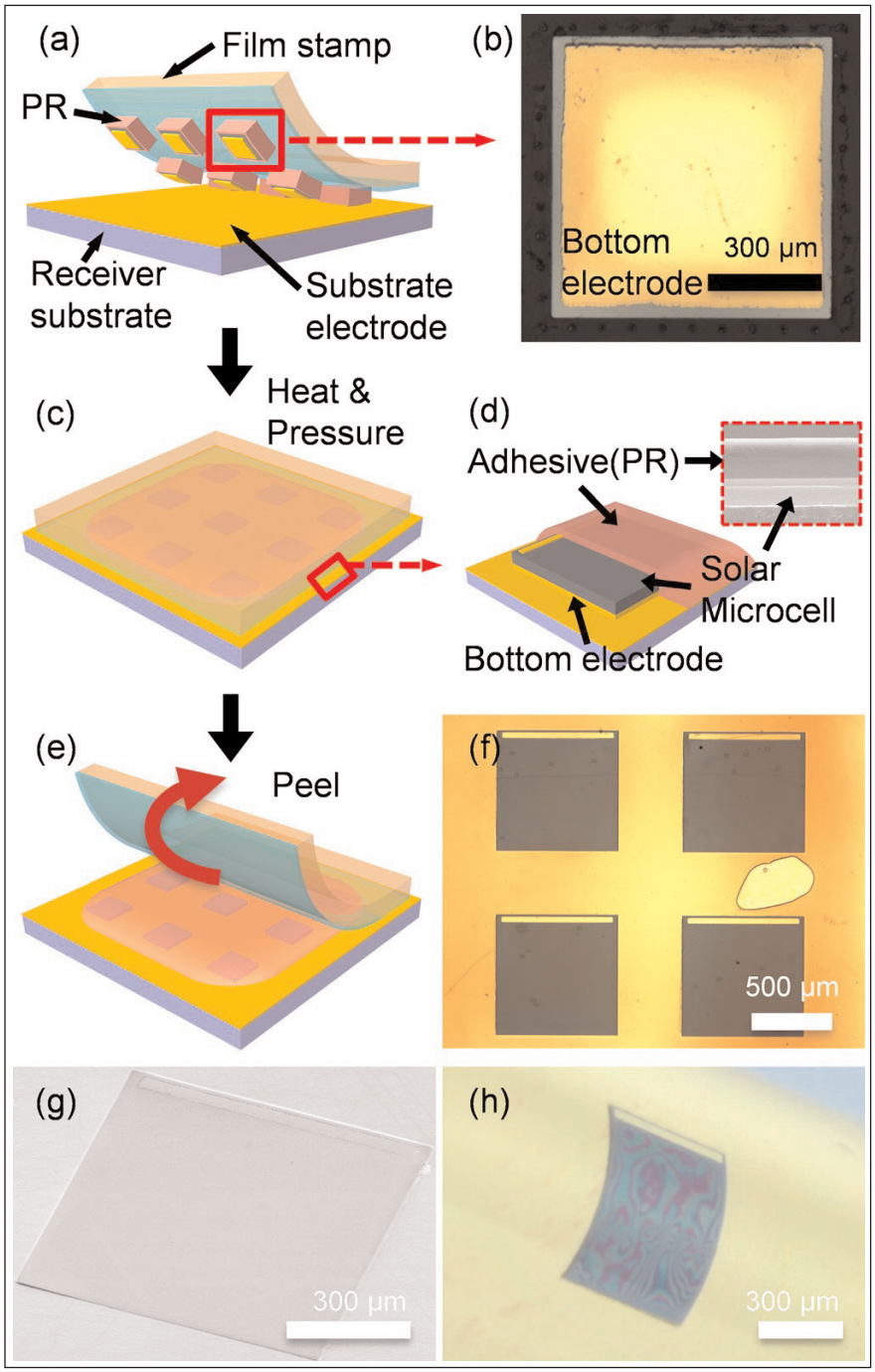


Figure 2. Fabrication of flexible vertical ultra-thin GaAs solar microcells with back reflector. (a) Film stamp with vertical GaAs microcells fabricated and isolated from epitaxially grown source wafers. (b) Bottom electrode, which also serves as back reflector, is deposited onto backside of ultra-thin vertical GaAs microcells. (c) After film stamp is brought into contact with receiver substrate. (d) Schematic and cross-sectional scanning electron microscope (SEM) image of microcell. (e) Peeling film stamp leaves vertical ultra-thin solar microcells on receiver substrate. (f) Optical microscope image of printed microcells after peeling film stamp. (g) SEM image of vertical solar microcell transfer-printed onto receiver substrate after PR removal. (h) Optical image of microcell wrapped on glass slide with a radius of 1mm.

http://dx.doi.org/10.1063/1.4954039

Author: Mike Cooke

Yellow-green indium gallium nitride quantum dot laser

Researchers claim the first 'green gap' vertical-cavity surface-emitting laser to operate in continuous-wave mode at room temperature.

Yellow-green lasing at 560.4nm wavelength has been achieved under continuous wave (CW) operation of indium gallium nitride (InGaN) quantum dot (QD) vertical-cavity surface-emitting laser (VCSEL) diodes at room temperature "for the first time", according to researchers based in China and Germany [Guoen Weng et al, Optics Express, vol24, p15547, 2016]. Previously, pulsed operation in the shorter-wavelength 503nm green region for VCSELs was achieved by Nichia.

Up to now, CW lasing in the 'green gap' has been elusive. InGaN-based devices suffer from strong charge polarization effects that can lead to large electric fields, particularly in strained layers resulting from lattice mismatching. These electric fields tend to pull electrons and holes apart, reducing recombination into photons. This is often referred to as the quantum-confined Stark effect (QCSE). QDs are one way to reduce strain effects that exacerbate the charge polarization effects in InGaN.

The high-indium-content InGaN needed for green emission tends to suffer from a severe drop in radiation efficiency. The research team from China's Xiamen University, Suzhou Institute of Nano-tech and Nano-bionics, and East China Normal University, together with Technical University of Berlin in Germany, based their device on strong localization and negligible QCSE of QDs, as well as good coupling between the QD region and external electric fields. It was hoped that these factors would work together to give high radiation efficiency and thus lasing in the 'green gap'.

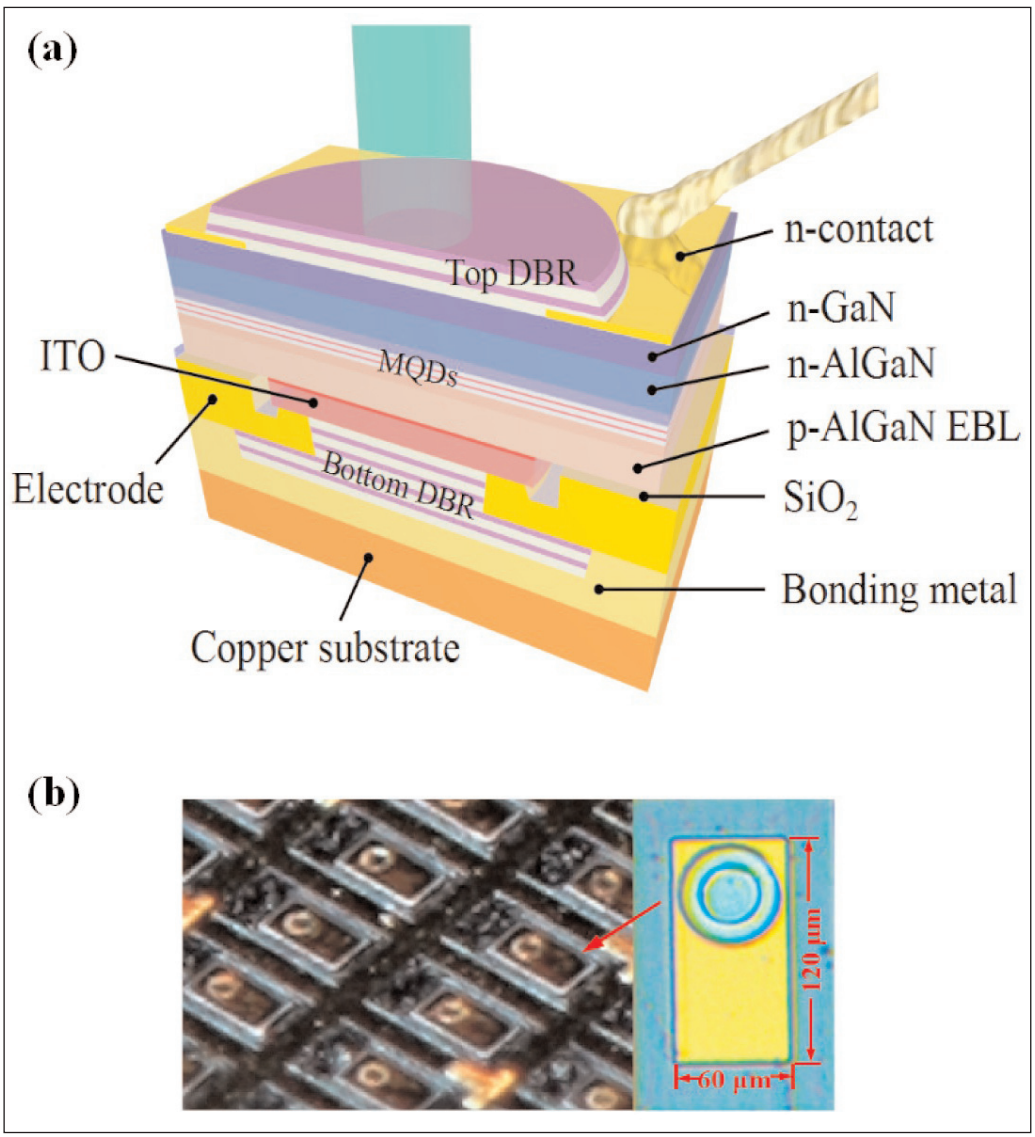


Figure 1. (a) Cross-sectional schematic of fabricated InGaN QD VCSEL. (b) Picture of array (left) and enlarged optical micrograph (right).

The device material was grown on (0001) sapphire using metal-organic chemical vapor deposition (MOCVD). The light-emitting active region consisted of two layers of InGaN QDs in a GaN barrier matrix. The GaN in the active region was grown in two temperature steps: 2nm at the 670°C used to make the QDs and 8nm at 850°C. The low-temperature GaN was used to protect the $In_{0.27}Ga_{0.73}N$ from the subsequent ramp to 850°C. The dot density was around $1.5x10^{10}/cm^2$, according to atomic force microscopy (AFM) scans.

Electron microscope analysis gave dot diameters ranging between 20nm and 60nm with an average height of 2.5nm.

Device fabrication began with depositing and patterning silicon dioxide (SiO_2) on the p-GaN surface of the grown material to create a 10μm diameter aperture, 30nm of indium tin oxide (ITO) as a p-contact and current-spreading layer, and chromium/gold around the aperture as electrode. A titanium dioxide (TiO_2) phase shifter was added to put the ITO layer at a node of the radiation field and the active region at an anti-node. Further layers of SiO_2 and TiO_2 were used as a 12.5-pair distributed Bragg reflector (DBR) back mirror.

The device was then flipped and metal-bonded to a copper heat-sink before removal of the sapphire substrate through laser lift-off. The n-GaN layer was thinned using inductively coupled plasma (ICP) etch and chemical mechanical polishing (CMP). The 60μm x120μm VCSEL (Figure 1) was completed with an n-contact and 11.5-pair TiO_2/SiO_2 DBR.

Photoluminescence analysis of the device material on sapphire at room temperature gave a broad peak around 524nm wavelength with full-width at half maximum (FWHM) of the order of 50nm. The broadness of the peak was attributable probably to the large variation in QD size and composition. Low-temperature photoluminescence at 5K, with no identifiable blue-shift with excitation power increase on the long wavelength side, suggested that the QCSE was weak to negligible.

The threshold current and voltage were 0.61mA (0.78kA/cm^2) and 6.7V, respectively. The researchers comment: "Such a low threshold is attributed to the high reflectivities of the DBR mirrors, the strong localization effect and the negligible QCSE in InGaN QDs, and a good coupling between QDs region and the electric field of the lasing mode". The team adds that filamentation effects due to "inhomogeneous distribution of refractive index caused by both indium content and the higher efficiency of carrier capture of QDs than the surrounding material" may also play a role.

The measured full-width at half-maximum was 0.16nm, as limited by the setup resolution (Figure 2). The 24nm separation between lasing modes indicated a cavity length of 2.6μm. The polarization was 94% at 1.96x threshold current, a 30dB suppression of the orthogonal polarization.

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Author: Mike Cooke

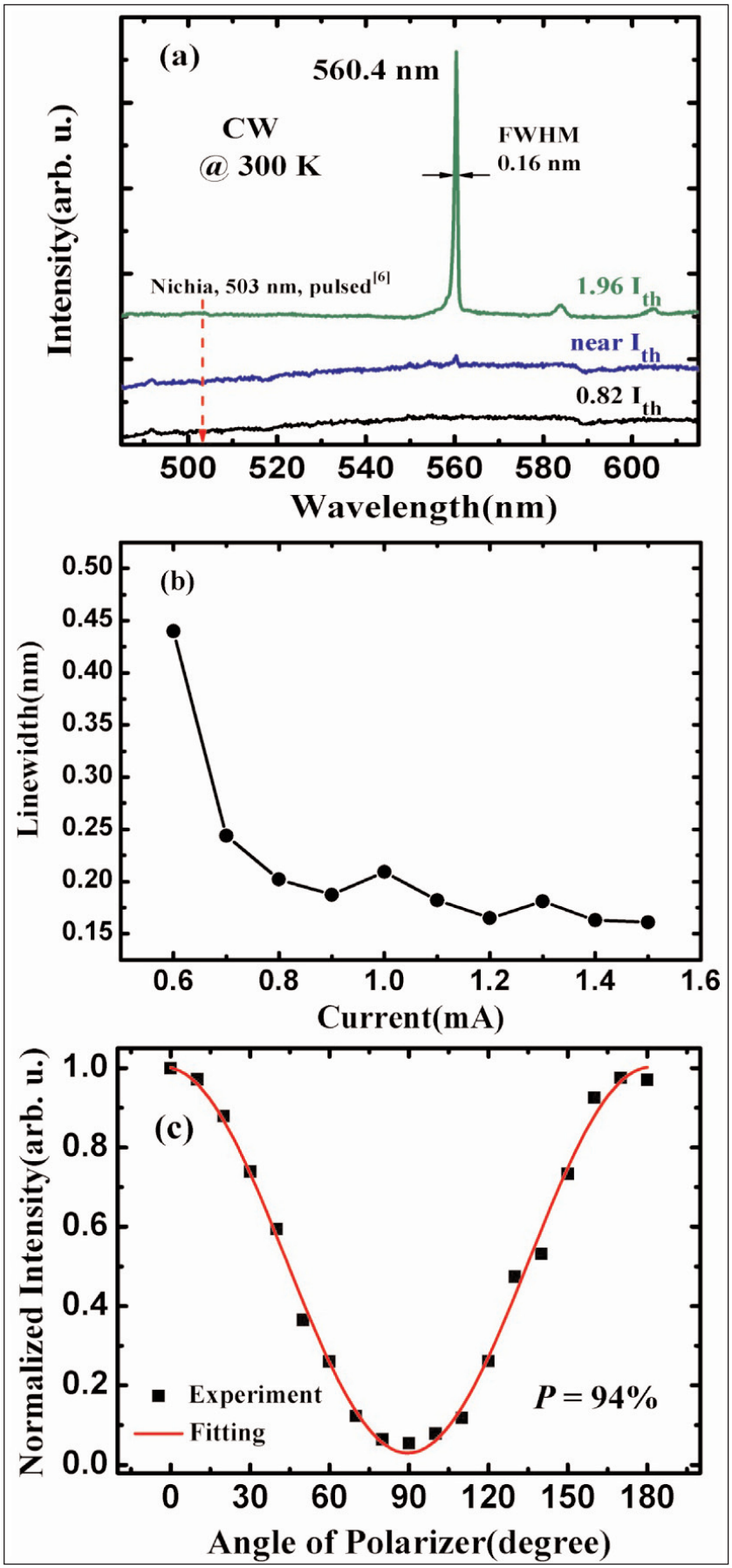

Figure 2. (a) Laser emission spectra at various injection current levels measured at 300K. (b) Laser emission linewidth versus injection current. (c) Polarization characteristics of laser emission at injection current of 1.96x threshold (I_{th}).

Sodium flux route to free-standing gallium nitride substrates

Osaka University develops liquid phase epitaxy method to both grow GaN and dissolve sapphire at high temperature, avoiding cracking.

Osaka University in Japan has developed a liquid phase epitaxy (LPE) process for the growth of gallium nitride (GaN) in a sodium (Na) flux with a small amount of carbon (C) that, with the addition of lithium (Li) and gallium, can also be used to dissolve sapphire (aluminium oxide, Al_2O_3), leaving free-standing GaN [Takumi Yamada et al, Appl. Phys. Express, vol9, p071002, 2016].

Without dissolving the sapphire substrate, the Ga-Na-C growth process results in cracks that the researchers attribute to stresses generated by cooling as a result of the mismatch in the thermal expansion coefficients of GaN and sapphire. By contrast, GaN with the sapphire substrate removed before cooling avoided cracking.

Free-standing GaN substrates are usually of higher quality than material left on the growth substrate due to the much lower dislocation densities of ~10^6/cm^2, compared with ~10^8/cm^2. Lower dislocation densities improve the performance of laser diodes, light-emitting diodes, and high-power, high-frequency electronic devices that harness the higher critical electric field, higher electron mobility and higher thermal conductivity of GaN.

The liquid phase epitaxy was performed on a 5μm GaN 'seed' on c-plane sapphire templates produced by hydride vapor phase epitaxy (HVPE) — see Figure 1. The liquid-source 20% Ga was combined with 80% Na and 0.05% graphite. Growth was carried out for between 72 and 200 hours at 870°C with nitrogen gas introduced at

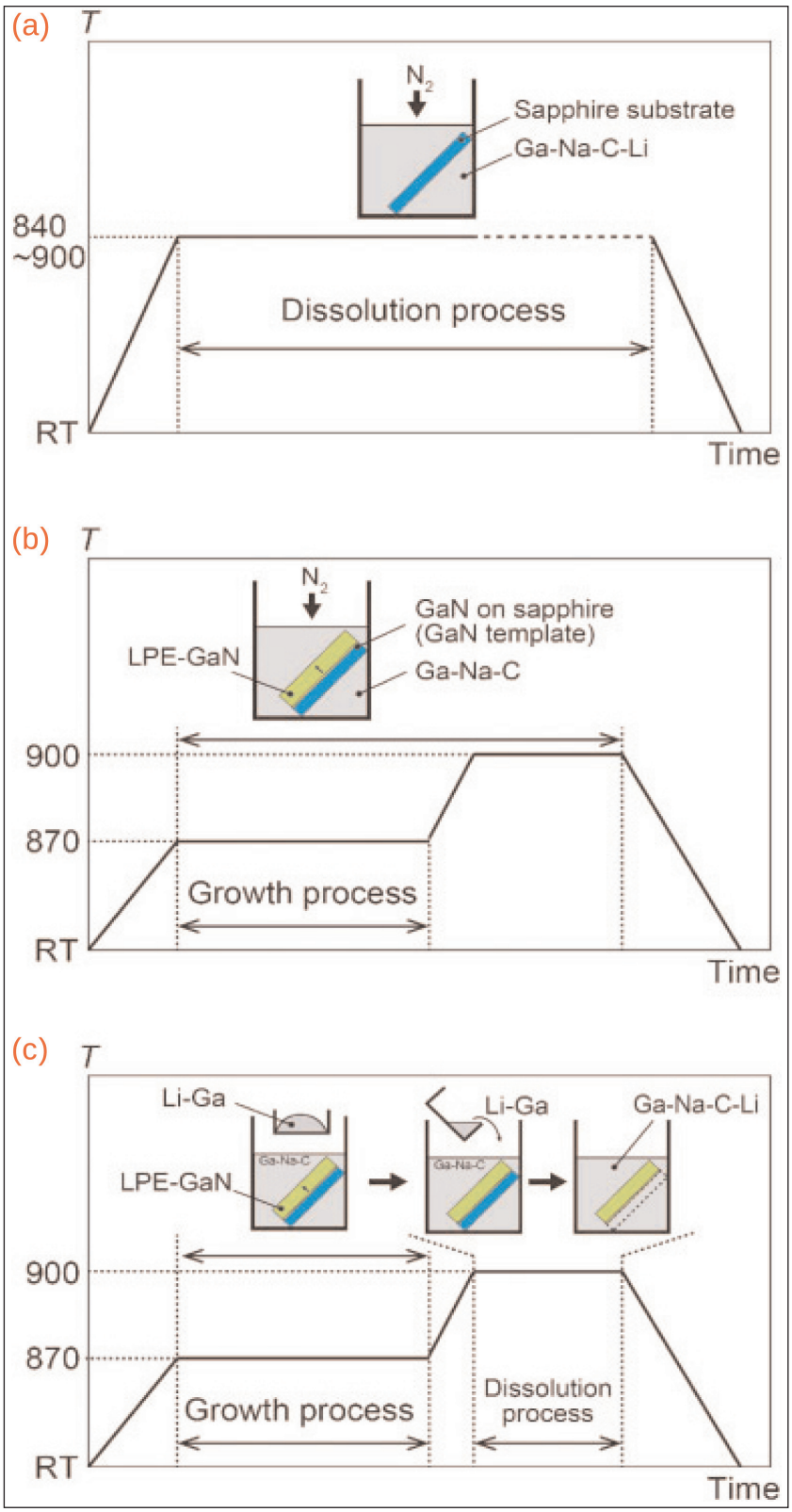

Figure 1. Diagrams of growth temperature and schematics of processes: (a) investigating sapphire solubility, (b) typical LPE, and (c) dissolving sapphire substrate after LPE.

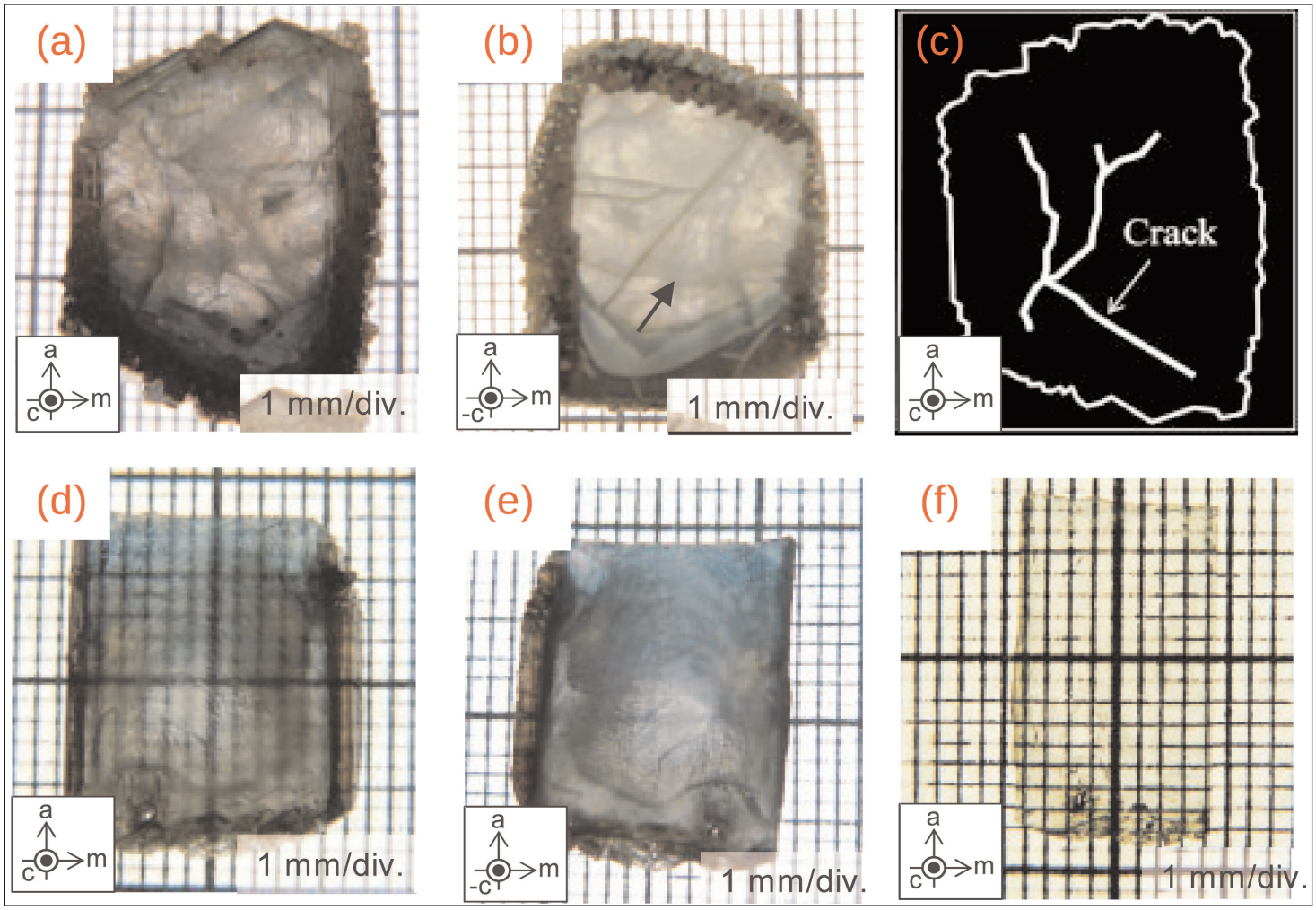

Figure 2. Transmission optical images of as-grown (a) c-face and (b) back-side surfaces of GaN crystal grown on c-GaN template without sapphire dissolution (sample 1). Black arrow indicates sapphire substrate. (c) Schematic of as-grown c-face surface. Transmission optical images of as-grown (d) c-face and (e) back-side surfaces of GaN crystal grown on c-GaN template, followed by sapphire dissolution (sample 2). (f) Optical image of sample 2 finished with chemical mechanical polishing.

4.0MPa. Before the sapphire dissolution, the temperature was raised to 900°C for 24 hours. Then Li and more Ga were added to the crucible. The extra Ga was designed to suppress Li evaporation. The amount of Li and Ga was 4–5 mol%. The substrate was removed after 24 hours dissolution. The dissolution process was optimized to avoid the formation of GaN polycrystals that can deposit on the grown GaN, reducing its crystallinity.

X-ray analysis of the residues left in the crucible after the dissolution of the sapphire indicated that the Al_2O_3 reacted with Li to form Al, Li_2O, $LiAlO_2$, Li_5AlO_4 and Li_9Al_4, as reported by others.

The sample (1) with sapphire substrate had a GaN layer that was 1.9mm thick. For sample (2), where the sapphire substrate was removed by the Ga-Na-C-Li solution, the thickness was 1.0mm. The dislocation densities of both samples was about $10^6/cm^2$. X-ray analysis showed a reduced full-width at half-maximum (FWHM) of the 002 rocking curve for sample 2: 50arcsec compared with 100 arcsec for sample 1. The reduced crystal quality of sample 1 was possibly due to slight misorientation arising from cracks.

We will fabricate an extremely low-dislocation-density, low-curvature, and large-diameter GaN substrate with high yield by combining the Na-flux coalescence growth and sapphire dissolution techniques

The researchers also believe that the sapphire dissolution technique would be useful for avoiding cracks in Na-flux growth on multipoint-seed GaN substrates. With such epitaxy, cracks form where there is a large contact interface between coalesced GaN and the sapphire substrate.

The researchers write that "in the future, we will fabricate an extremely low-dislocation-density, low-curvature, and large-diameter GaN substrate with high yield by combining the Na-flux coalescence growth and sapphire dissolution techniques." ■

http://doi.org/10.7567/APEX.9.071002

Author: Mike Cooke

Correcting charge polarization calculations

Simulations could need amendments, with practical and theoretical implications.

Researchers at University of California Santa Barbara (UCSB) and Rutgers University in the USA believe that charge polarization in III-nitride materials has not been adequately understood up to now [Cyrus E. Dreyer et al, Phys. Rev. X vol6, p021038, 2016]. Understanding charge polarization is vital for improving both light-emitting and electronic devices based on III-nitride (III-N) semiconductors, where the 'III' component consists of gallium (Ga), indium (In) and/or aluminum (Al).

For light-emitting devices, differences in charge polarization of the III-N chemical bond in the various epitaxial layers induce interface charges and electric fields that reduce the efficiency of electron–hole recombination into photons. This is commonly referred to as the quantum-confined Stark effect (QCSE).

By contrast, the effect of polarization is positive for electronics, where the charge polarization leads to the creation of a high-mobility confined 'two-dimensional' electron gases (2DEGs) near the interface between a GaN buffer and AlGaN or InAlN barrier layers. The 2DEG is used as a conduction channel controlled by a gate structure, giving a high-electron-mobility transistor (HEMT) operation with potential applications to power switching and high-frequency power amplification.

The III-nitrides used for light-emitting devices and for electronics have a wurtzite crystal structure and are typically grown along the c-axis by metal-organic chemical vapor deposition (MOCVD), molecular beam epitaxy (MBE), or hydride vapor phase epitaxy (HVPE) processes. The wutzite crystal structure is not inversion symmetric along the c-axis direction and this leads to the presence of polarization fields in heterostructures and quantum wells. The effect is worst when growth is along the c-axis, as is normal for commercial production.

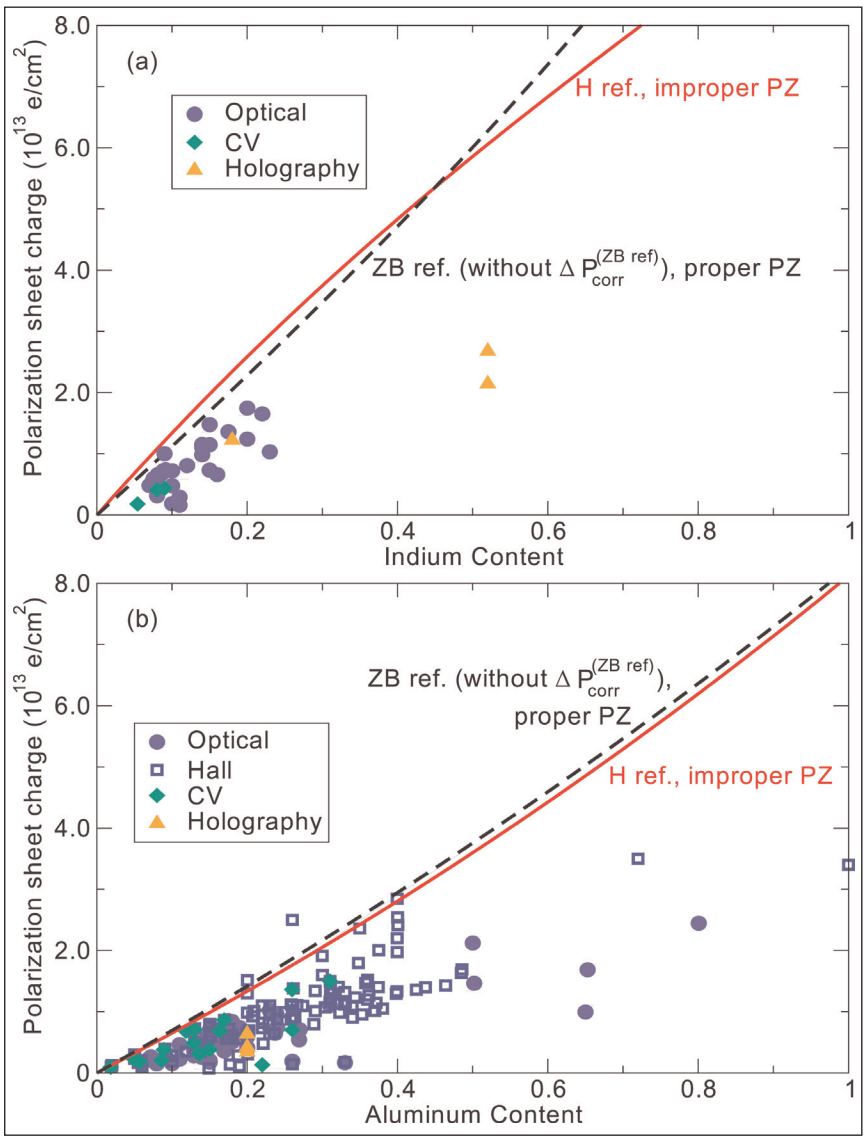

Figure 1. Absolute values for polarization sheet charges at (a) InGaN/GaN and (b) AlGaN/GaN interface as function of alloy content predicted from spontaneous polarization constants calculated using either zincblende (ZB) reference structure and proper piezoelectric constants (black dashed curve), or hexagonal (H) reference structure and improper piezoelectric constants (red solid curve). Points are experimental values from literature.

"For the past two decades, analysis and modeling of these fields has been based on a set of calculated polarization constants for both spontaneous polarization (SP) and piezoelectric (PZ) polarization," says UCSB's Chris van der Walle. "While these published constants are not wrong 'per se', due to lack of clarity about how to implement them, they have been used incorrectly in all the work that has been done since then. The main paper containing these constants has been cited more than 1800 times, just to give an idea how widespread the use of these values is," he adds. "We point out the error in the implementation, and we explain how to do the calculations correctly. We also explain why these

errors have not been noticed to date: it is due to the fact that actually TWO errors have been made, which fortuitously approximately cancel. We show, however, that in some cases the correct implementation does lead to qualitatively different results. Of course, for such an important piece of physics, with such important applications, doing things correctly is important in its own right."

As van der Valle notes, charge polarization of wurtzite structures contains both spontaneous and strain-dependent (piezoelectric) components. Piezoelectricity has many sensor and transducer applications from the ability to create voltages from strain. In the reverse direction, mechanical effects can arise from applied voltages.

The first of the problems concerns calculated coefficients for spontaneous polarization. These are defined with respect to a reference structure. The researchers claim it is crucial to choose this structure such that it allows consistent comparisons between materials.

The other factor concerns the piezoelectric constants that need to take into account changes in interface area with strain. According to the team, the correct coefficients for this are the so-called 'improper' constants. 'Proper' constants arise from short-circuited conditions, while the 'improper' open-circuit condition includes strain modifications.

Traditionally, zincblende has been used as the reference structure for calculating spontaneous polarization. The UCSB/Rutgers researchers comment: "We show that, because the zincblende structure has a non-zero formal polarization, this method results in a spurious contribution to the spontaneous polarization differences between materials." The team believes that a better choice of reference is a layered hexagonal structure, for which no correction term is needed when calculating polarization discontinuities.

Separating spontaneous and piezoelectric contributions in experimental data is very difficult and theory is often used to give constants for use in simulations. The UCSB/Rutgers considerations are not restricted to III-nitrides, but the researchers chose to focus on them due to their technological importance.

The researchers have compared their theory with experimental attempts to determine the sheet charge effects of polarization at InGaN/GaN and AlGaN/GaN interfaces (Figure 1). The conventional calculation gives very similar results to the new UCSB/Rutgers evaluation.

With a few exceptions, both models give higher values than the widely scattered data. Experimental methods often make assumptions about sample structures — quantum well (QW) widths, compositions, profiles, etc — that deviate from reality.

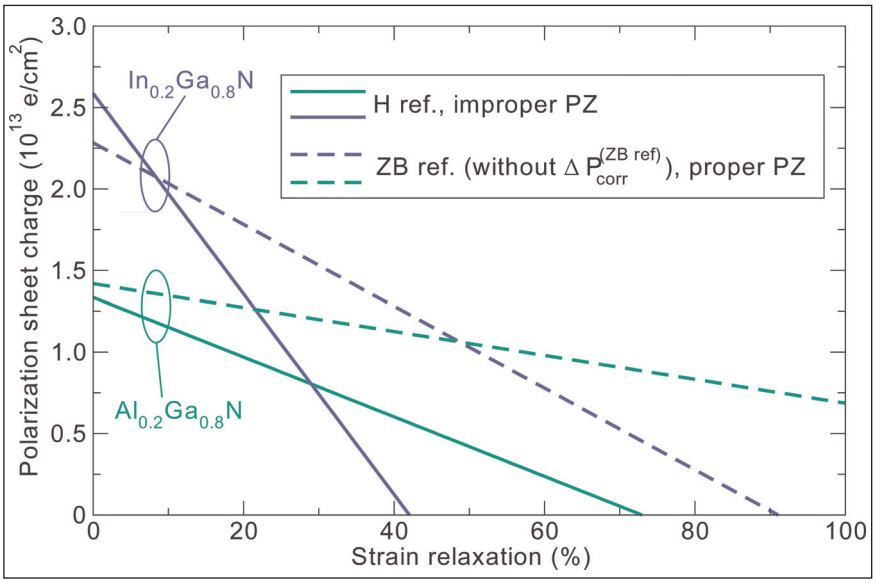

Figure 2. Absolute values for polarization sheet charges at $In_{0.2}Ga_{0.8}N$/GaN (blue) and $Al_{0.2}Ga_{0.8}N$/GaN (green) interface as a function of percentage strain relaxation: 0% relaxation corresponds to perfectly strained layers, 100% relaxation to an unstrained overlayer at its bulk lattice constant. Solid curves are proposed 'correct' implementation (H reference for SP and improper PZ constants); dashed curves are current practice (ZB reference for SP, without correction term, and proper PZ constants).

"It has been shown recently that taking into account the deviations from ideal QW structures when interpreting experimental observations can account for the apparent discrepancy between the measurements and theoretical prediction of polarization fields," says the researchers. "Such deviations are expected to be significant for InGaN/GaN because of the large lattice mismatch and the large difference in optimal growth temperatures for GaN and InGaN."

For AlGaN, "experimental uncertainties that can influence fields, such as incomplete strain relaxation in buffer layers, and differences in background doping" are cited as problems in matching data and models.

The researchers suggest that the small lattice mismatch between AlGaN and GaN also makes the difference less significant between the models. For InGaN/GaN, the difference is more significant at indium contents above 0.5 due to increasing lattice mismatch. Present growth technologies restrict high-quality InGaN to indium content less than about 20%. "This will be important for the prediction of polarization fields in applications such as tunnel field-effect transistors based on thin, high-indium-content interlayers," the researchers suggest.

There are also larger expected effects where there is strain relaxation, according to the research (Figure 2), where there is a much faster fall-off in bound charge than the conventional approach would predict. ■

http://journals.aps.org/prx/abstract/10.1103/PhysRevX.6.021038

Author: Mike Cooke

Probing potential to understand efficiency droop in InGaN LEDs

Korea University sees shift of electron depletion from light-emitting region to non-radiative p-type contact region with increasing current.

Korea University has sought to better understand the efficiency droop phenomenon that hits the performance of indium gallium nitride (InGaN) light-emitting diodes (LEDs) at higher currents by using a conducting diamond tip to probe the potential in the various layers of the device [Taewoong Kim et al, Appl. Phys. Lett., vol108, p231101, 2016].

The sample for the voltage probing consisted of 2.5μm of n-GaN, a 110nm superlattice (SL), an 80nm multiple quantum well (MQW), a 45nm electron-blocking layer (EBL), 60nm of p-GaN, and 60nm of indium tin oxide (ITO). These layers were grown on sapphire. The quantum wells consisted of $In_{0.14}Ga_{0.86}N$ with an estimated 2.76eV bandgap.

The experimental setup consisted of the LED material mounted on its side and probed with a conductive diamond tip probe (Figure 1). A similar setup has been used by Korea University and LG Innotek to probe temperature variations in InGaN LEDs [E. Jung, et al, Appl. Phys. Lett. vol106, p041114, 2015]. Series resistance of the LED sample was estimated at 2.96Ω, based on current-voltage measurements. Maximum external quantum efficiency (EQE) was estimated to occur at 3.48A/cm^2, according to Jung et al.

The conductive diamond tip was designed for Seebeck microscopy. The conducting boron-doped diamond was grown by chemical vapor deposition (CVD). The tip radius was around 50nm. High contact pressure (~27GPa) was used to reduce the bandgap difference between the probe and sample, allowing electrical connection to be made. The contact diameter was around 25nm.

Measurements were carried out after about 10 minutes when the LED and probe had attained a thermal steady state. Potential profiles for four different

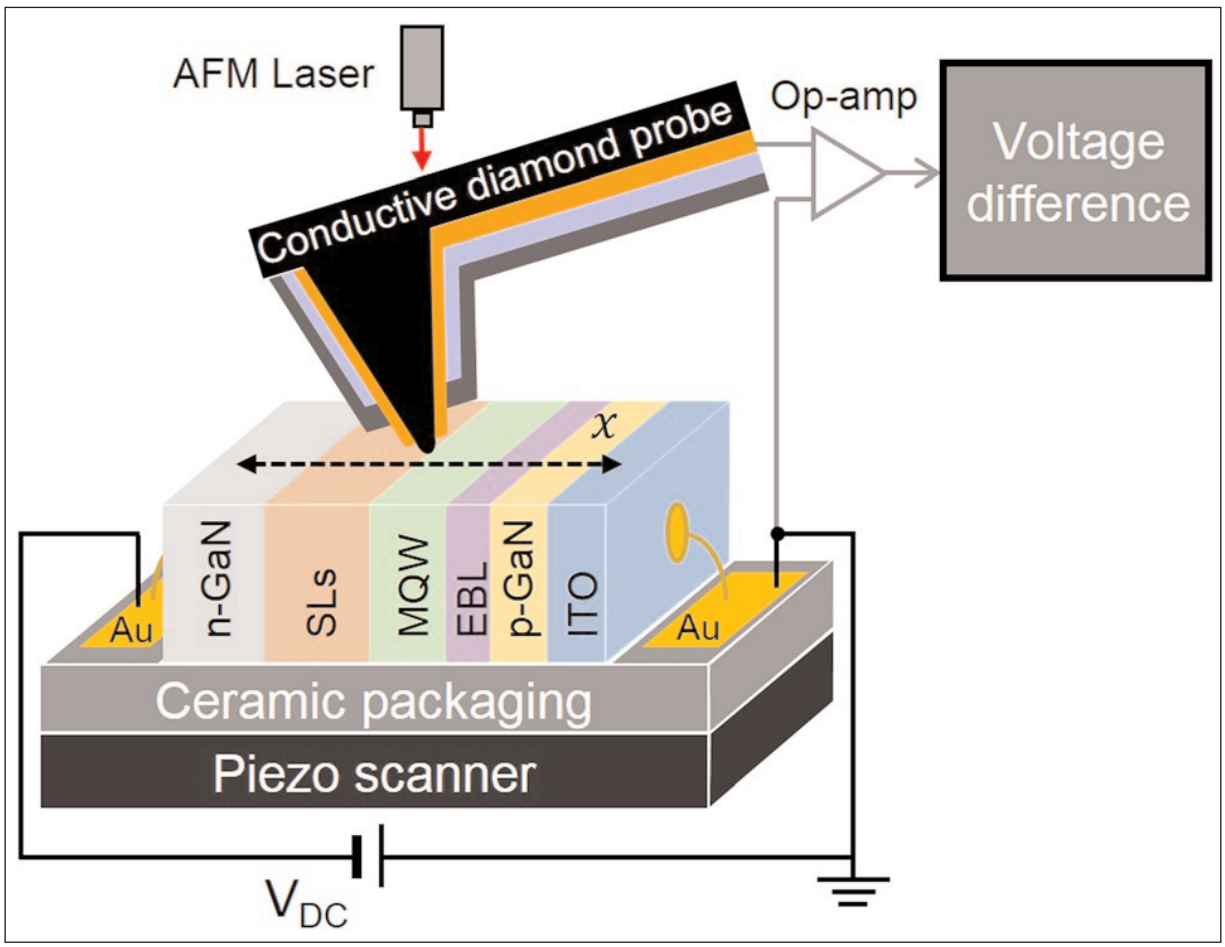

Figure 1. Schematic of experimental setup for measuring voltage profile on cross section of operating LED. Gold electrode of p-GaN side is grounded, measured voltage drops from 0V to negative value, approaching n-GaN.

current densities were averaged over 20 measurements to reduce noise effects (Figure 2).

The researchers interpret the kink in the profile as showing increased conductivity of electrons into the p-GaN region with increased current. These electrons then recombine non-radiatively in an electron 'depletion region'.

The researchers attribute the larger potential drop over the last part of the MQW region at higher currents (Figure 2d) as an indication that "more electrons and holes recombine in the last quantum well near the EBL as the current density increases."

Where efficiency droop begins to set in at lower current injection (Figure 2b), it is more difficult to see a kink and the researchers suggest that the electron depletion occurs then within the EBL.

At maximum EQE (Figure 2a), the researchers believe the electron depletion occurs in the MQW, as desired. "However, even the steepest voltage gradient in the profile shown in [Figure 2a] is relatively gentle compared with those shown in [Figures 2b-d]," the team writes. "This is because, at this lowest current density, the charge carriers deplete through a different mechanism (radiative recombination) to those occurring at other higher current densities (non-radiative recombination)."

The proportion of voltage drop across the MQW also varies with increasing current from ~50% of the total at 3.48A/cm^2 to ~30% at 22A/cm^2. "This directly shows that the proportion of the applied energy spent for radiative recombination decreases with increases in current density," the researchers comment.

The decrease in EQE in the same range is about 10%, compared with 40% ((50−30)/50) for the MQW potential drop fraction.

The researchers explain: "The actual electrochemical potential should be the average of the electrochemical potentials of electrons and holes weighted by carrier densities only. However, the measured voltage is the average of the electrochemical potentials weighted not only by the carrier densities but also by the carrier mobilities as well. As the mobility of electrons in GaN is much higher than that of holes, the measured voltage drop occurring in the EBL and p-GaN appears to be much greater than the actual potential energy drop."

The researchers give 50 as the approximate factor of electron/hole mobility in GaN. ■

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Author: Mike Cooke

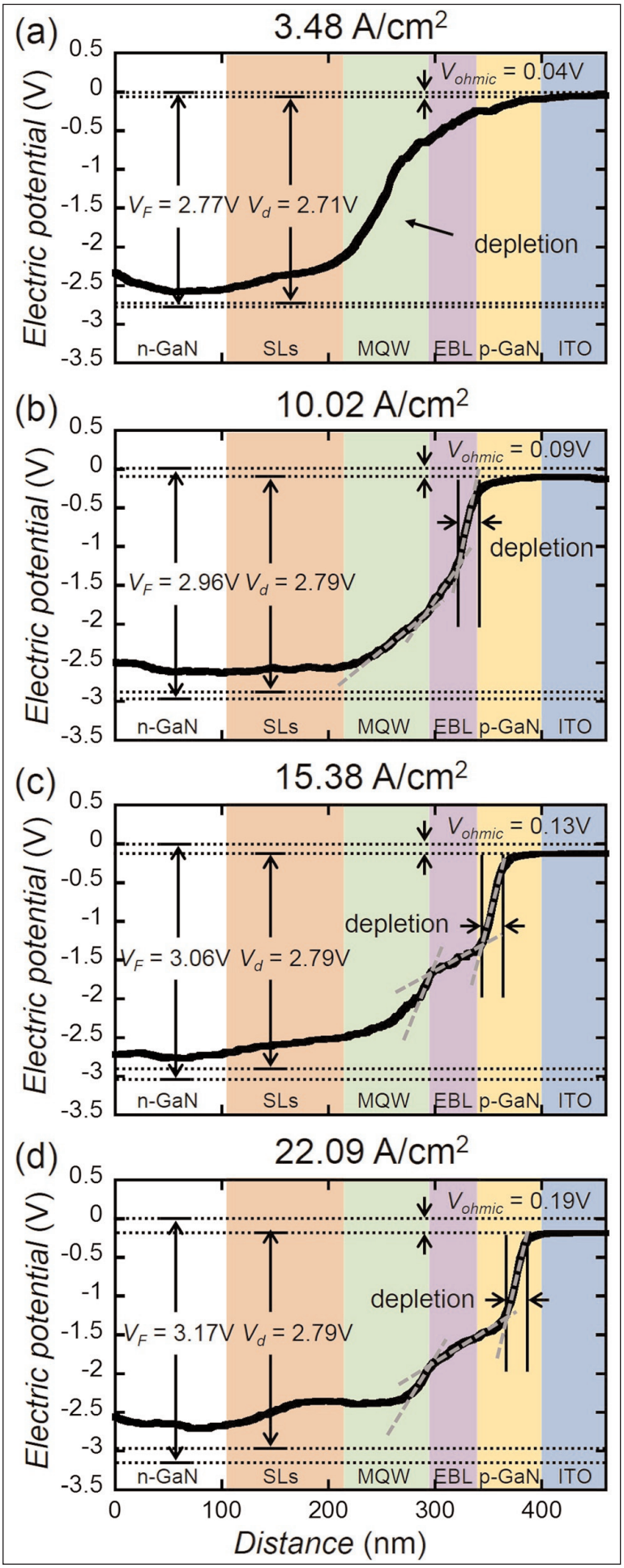

Figure 2. Averaged voltage profiles on cross section of operating LED obtained at (a) 3.48A/cm^2, (b) 10.02A/cm^2, (c) 15.38A/cm^2, and (d) 22.09A/cm^2.

Dependence of efficiency droop on carrier density in non-polar samples

Researchers in the UK find behavior is similar to that of conventional polar samples.

The University of Manchester and the University of Cambridge in the UK have been comparing efficiency droop in low-temperature photoluminescence (PL) experiments on non-polar m-plane and polar c-plane indium gallium nitride (InGaN) quantum wells (QWs) [M. J. Davies et al, Appl. Phys. Lett., vol108, p252101, 2016]. The researchers found similar droop behavior in the samples, suggesting that the effect is intrinsically determined by carrier density.

The team comments: "These observations suggest that there is a common mechanism responsible for the efficiency droop, in which delocalized carriers recombine non-radiatively. Our data do not reveal the nature of the non-radiative recombination mechanism, although either Auger recombination or Shockley–Read–Hall recombination at defects is a plausible candidate."

Using non-polar or semi-polar InGaN structures for light-emitting diodes (LEDs) has been found to ease droop in terms of current density. It is usually thought that the reduced efficiency droop in non-polar or semi-polar devices is due to the partial removal of electric fields created by interface charges arising from differences in charge polarization between the various layers of the device. However, some theoreticians at University of California Santa Barbara (UCSB) and University of Michigan have suggested that the carrier density achieved at a certain current density is lower in non-/semi-polar devices, delaying droop onset.

The researchers grew InGaN multiple quantum wells (MQWs) on non-polar m-plane free-standing GaN from wafer company Ammono SA. The wafer was mis-cut 2° towards the (0001) axis. Metal-organic vapor phase epitaxy (MOVPE)

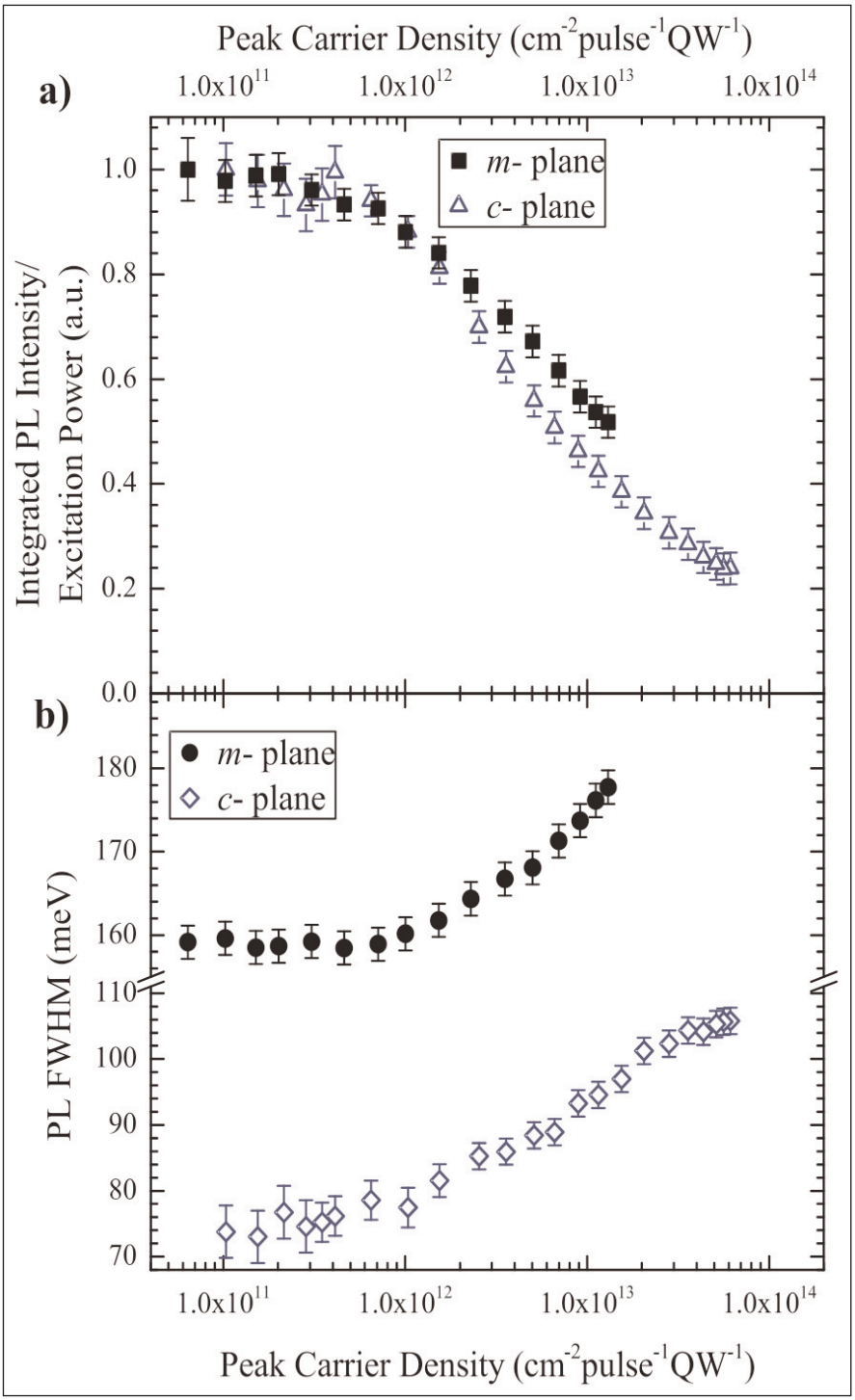

Figure 1. (a) Integrated PL intensity as a function of peak carrier density of m-plane and c-plane samples, measured at 10K, as a function of peak carrier density. (b) FWHM of PL spectra as a function of peak carrier density.

was used in a quasi two-temperature process. Five 2.4nm $In_{0.28}Ga_{0.72}N$ wells were grown separated by 6.1nm GaN barriers. The final GaN barrier provided a capping layer. The polar c-plane sample consisted of a single 2.9nm $In_{0.15}Ga_{0.85}N$ well grown using a 750°C single-temperature MOVPE process. Both samples had low-temperature peak emission at ~2.660eV.

The 10K photoluminescence (PL) measurements were carried out with excitation from 100fs (10^{-13}s) 400kHz pulses of 4.881eV photons sourced by a frequency-tripled mode-locked titanium-doped sapphire laser beam. "The use of a pulsed laser, with a pulse duration much shorter than the carrier recombination lifetimes for both samples, ensures that the peak carrier concentration in the QWs is determined by the power density of the excitation source," the researchers comment.

The low-excitation PL peaks for the m- and c-plane samples came at 2.615eV and 2.669eV, respectively. The corresponding full-widths at half maximum (FWHMs) were 158meV and 75meV. The FWHM values remained constant within experimental error until the excitation reached a level where the carrier density in the wells was around $1x10^{12}/cm^2$ per pulse per well (Figure 1). The efficiency in both samples begins to droop around $3x10^{11}/cm^2$/pulse/well.

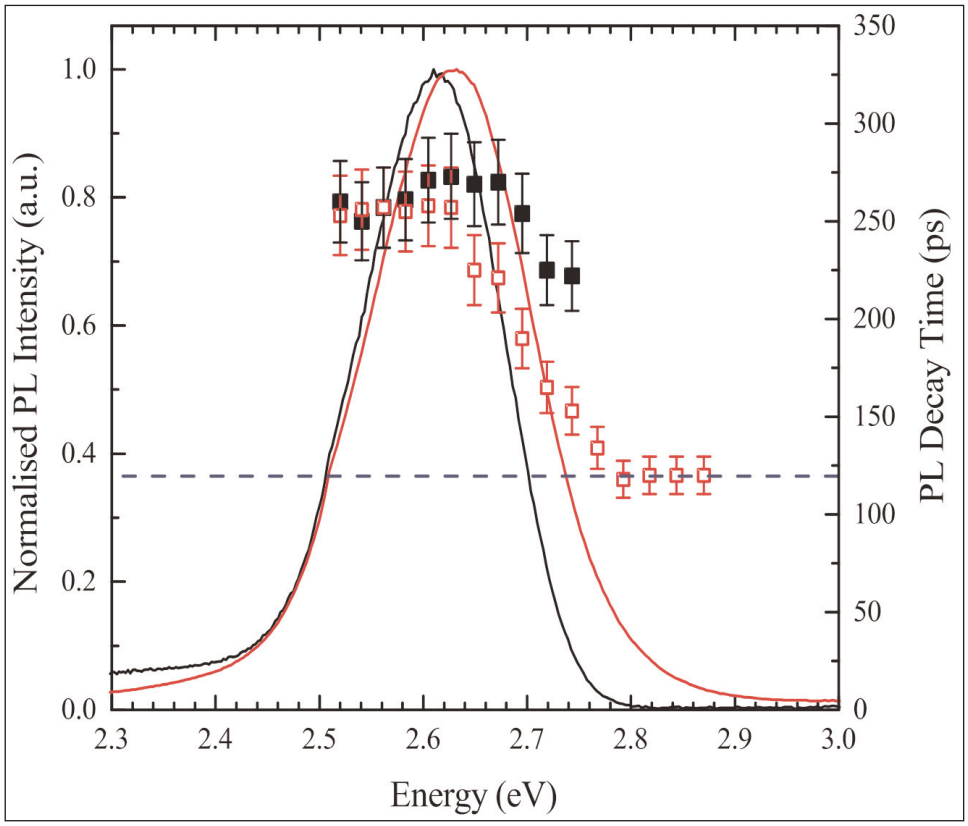

Figure 2. Time-integrated PL spectra for m-plane sample along with PL decay times measured across PL spectrum for peak carrier excitation densities of $10^{11}/cm^2$/pulse/QW (black line and black data points) and $1.4x10^{13}/cm^2$/pulse/QW (red line and red data points), i.e. measured below and above the onset of efficiency droop. Blue dashed line indicates instrumental time response.

Although the carriers were largely created in the GaN layers, given the excitation energy being higher than the ~3.4eV bandgap, the ~2.6eV PL peak led the researchers to "assume that all the carriers are captured by the QW(s); this assumption is supported by the fact that we do not observe a significant amount of recombination from the various GaN layers in the samples." The researchers also believe that in the 5-well m-plane sample, the carriers are evenly distributed between the wells.

The researchers also measured the decay time across the spectra below and above the onset of droop in the m-plane sample (Figure 2). Above the onset, there was a high energy tail in the spectrum, increasing the FWHM. On the low-energy side of the peak, the decay constant remained relatively the same (~260ps) below and above droop onset.

In the non-droop condition with low excitation, there was a slight drop in decay time on the high-energy side of the peak to around 225ps. The team comments: "The origin of this reduction is currently unclear but we suggest that it may be due to the effects of carrier hopping to deeper localized states, as has been observed previously in other localized systems."

For the high excitation droop measurements, the high-side decay constant falls to the instrumental response limit of 120ps. The researchers comment: "The fact the decay constants associated with the main emission band are unchanged at high excitation power densities suggests that the recombination responsible for the main emission band remains purely radiative at the highest carrier densities. This suggests that the new recombination channel on the high-energy side of the spectrum is affected by non-radiative processes that could be responsible for the short decay constant."

The m-plane decay behavior is similar to results of other groups on c-plane samples. In that case, the fast high-energy side decay was attributed to recombination of weakly localized or delocalized carriers when the localized states are saturated. The localization/delocalization of holes seems to be a particularly important precursor for non-radiative losses, giving droop. ■

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Author: Mike Cooke

Boosting hole injection by including indium gallium nitride in two-layer p-contact

Technique increases LED light output power by almost 40% at 75mA injection and wall-plug efficiency (WPE) by 26%.

China's South China University of Technology and Taiyuan University of Technology have developed a p-contact layer for indium gallium nitride (InGaN) light-emitting diodes (LEDs) with improved hole injection [Zhiting Lin et al, J. Phys. D: Appl. Phys., vol49, 285106, 2016]. The researchers designed a two-layer p-contact consisting of p-GaN and p-$In_{0.05}Ga_{0.95}N$ that increased light output power by almost 40% at 75mA injection and wall-plug efficiency (WPE) by 26%.

Hole injection is a particular problem in InGaN and other III-nitride LEDs since p-type doping is conventionally achieved with magnesium that has an acceptor level a couple of hundred meV (~180meV) above the GaN valence band. Doping for electron-majority n-type material is usually achieved with silicon, where the donor level is ~15meV below the GaN conduction band. The disparity leads to an imbalance of carrier injection into the active region where it is hoped the electrons and holes will recombine as photons. The imbalance causes non-radiative recombination and other losses such as electron overshoot into the p-GaN contacts.

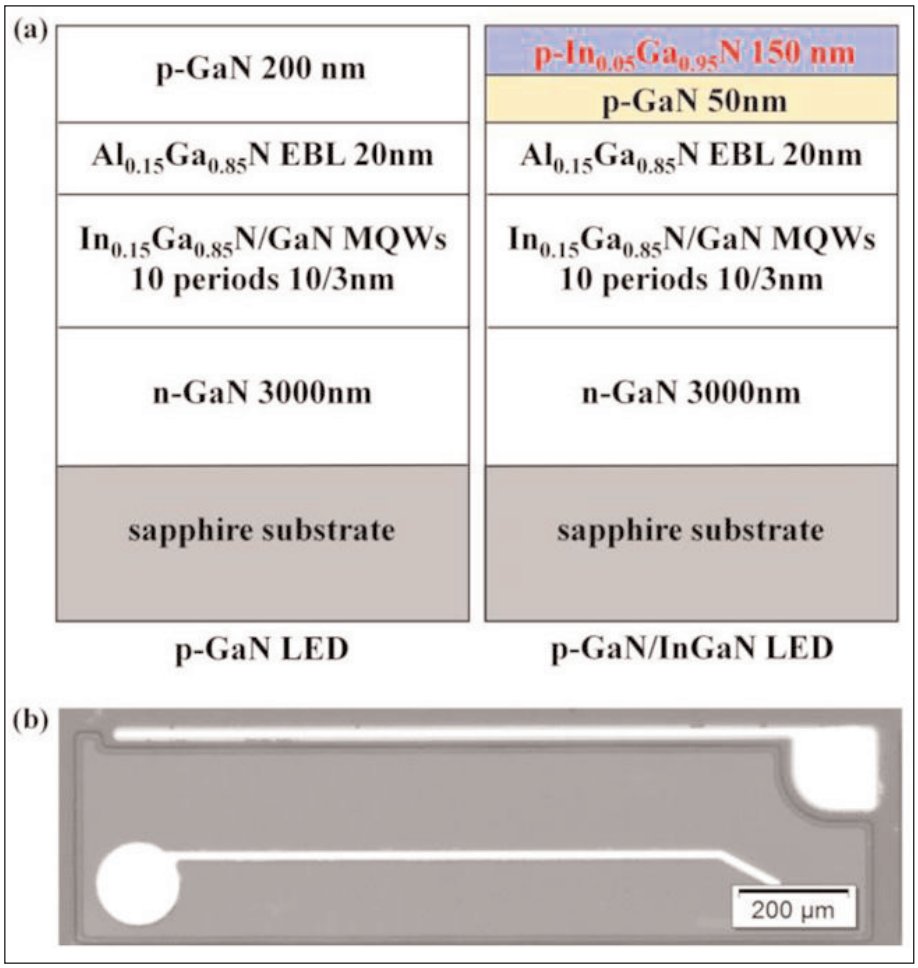

Figure 1. (a) Structures of p-GaN and p-GaN/p-InGaN LEDs and (b) optical microscope image of LED chip.

Two LED samples were created — one a traditional LED wafer with p-GaN contact and the other with a combination of 50nm p-GaN and 150nm p-InGaN (Figure 1). The materials were grown by metal-organic chemical vapor deposition (MOCVD) on sapphire. The fabricated devices were conventional lateral LEDs with plasma etched mesas, 250nm ITO (indium tin oxide) transparent conductive p-electrode, and chromium/platinum/gold contact pads. The chip areas were 750μmx220μm.

In actual electroluminescence experiments (Figure 2), the p-GaN/p-InGaN LED showed a 39.4% increase over the pure p-GaN device in light output power at 75mA injection (83.2mW/59.7mW = 1.394).

The droop in WPE was 26.2% from the peak for the pure p-GaN LED, compared with 41.6% for p-GaN/p-InGaN. However, the WPE peak was lower for the pure p-GaN LED and the p-GaN/p-InGaN maintained higher WPE values through to 75mA. At 75mA, the WPE of the p-GaN/p-InGaN LED was still 26% greater than for the pure p-GaN contacted device.

The increased droop for the p-GaN/p-InGaN LED arises from increased resistance at increased current injection. At 20mA, the forward voltage was 3.46V for a pure p-GaN contact and 3.71V for p-GaN/p-InGaN.

The researchers comment: "The increasing electric

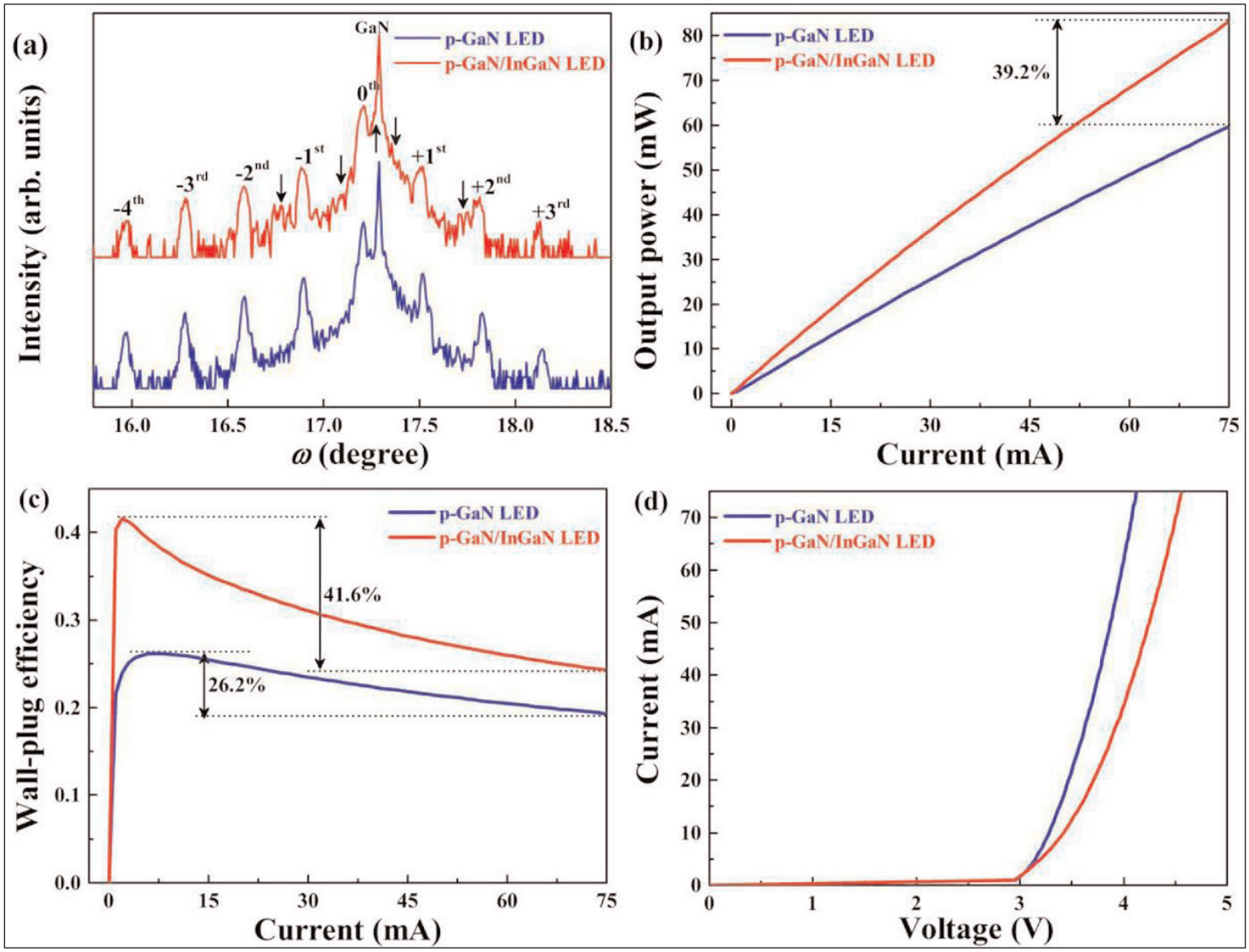

Figure 2. Comparisons of p-GaN and p-GaN/p-InGaN LED wafers and LED chips: (a) high-resolution x-ray diffraction ω – 2θ symmetrical (0002) scans; (b) light output power; (c) wall-plug efficiency; and (d) current versus voltage curves.

resistance could result from the fact that the thick p-InGaN layer might relax on the p-GaN layer and thus crystalline defects are generated in the p-InGaN layer. These crystalline defects serve as scattering centers, resulting in reduction of hole mobility."

Simulations suggest one effect of the p-GaN/p-InGaN contact layer is to increase the electron barrier of the aluminium gallium nitride (AlGaN) electron-blocking layer (EBL), while at the same time reducing the barrier to hole injection. The electron barrier was increased in the models from 489meV for a pure p-GaN contact to 528meV for p-GaN/p-InGaN. The respective hole injection barriers were 318meV and 306meV. EBLs are commonly implemented to confine electrons to the MQW active region, preventing overshoot into the p-GaN contacts.

Another effect suggested by the simulation is the creation of a triangular hole well at the p-GaN/p-InGaN interface. The density of holes in the region of the well is estimated to be $2x10^{18}/cm^3$, compared with less than $5x10^{16}/cm^3$ for the same position in the pure p-GaN contact layer. The knock-on effect at the EBL interface is an increase in hole density from $2x10^{18}/cm^3$ to $6x10^{18}/cm^3$.

"This phenomenon means that there are more holes available to inject into the MQW region, which is very similar to the result of increasing acceptor-doping density of GaN-based materials," the team writes.

The result of the increased hole injection with p-GaN/p-InGaN contacts at $100A/cm^2$ is expected to be a 25% increase in the number of holes in the multiple quantum well (MQW) light-emitting active region. There is also predicted a 10% increase in electron numbers in the MQW. The radiative recombination at $100A/cm^2$ should also increase by 55%. The simulated droop in internal quantum efficiency (IQE) from the peak value to that at $100A/cm^2$ is 32.9% for the p-GaN LED and 21.7% for the p-GaN/p-InGaN device. ■

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Author: Mike Cooke

Relaxing multiple quantum wells with low-temperature barriers

South China University of Technology has used low growth temperature to relax strain in III-nitride heterostructures, boosting light output power by 23%.

South China University of Technology has used low-temperature barriers between indium gallium nitride (InGaN) multiple quantum wells (MQWs) to improve the light output power of light-emitting diodes (LEDs) by 23% to 63.83mW at 65mA [Zhiting Lin et al, Optics Express, vol24, p11885, 2016].

The aim of using low growth temperature was to relax strain in the III-nitride heterostructures. Strain can lead to piezoelectric fields that tend to pull electrons and holes apart, reducing recombination into photons. The researchers hope that their work will lead to increased application of III-nitride LED technology as solid-state lighting (SSL).

The team comments: "Improving the luminous efficiency for LEDs is very important in regard of the energy efficiency and cost efficiency for packaging processes by easing the challenge of heat dissipation, which is the best choice to cope with the large demands from the SSL market. However, the state-of-the-art LEDs are suffering from efficiency droop at high injection current, which has not been fully resolved so far."

The LED material (Figure 1) was grown on c-plane patterned sapphire by metal-organic chemical vapor deposition (MOCVD). The layer thicknesses were: 200nm GaN buffer, 4μm unintentionally doped GaN, 3μm silicon-doped n-GaN, 2nm/6nm 5-period $In_{0.13}Ga_{0.87}N$/GaN MQW, 3nm/12nm 7-period $In_{0.13}Ga_{0.87}N$/GaN MQW, 20nm magnesium-doped p-$Al_{0.15}Ga_{0.85}N$ electron-blocking layer (EBL), and 150nm magnesium doped p-GaN.

The quantum well layers were all grown at 750°C. However, the barriers for the first 5-period MQW were deposited at 840°C, while the second 7-period MQW barrier were processed at varying temperatures. The first MQW acted as a pre-strained layer over which the second MQW could be grown with reduced biaxial stress.

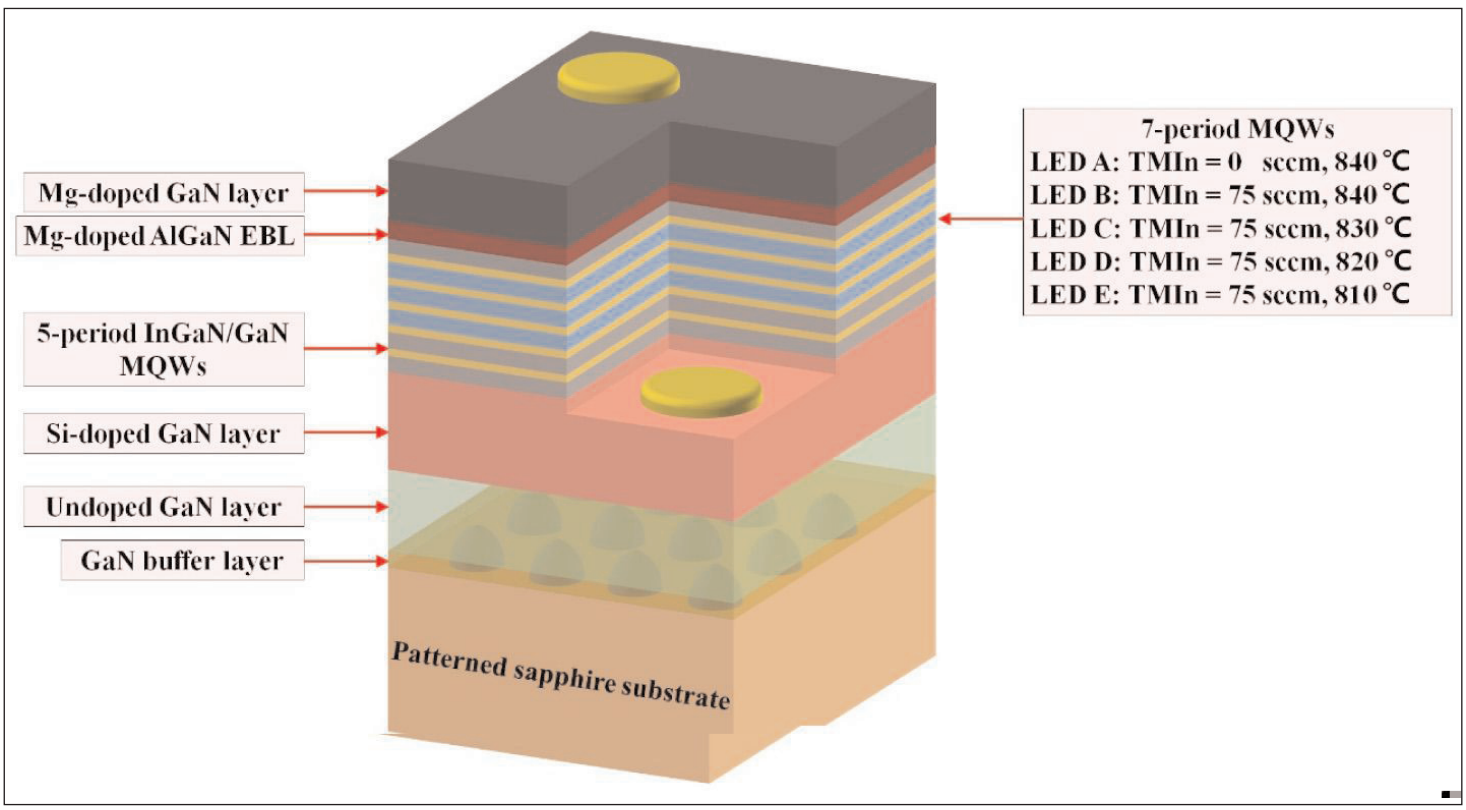

Figure 1. LED structure schemes.

Table 1. Structural parameters of second MQW pairs, FWHMs of −1st satellite peak and relaxation values of wells, R.

	Barrier parameters		Well parameters			
Samples	Thickness (nm)	In content	Thickness (nm)	In content	FWHM (arcsec)	R
LED A	12.09	0	2.92	13.14%	89.78	0%
LED B	12.05	0.60%	2.93	13.10%	92.55	0.96%
LED C	12.02	0.93%	2.97	13.11%	93.25	1.53%
LED D	11.98	1.28%	2.94	13.16%	97.46	2.88%
LED E	12.06	1.89%	2.92	13.13%	97.77	4.59%

Most of the barriers in the second MQW also contained indium. Changing the growth temperature of the barriers in the second MQW alters the strain and indium incorporation, as indicated by x-ray diffraction analysis (Table 1). Increased indium incorporation in the barriers reduces the difference in relaxed lattice constant compared with the well. The difference in coefficient of thermal expansion (CTE) is also reduced. This, along with the lower growth temperature, reduces thermally induced stress.

The materials were fabricated into standard lateral mesa LEDs with 250nm of indium tin oxide (ITO) transparent conductive oxide on the p-GaN top layer and chromium/platinum/gold n- and p-electrodes. The resulting chips were 750μmx220μm.

One effect of lower strain/stress on electroluminescence was found at low current injection, with the lowest-strain device E having a smaller blue-shift of 0.5nm between 2mA and 9mA, compared with 1.7nm for the highest-strain LED A. The researchers attribute this to the reduced quantum-confined Stark effect (QCSE) that arises from strain-dependent piezoelectric fields that become screened with increased current injection.

In terms of power output, the best performance was achieved by the medium-strain LED C (Figure 2).

At 65mA current injection, LED C had a boost of 23% over the normal LED A. The forward voltage at 20mA of the devices increased with decreasing strain. The forward voltage values for LEDs A to E were, in order, 3.28V, 3.30V, 3.34V, 3.37V and 3.39V. Higher forward voltage indicates increased resistance and power loss.

The researchers attribute the forward voltage trend probably to degraded crystal quality in the lower-strain devices. Degraded crystal quality can also increase non-radiative recombination of electrons and holes, reducing power output. Increasing full-width at half maximum (FWHM) values for photoluminescence with strain relaxation, from 19.2nm for LED A to 27.8nm for LED E, also supports the inference of degraded crystal quality in LEDs D and E.

The researchers also determined the wall-plug efficiency (WPE) droop at 65mA for devices A to E to be 34.69%, 33.66%, 33.48%, 22.83% and 15.79%, respectively. "From this result, we can see that the LED with larger relaxation in MQWs owns the weaker WPE droop, which is consistent with the mitigation of the QCSE," the researchers observe. It should also be pointed out that the peak of device E is lower than the other LEDs, making the low droop less impressive. ■

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Author: Mike Cooke

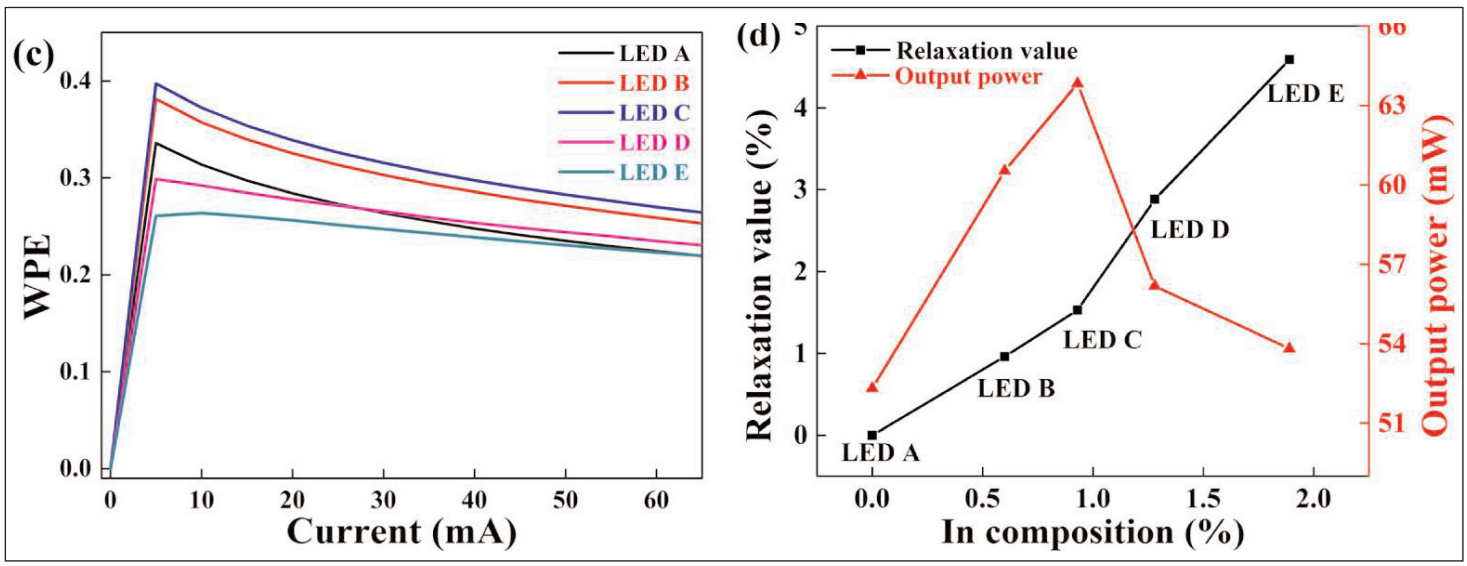


Figure 2. (a) Light output power versus current, (b) current versus voltage and (c) WPE versus current for LEDs A to E; (d) relaxation value of wells and light output power versus indium composition of barriers at 65mA.

Integrating gallium nitride optoelectronics on silicon

Researchers combine light-emitting diodes, photodetectors and waveguides on single chips, reports Mike Cooke.

Nanjing University of Posts and Telecommunications in China has been developing gallium nitride (GaN) on silicon technology with a view to monolithically integrated optoelectronic devices consisting of light-emitting diodes, photodiodes and waveguides [Wei Cai et al, Appl. Phys. Express, vol9, p052204, 2016]. Target applications include smart transmitters/receivers for wireless visible light communication (VLC).

The large difference in refractive index between gallium nitride (~2.45) and air (1) leads to total internal reflection, which makes it difficult to extract light from LEDs. However, total internal reflection is just what is needed for efficient low-loss confinement in waveguides.

The researchers comment on the particular fabricated structure (Figure 1): "The integrated device is similar to a bipolar junction transistor. The common n-contact is the base and the emitter is the LED, whereas the photodiode is the collector. The suspended waveguide is used for device connection. When the LED is turned on, photons are transported through the waveguide and absorbed in the photodiode, achieving the photonic integration of the emitter, waveguide, and photodiode on a single chip."

The devices were fabricated from heterostructure material deposited on 2-inch GaN-on-silicon templates. The layer structure consisted of a 900nm aluminium gallium nitride (AlGaN) buffer, 400nm of undoped GaN,

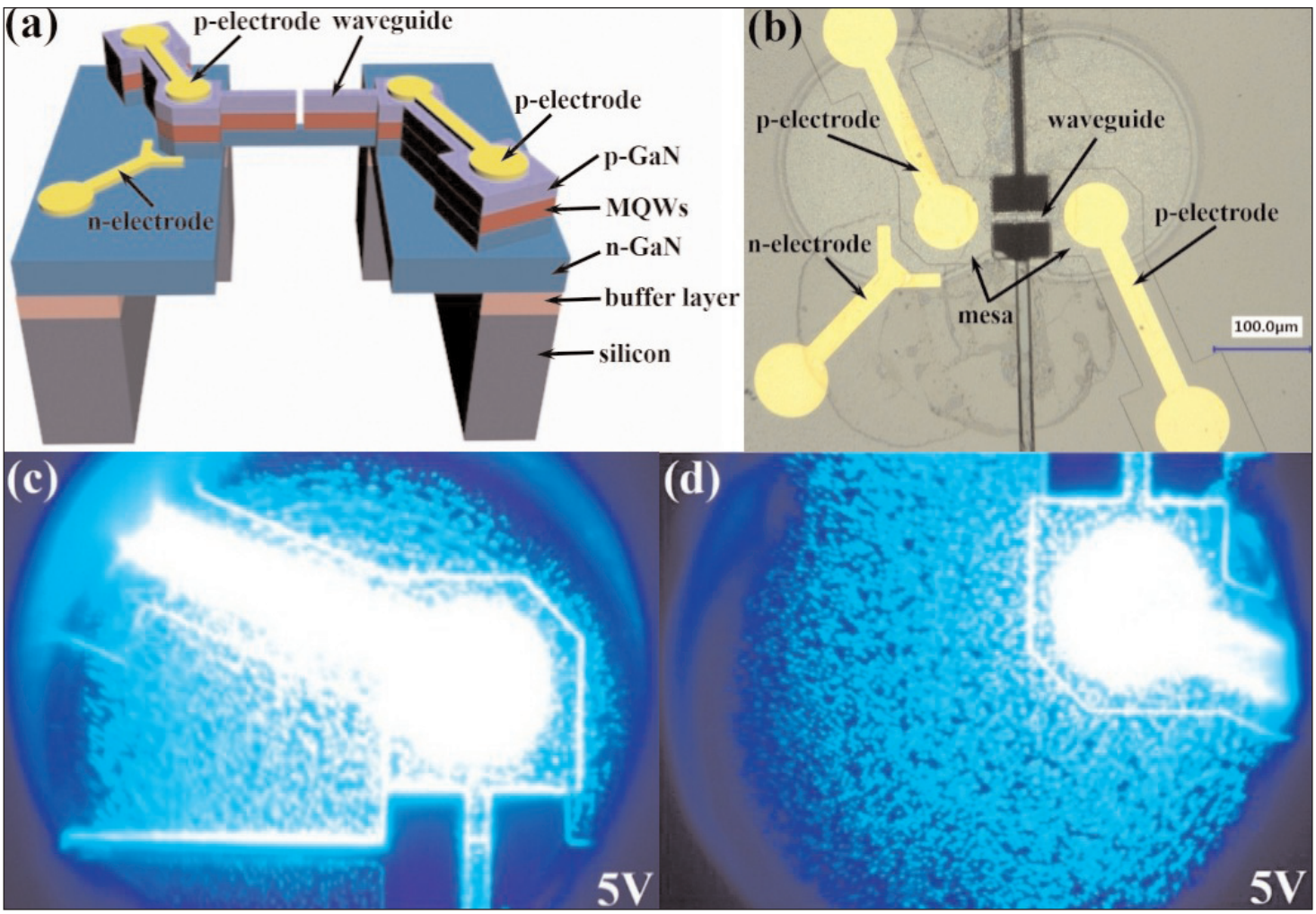
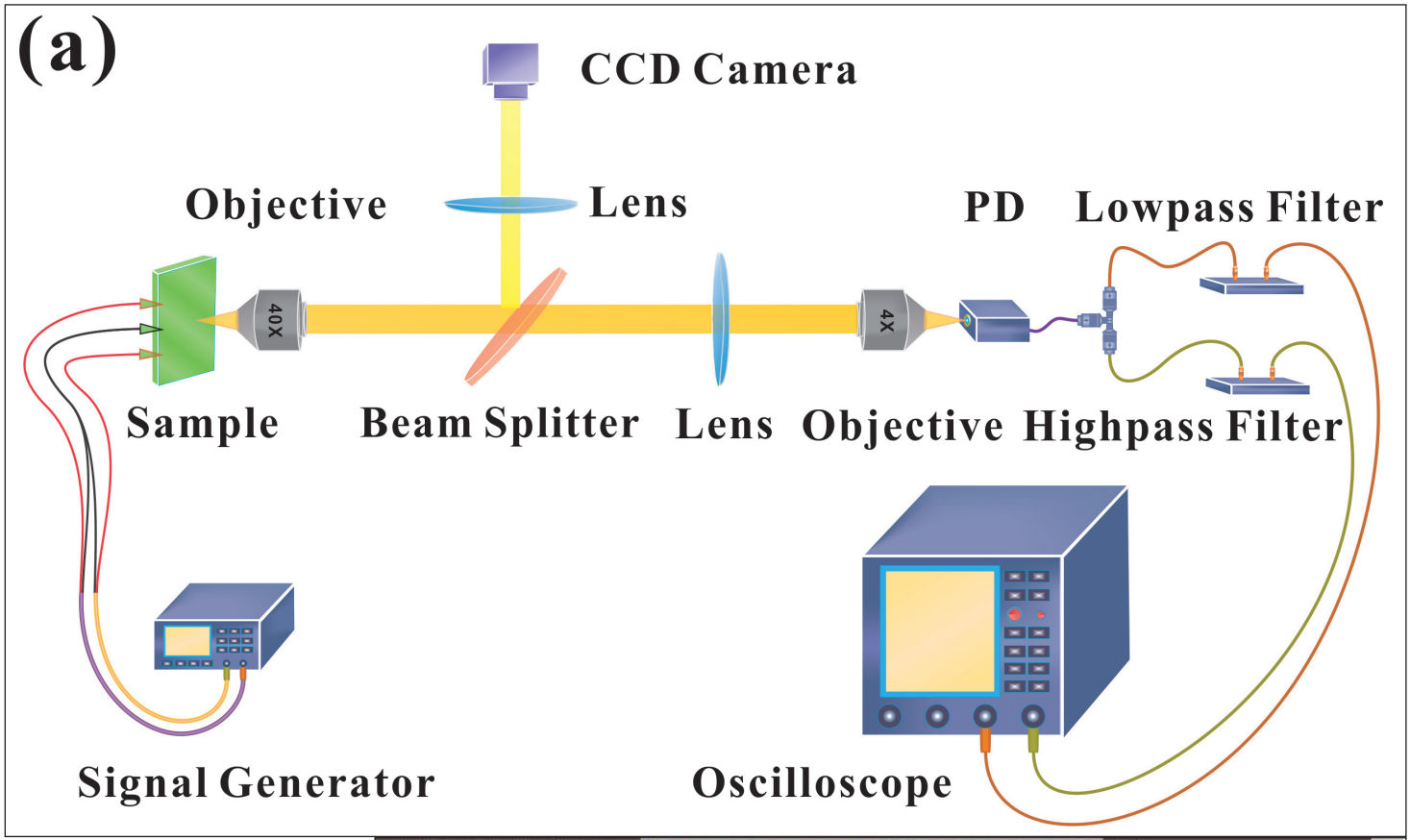


Figure 1. (a) Schematic cross section of integrated devices; (b) optical micrograph of suspended devices; (c, d) optical micrographs of light emission images obtained from silicon substrates.



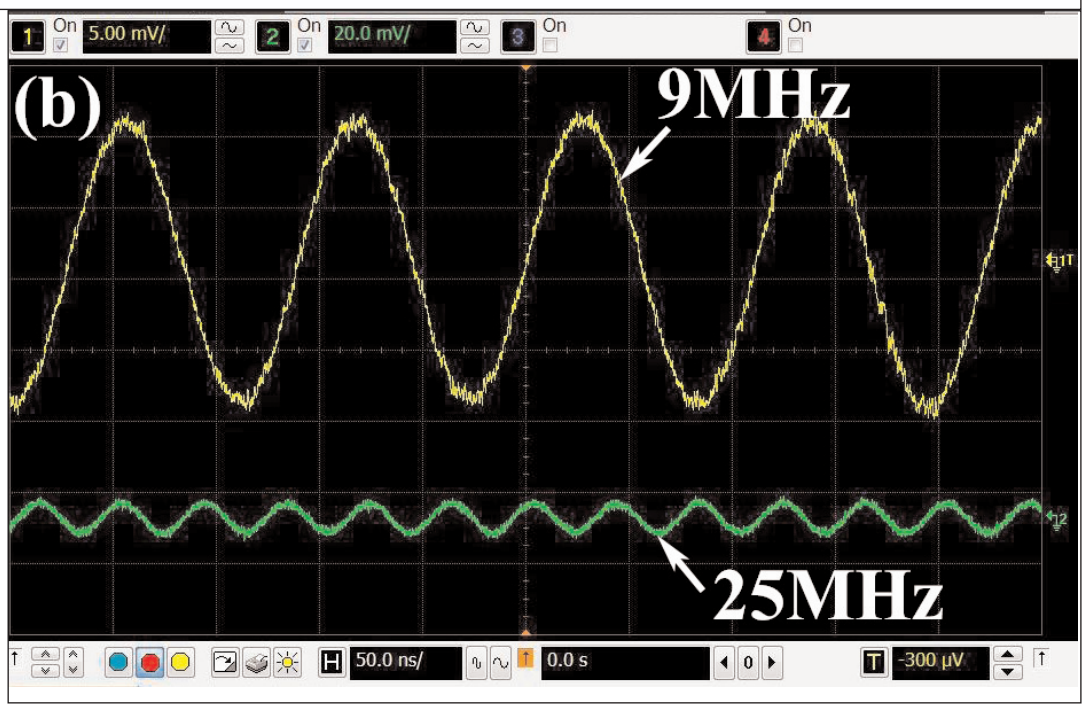


Figure 2. (a) Micro-transmittance setup. (b) Received output signals for integrated devices.

a 3.2µm n-GaN contact, a 250nm indium gallium nitride (InGaN) multiple quantum well with GaN barriers, and a 220nm p-GaN contact.

Fabrication began with isolation mesa etching. Contact with the n- and p-contact regions was made with annealed nickel/gold. Waveguide structures were formed with reactive ion etch (RIE). Silicon was also removed to give suspended membrane structuring when the wafers were thinned on the silicon side. The suspended waveguide region was 60µm long, 3µm thick and 10µm wide. Removal of silicon avoids light absorption by the substrate material.

Both ends of the waveguide could emit light under current injection, although the side closer to the common n-electrode was naturally brighter. Light guided in-plane could emerge at mesa facets. Some light escaped to air from the roughened bottom surface caused by reactive ion etch. The peak electro-luminescence emission was around 458.5nm wavelength at 6V bias.

The devices could be used with one for light emission and the other for photodetection. When a 10µm gap was made in the waveguide the photocurrent was much reduced, suggesting that the current was mainly induced by the guided light.

The researchers also tested the ability of both sides of the device to emit light modulated separately at 9MHz and 25MHz into free space (Figure 2). The researchers report: "The sine waves at 9MHz and 25MHz are

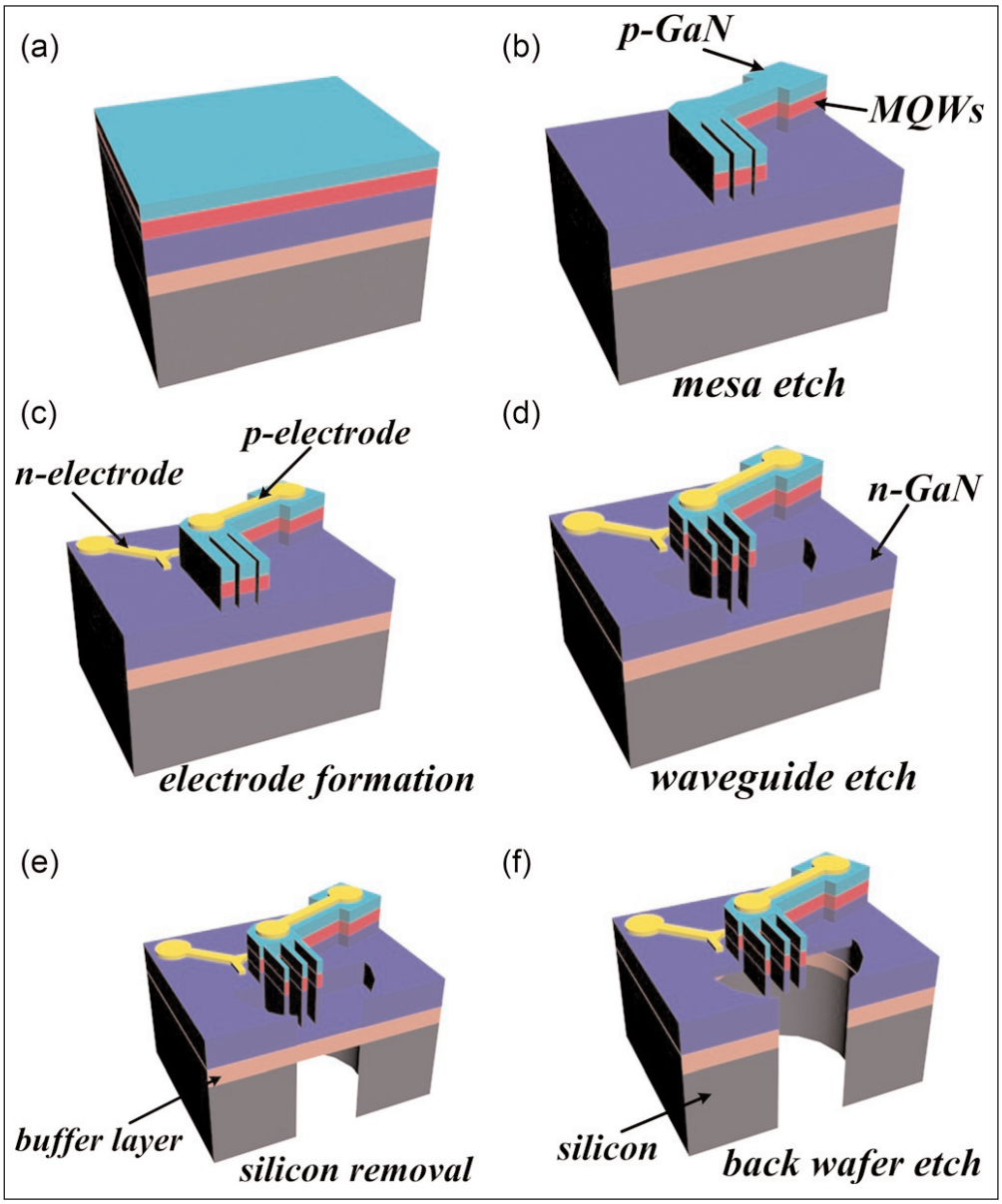


Figure 3. Schematic fabrication process of on-chip integration of suspended pn-junction InGaN/GaN MQW device and multiple waveguides.

clearly observed, indicating that the integrated devices can be feasibly used as multiple transmitters for wireless VLC applications."

In the other direction, both devices were also tested as simultaneous photodiodes. A fiber-coupled 450nm light beam was focused on the back-side of the device with a signal that was on for 0.2 seconds and off for 0.2 seconds. A photocurrent of –42nA was induced at 0V bias. The researchers comment: "The photocurrent temporal trace shows a distinct on/off switching performance, indicating its potential use as multiple receivers for wireless VLC applications."

The University of Posts and Telecommunications researchers have also worked with Nanjing Institute of Technology, China, on further work integrating III-nitride devices with III-nitride waveguides on silicon [Yongjin Wang et al, Appl. Phys. Lett., vol108, p162102, 2016].

The researchers used material with the same heterostructure as detailed above. The fabrication process was also similar. The resulting membrane structures (Figure 3) were somewhat deformed due to stress release after removal of the silicon. Three 50μm-long waveguides were produced with different thicknesses: 12μm, 10μm and 8μm. The height was given by the 3μm membrane thickness.

The device was wire bonded to a test pad for characterization. As an LED, the device emitted blue light with 449.2nm dominant wavelength at 4V bias. There were also two sub-peaks at 467.5nm and 494.1nm (blue-green).

In-plane data transmission from the LEDs driven by an arbitrary waveform generator showed good performance from the 12μm-wide waveguide up to 25 megabits per second (Mbps) with open eye diagrams, indicating low signal distortion (Figure 4). Narrower waveguides restrict the occurrence of multi-mode transmission. Since multi-mode transmission leads to pulse broadening due to the different transmission velocities (dispersion), narrow waveguides should have higher transmission rates.

Reversing the light direction, so that the device operated as a photodiode, 450nm light from an optical fiber was focused on the waveguide facets. With a mechanical shutter giving 0.2 seconds on and 0.2 seconds off, –42nA photocurrent at 0V bias was observed with 70μW input power on the 10μm waveguide.

In March another device was reported by the same researchers with 3 p-electrodes, 3 n-electrodes, and 2 sets of connecting waveguides [Wei Cai et al, Optics Express, vol24, p6004, 2016]. In this work, the low cost of GaN on silicon is stressed. "The obvious advantages, such as use of the cheaper, widely available silicon wafer and the ability to use automated back-end manufacturing tools in silicon fabs, make mass production of monolithic photonic integration possible," the team writes.

Further, it is found that removal of the silicon substrate material from under the devices increases carrier concentrations and thus reduces resistance to current

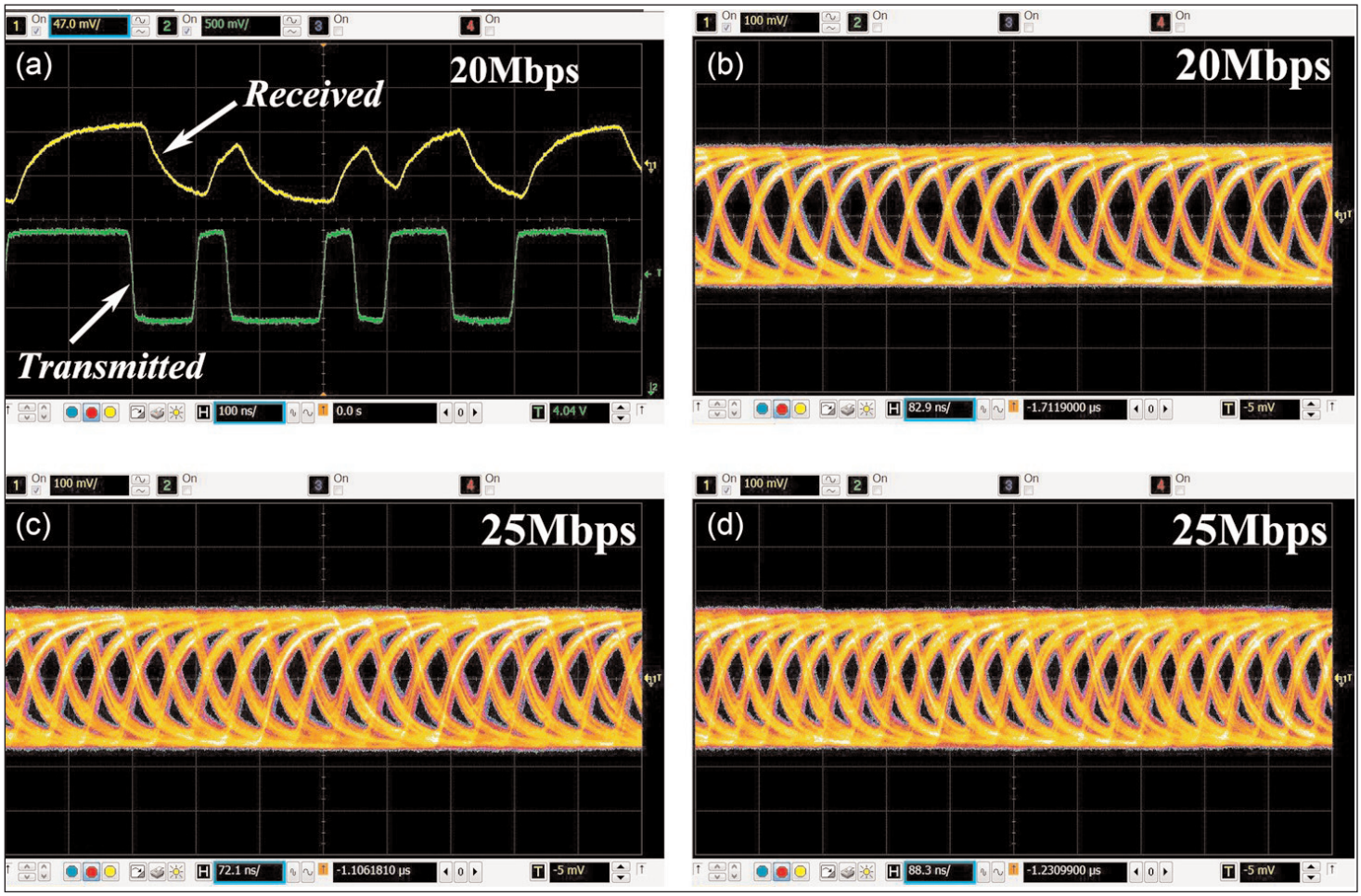


Figure 4. (a) Received output signal for 12μm-wide suspended waveguide; (b) eye diagram at 20Mbps for 12μm-wide suspended waveguide; (c) eye diagram at 25Mbps for 12μm-wide suspended waveguide; and (d) eye diagram at 25Mbps for 8μm-wide suspended waveguide.

spreading. Electronic performance is also enhanced by releasing residual stress arising from lattice mismatching between the silicon substrate and III-nitride layers. ■

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

Zirconium dioxide dielectric for gallium nitride high-mobility transistors

US-based researchers claim record positive threshold for normally-off operation.

The Naval Research Laboratory (NRL) and University of Maryland in the USA claim a record positive threshold voltage of +3.9V for a gallium nitride (GaN) metal-oxide-semiconductor high-electron-mobility transistor (MOS-HEMT) [Travis J. Anderson et al, Appl. Phys. Express, vol9, p071003, 2016]. The team used zirconium dioxide (ZrO_2) as a gate dielectric insulator. The positive threshold means that the transistor had normally-off or 'enhancement-mode' operation.

Normally-off transistors are particularly desired in power applications, giving fail-safe operation and more efficient power consumption. The high-power radio frequency (RF) and power switching characteristics of such devices could lead to power amplifier (PA), monolithic microwave integrated circuit (MMIC) and voltage conversion applications.

Using a MOS gate structure significantly reduces gate leakage current, improving reliability and reducing off-state power consumption. ZrO_2 has a high dielectric constant of 25, a large bandgap of 7.8eV, and a high breakdown voltage in the range 15–20MV/cm.

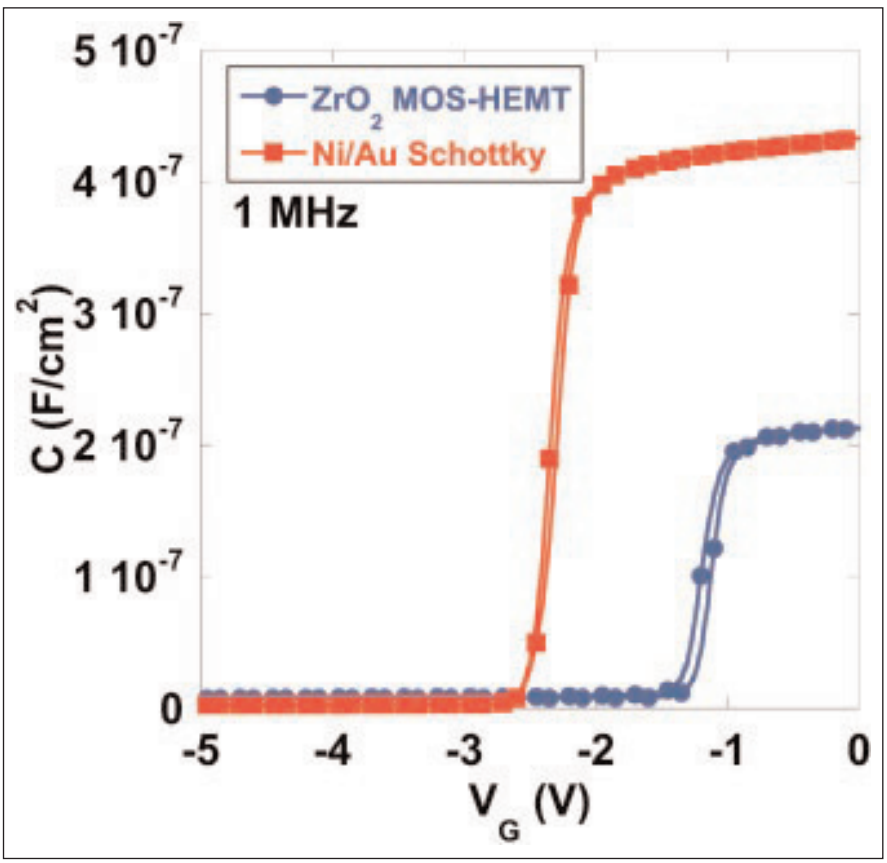


Figure 1. Capacitance–voltage characteristics of Schottky-gated HEMT and ZrO_2 MOS-HEMTs.

The III-nitride heterostructure was grown on high-resistivity silicon with a ~2μm nucleation/transition/GaN-buffer, followed by an 18nm $Al_{0.26}Ga_{0.74}N$ barrier and a 2nm GaN cap. Fabrication began with standard mesa isolation, titanium/aluminium/nickel/gold ohmic metal deposition and annealing, and titanium/gold metal overlay deposition.

Two types of gate were fabricated: a standard Schottky HEMT with nickel/gold gate and plasma-enhanced silicon nitride (PECVD SiN_x) passivation; and a MOS-HEMT with full recessing through the AlGaN barrier, 20nm of atomic layer deposition (ALD) ZrO_2 gate insulation and a nickel/gold electrode. A ZrO_2 MOS-HEMT without recessing was also produced.

The ALD precursors were zirconium(IV) tert-butoxide (ZTB) and deionized water. The researchers comment that no previous ZrO_2 GaN MOS-HEMT has used ZTB precursor. Usually, tetrakis(dimethylamino)zirconium is employed. An advantage of ZTB is that its structure already contains some oxygen, which should lead to higher-quality ZrO_2 films. The ALD cycle consisted of 0.2-second ZTB and 0.03-second dionized water doses separated by 20-second nitrogen purges, giving ~0.07nm/cycle growth.

Capacitance–voltage measurements at 1MHz indicated that the MOS-HEMT had lower capacitance (Figure 1). The dielectric constant of the ZrO_2 was estimated at 25. "This indicates that thermal ALD and the ZTB precursor are as effective at producing films with low leakage and a high dielectric constant as plasma-enhanced ALD using amine-based precursors," the team writes.

The measurements also showed a positive threshold

Table 1. Summary of device characteristics.

	Reference HEMT	ZrO_2 MOS-HEMT	Recessed ZrO_2 MOS-HEMT
$I_{D,MAX}$ (A/mm)	0.516	0.482	0.286
I_D @ $V_G = V_T + 4V$ (A/mm)	0.395	0.362	0.274
$g_{m,MAX}$ (mS/mm)	114	92.5	131
V_T (V)	−2.13	−1.43	+3.99
I_G @ $V_G = -5V$ (A)	1.22×10^{-7}	7.41×10^{-13}	1.53×10^{-11}
R_{ON} (Ω-mm)	13.5	14.8	24.0
SS (mV/decade)	191	92.9	187
D_{it} (/cm^2-eV)	2.03×10^{13}	7.00×10^{12}	4.87×10^{13}

voltage shift, "likely the result of excess oxygen in the film, either from excess precursor ligands or from adsorption of water or hydroxyl groups from the background." The team also points out: "most other oxides deposited on GaN suffer from positive charge, resulting in negative V_T shifts."

The resulting devices had comparable DC electrical performance (Table 1). The recessed ZrO_2 MOS-HEMT achieved normally-off behavior with a threshold (V_T) of +3.99V. Although the maximum drain current ($I_{D,MAX}$) was lower than the other devices, the maximum transconductance ($g_{m,MAX}$) was higher (Figure 2). The non-recessed devices had similar on-resistance (R_{ON}).

The subthreshold swing (SS) was used to estimate interface trap densities (D_{it}). The lowest Dit was for the non-recessed MOS-HEMT. "This suggests that the ZrO_2 gate oxide reduces the interface trap density at the AlGaN surface in the gate region," the researchers say.

The higher D_{it} of the recessed device was probably due to crystal damage from the recess etch process, according to the researchers. They add: "Current collapse was poor in this device structure, as the negative charge in the oxide will enhance the virtual gating effect rather than passivate it. An ideal device structure would implement PECVD SiN_x in the access regions and ZrO_2 under the gate; however, the process steps to enable this are still being developed."

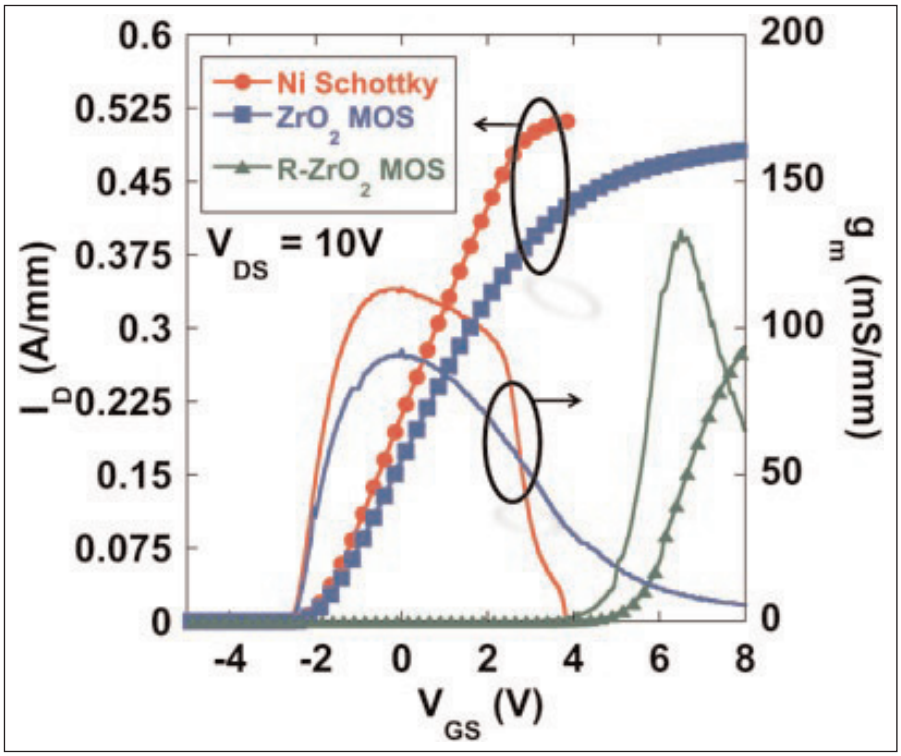


Figure 2. Transfer curves for Schottky-gated HEMT, ZrO_2 MOS-HEMT, and recessed barrier ZrO_2 MOS-HEMT.

The ZrO_2 reduced gate leakage (I_G) by four orders of magnitude. ■

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Author: Mike Cooke

Bi-directional silicon carbide planar insulated-gate bipolar transistor

Researchers claim the first experimental demonstration of bi-directional 4H-SiC planar-gate IGBTs on free-standing substrates.

Rensselaer Polytechnic Institute and General Electric Global Research Center in the USA "experimentally demonstrate, for the first time, bi-directional 4H-silicon carbide planar gate, insulated-gate bipolar transistors (IGBTs) fabricated on 250µm-thick, lightly doped free-standing substrates" [Sauvik Chowdhury et al, IEEE Electron Device Letters, vol37, p1033, 2016].

The researchers see potential for their bi-directional (BD) IGBTs as switches that can control current in both directions with application in matrix or neutral point piloted multi-level converters. Compared with multi-component implementations, the BD-IGBT should offer reduced production costs and increased reliability.

The researchers used a wafer with lightly n-doped (N–) 250µm-thick epilayer grown on 4° off-axis N+ 4H SiC substrate. The growth wafer was removed to give a lightly doped free-standing substrate for the IGBT fabrication. Wafer-bonded silicon-based BD-IGBTs offer breakdown voltage ratings in the range 1.2–3.3kV. Unidirectional IGBTs produced using silicon carbide (SiC) technology have achieved breakdown voltage ratings up to 27kV.

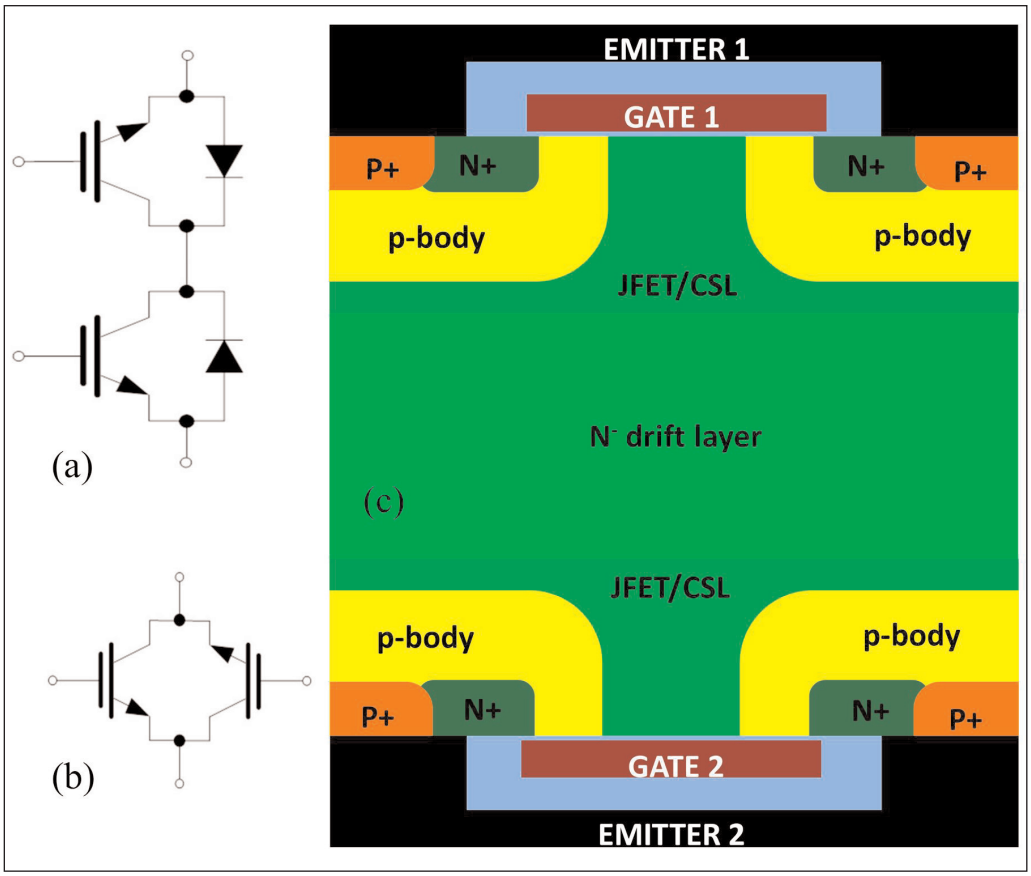

Figure 1. Bi-directional switches implemented using (a) conventional IGBTs and anti-parallel diodes (b) reverse blocking IGBTs and (c) schematic cross-section of monolithically integrated planar gate BD-IGBT.

The device was produced by lithographic patterning of planar gate metal-oxide-semiconductor (MOS) cells on both sides of the free-standing substrate (Figure 1). The gate insulator consisted of 75nm of low-pressure chemical vapor deposition (CVD) silicon dioxide dielectric. The oxide was annealed in nitric oxide (NO) gas at 1175°C for two hours. Junction termination extensions were achieved by aluminium implantation. Aluminium provides p-type doping in SiC. The individual IGBT devices were similar to unidirectional IGBTs reported earlier this year by Rensselaer [Sauvik Chowdhury et al, IEEE Electron Device Letters, vol37, p317, 2016]. The active area of the bi-directional IGBTs was $3.1x10^{-4}cm^2$.

With a collector current density of $50A/cm^2$, the Si-face forward voltage (V_F) was 9.7V at room temperature and 11.5V at 150°C. The researchers claim the small positive temperature coefficient for V_F is "attractive for stable current sharing among devices connected in parallel". The 11.5V V_F compares with 27V for 15kV 4H-SiC power MOSFETs power switching devices reported by Cree/US Army Research Laboratory.

The differential specific on-resistance ($r_{on,diff}$) of 140mΩ-cm^2 was three times lower than the unmodulated drift layer. At higher temperatures, the decrease in mobility is compensated to some extent by an increase in carrier lifetimes and ionization of the aluminium acceptors. The $r_{on,diff}$ was only marginally higher: 160mΩ-cm^2 at 150°C.

The voltage drops were higher in the reverse direction. Measured at a lower 10A/cm^2 collector current density, V_F was 9.5V at room temperature and 6.3V at 150°C. The $r_{on,diff}$ values were 600mΩ-cm^2 and 400mΩ-cm^2, respectively. The worse performance is attributed to a higher 13.7V threshold voltage for the C-face MOS gate, compared with 7.3V for the Si-face.

The researchers comment: "The threshold voltage on C-face also showed a faster rate of decrease with increasing temperature than Si-face. Higher V_T, as well as the higher rate of decrease of V_T with temperature, is indicative of a larger concentration of interface trapped charges (Q_{it}) on C-face."

The team believes that through further optimization of the gate oxide process (reducing Q_{it} on the C-face), a symmetric current–voltage performance could be achieved.

Breakdown measurements varied widely, with a maximum 7.2kV on the BD-IGBTs. Co-fabricated pin diodes had a higher 11kV breakdown. "This large variation in breakdown performance may be due to defects in the epilayer or surface passivation problems," the team writes. The expected breakdown characteristic of the drift layer was more than 17.5kV, giving a 15kV rating. ■

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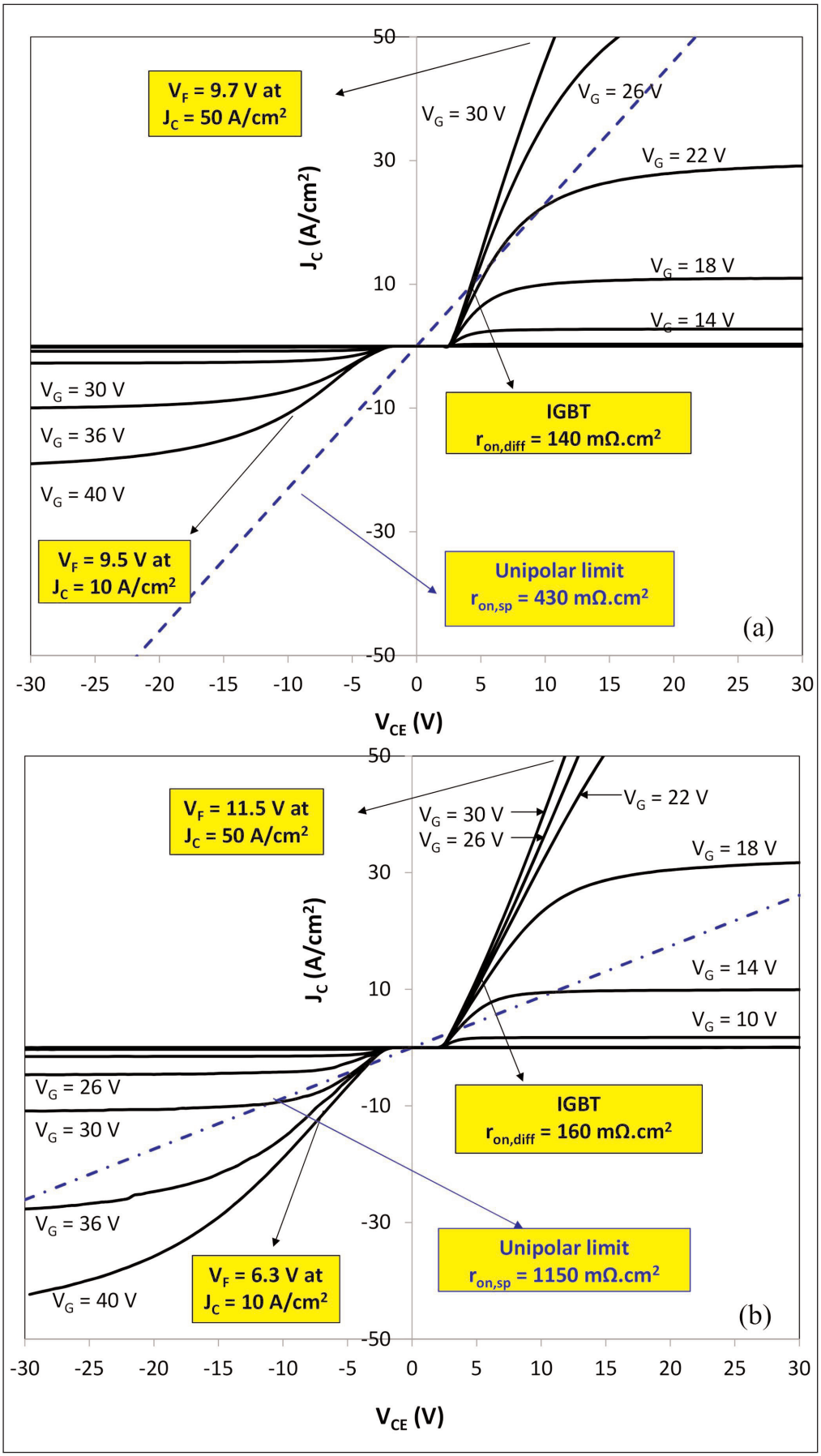

Figure 2. Typical experimental output current-voltage characteristics of fabricated 4HSiC BD-IGBT at (a) room temperature and (b) 150°C. Dashed line indicates calculated current-carrying capability of unmodulated drift layer. Cell pitch of measured device 17μm.

Reaching new heights by producing 1200V SiC MOSFETs in CMOS fab

Monolith Semiconductor and Littelfuse describe how 1200V silicon carbide MOSFETs can be mass produced on 150mm wafers in a CMOS silicon fab.

The emergence of silicon carbide (SiC) power devices has brought the advantages of high-speed unipolar devices into much higher-voltage classes than would be achievable with silicon devices. SiC metal-oxide-semiconductor field-effect transistors (MOSFETs) demonstrate dramatically lower switching losses than similarly rated silicon IGBTs.

The very first commercial SiC MOSFETs rated at 1200V were introduced to the market back in January 2011 [1]. Since then, a growing number of power electronics systems manufacturers have turned to subsequent generations of these devices in order to achieve greater efficiency, power density, and reliability at a lower cost. However, in order for these devices to reach their commercial potential, providing a high-performance, near-ideal switch is not enough to ensure the widespread adoption of these devices. SiC MOSFET manufacturers also must be able to offer their power electronics customers' devices that combine good manufacturability, long-term reliability, and exceptional ruggedness, all at a competitive price (Figure 1).

One approach to reaching this goal is to move from 76mm (3-inch)- and 100mm (4-inch)-diameter SiC wafers to 150mm (6-inch) SiC wafers and develop design and process techniques that are compatible with processes in a CMOS fab. Integrating the process flows for both silicon and SiC wafers and running them in parallel allows one to take advantage of enormous economies of scale. The results of this approach, employed recently in the production of 1200V SiC MOSFETs in an automotive-qualified 150mm CMOS fab, have demonstrated not only high manufacturability but also superior device performance, gate oxide reliability and robustness at operating junction temperatures of 175ºC.

Figure 1. Widespread adoption of high-voltage SiC MOSFETs will require much more than just high-performance devices.

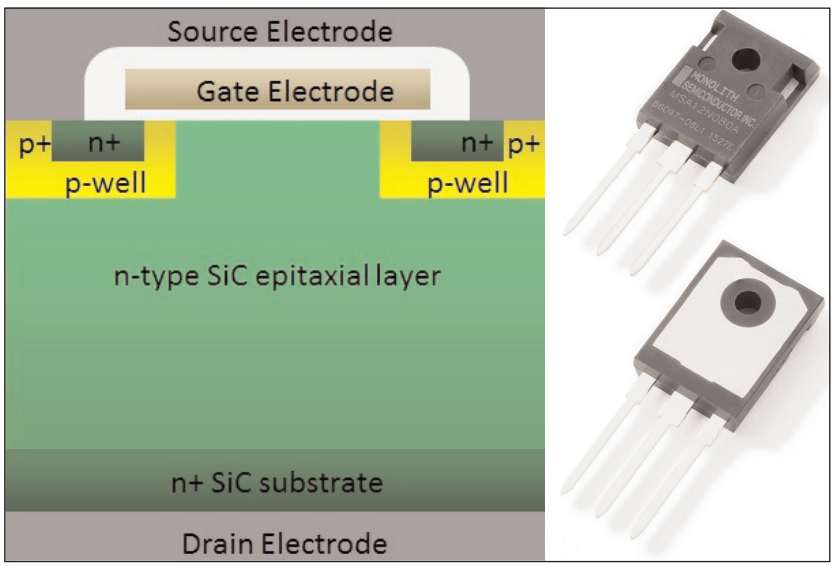

Figure 2. Cross section of a planar SiC MOSFET. Proper design of a MOSFET with planar structure ensures the device is rugged and reliable. The SiC MOSFET packaged in an industry-standard TO-247 package.

Silicon carbide fabrication processes and device design

More than 90% of SiC device processes are compatible with processes already in use in silicon CMOS fabs. Although the nature of SiC as a material makes it fundamentally compatible with most CMOS fab processes, significant hurdles remain before this approach can be realized, including requirements for high-temperature processing. Other challenges include integrating CMOS- and SiC-specific process steps, as well as making metal and dielectric stacks used in the SiC MOSFET compatible with a conventional CMOS fab. Whenever possible, standard process steps available in a CMOS foundry should be reused with SiC wafers, such as implantation masks and top-level interconnects.

For steps such as gate oxidation and metallization, SiC-specific processes can be developed using CMOS production tools like high-temperature furnaces and rapid thermal processing (RTP) ovens, but dedicated tools are required for implant activation and certain ion implantation steps. It's also necessary to modify the mechanical wafer handling methods used because of the semi-transparent nature of SiC wafers. For example, sensors set up for use with opaque materials will respond incorrectly when used with SiC wafers, leading to wafer breakage during loading/unloading .Similarly, automated defect detection tools can confuse sub-surface features with surface defects. Differences in wafer thickness can also complicate wafer handling. Nevertheless, with the proper process modifications, SiC and silicon wafers can be run in parallel in a high-volume production environment, taking advantage of the economies of scale associated with the production processes already in place in the CMOS fab.

Producing rugged SiC MOSFETs (see Figure 2) with wide process margins demands ensuring stable and uniform avalanche breakdown in the device unit cells, avoiding high fields in the oxide, and breakdown in the edge termination. Ideally, device termination should achieve close-to-ideal parallel plane breakdown voltage over a broad dose range, providing a wide process margin.

In addition to the device termination, the JFET region of the device under oxide must be optimized with appropriate doping concentration and physical dimensions. Figure 3 illustrates an example of impact ionization contours at device breakdown. In this case, the device was designed to preferentially break down at the center of the unit cell, ensuring uniform avalanche conditions and a low peak field in the oxide. Other critical aspects of the device and process design included optimization of the channel and P-well designs to ensure the device remained off over the entire voltage and temperature envelope.

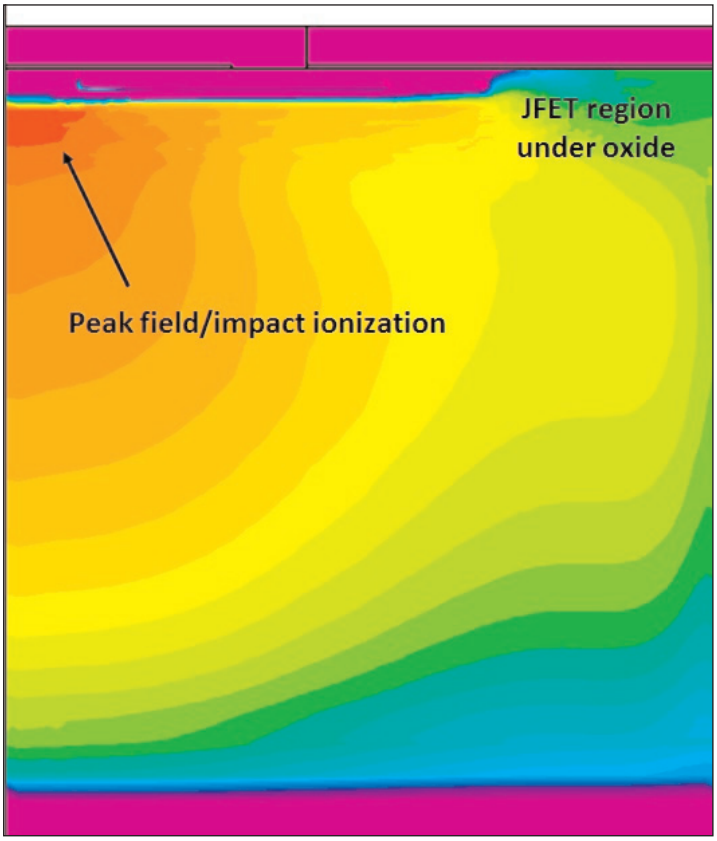

Figure 3. Impact ionization contours at device breakdown. The device was designed to break down at the center of the unit cell, ensuring stable avalanche breakdown.

Performance of fabricated devices

Figure 4 shows a fully processed 150mm SiC wafer with 1.2kV, 65mΩ MOSFETs fabricated in an automotive-qualified fab using the process outlined in this article. Multiple wafer lots have been produced with various process and design splits. The devices produced have been thoroughly characterized at both the wafer level and in TO-247 packages. Wafer-level results have been used to generate wafer maps and gain an understanding of various process-design interactions. Packaged parts are used for final reliability and ruggedness evaluations.

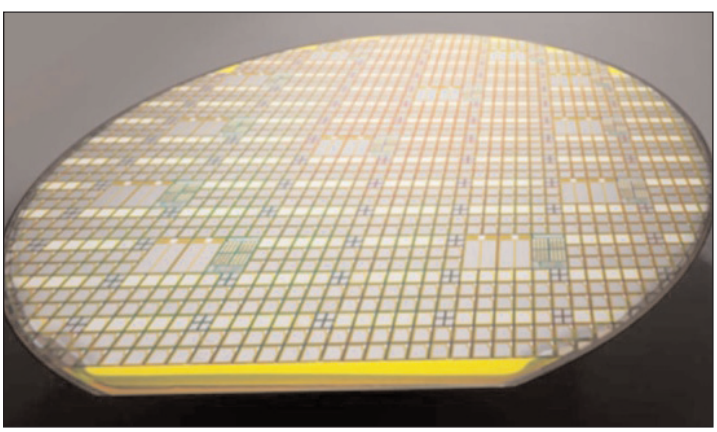

Figure 4. Fully processed 150mm SiC wafer with 1.2kV MOSFETs and process control monitors.

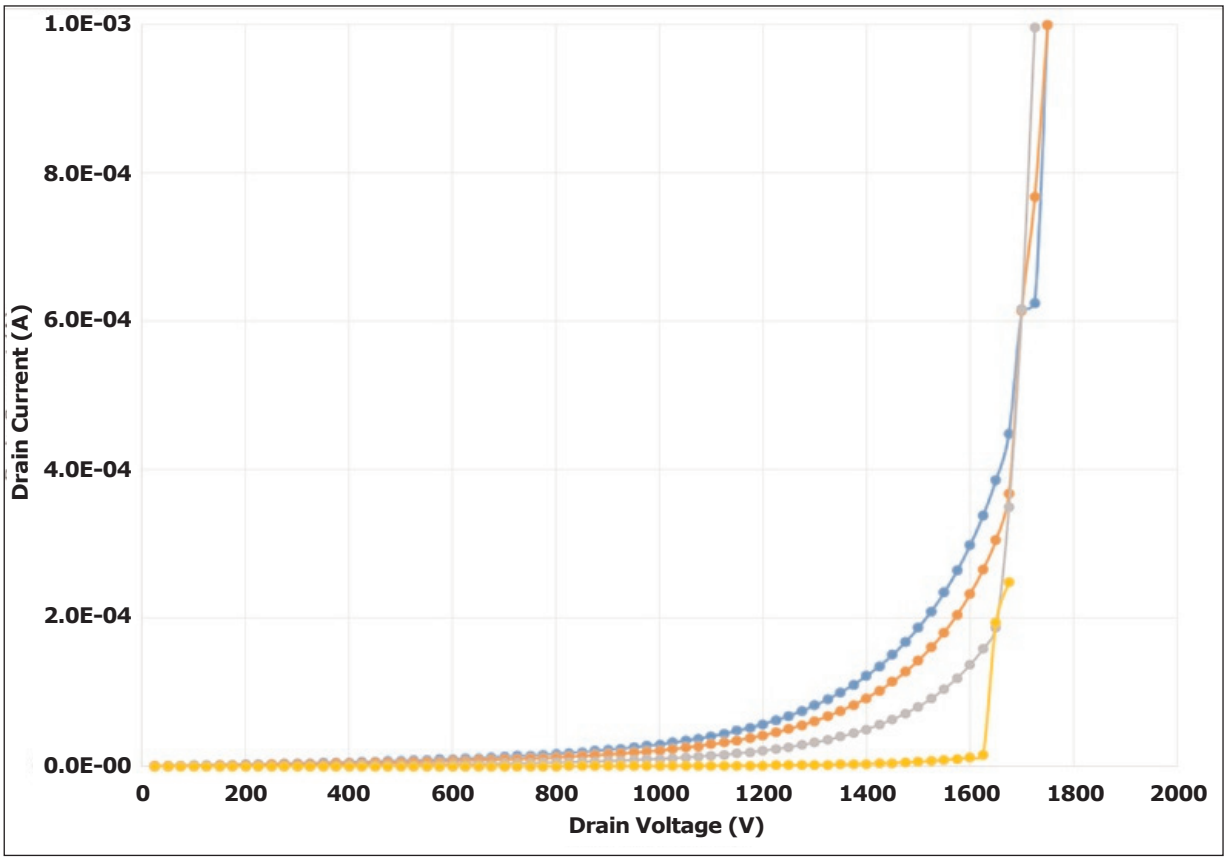

Figure 5. Typical forward characteristics (I_{DSS}; V_{GS} = 0) of manufactured MOSFETs for temperatures from 25ºC to 175ºC. Results show low leakage current up to 1200V and 175ºC.

Figure 5 presents the typical off-state IV (V_{GS} = 0) characteristics of the fabricated MOSFETs from 25ºC to 175ºC with low leakage current (<100μA) over a worst-case voltage and temperature envelope.

Figure 6 compares the forward characteristics of these devices at 25ºC and 175ºC. The typical on-resistance of these MOSFETs at V_{GS} = 20V, 25ºC is 65mΩ. Although these devices were optimized for robustness and manufacturability, the typical specific on-resistance R_{sp} (normalized to the devices' active area) is competitive with that of other commercially available 1200V SiC MOSFETs. With more aggressive processes and designs, it has proven possible to achieve R_{sp} of 3.1mΩ-cm^2 on an identical process platform.

Figure 7 details the SiC MOSFET's low switching losses when characterized at 800V, 20A. Switching loss at a gate resistance of 4.8Ω was under 400μJ, indicating superior switching performance.

Evaluating device manufacturability

Controlling SiC MOSFET production costs effectively demands a highly manufacturable process with sufficient margin. To evaluate the manufacturability of this process, we analyzed the breakdown voltage distribution of a

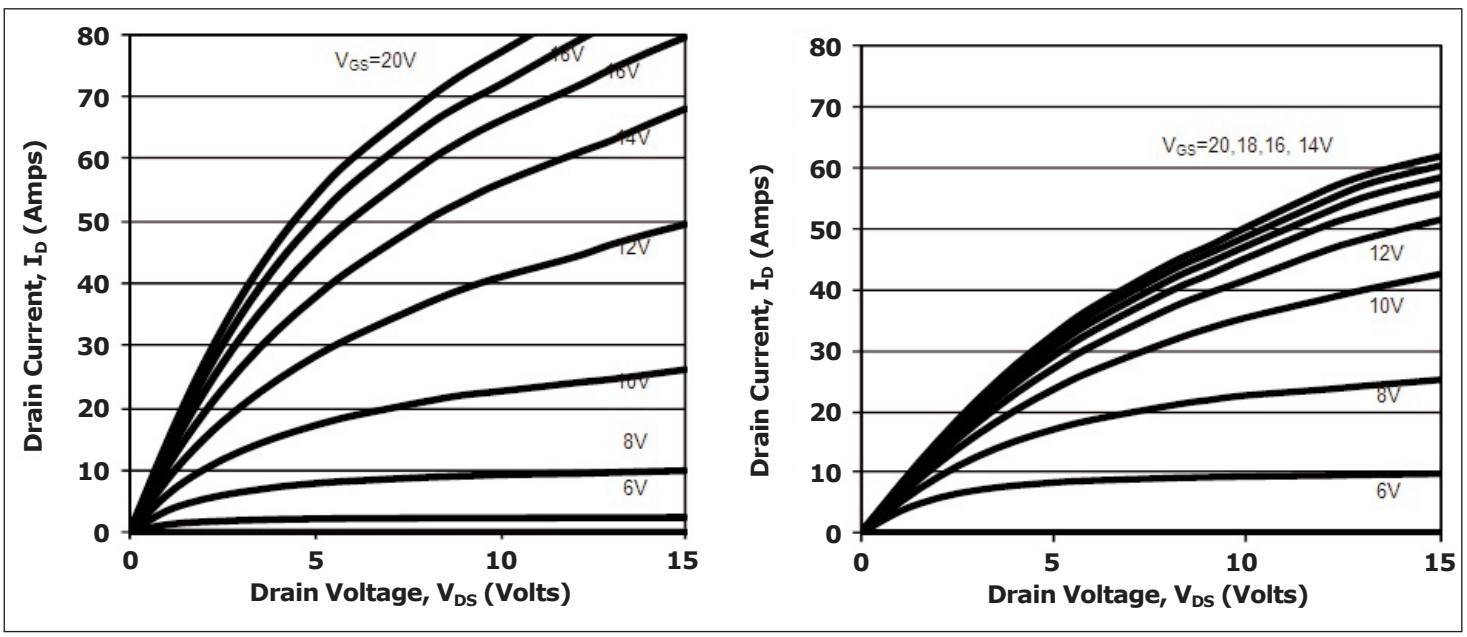

Figure 6. Forward characteristics at 25ºC (left) and 175ºC (right).

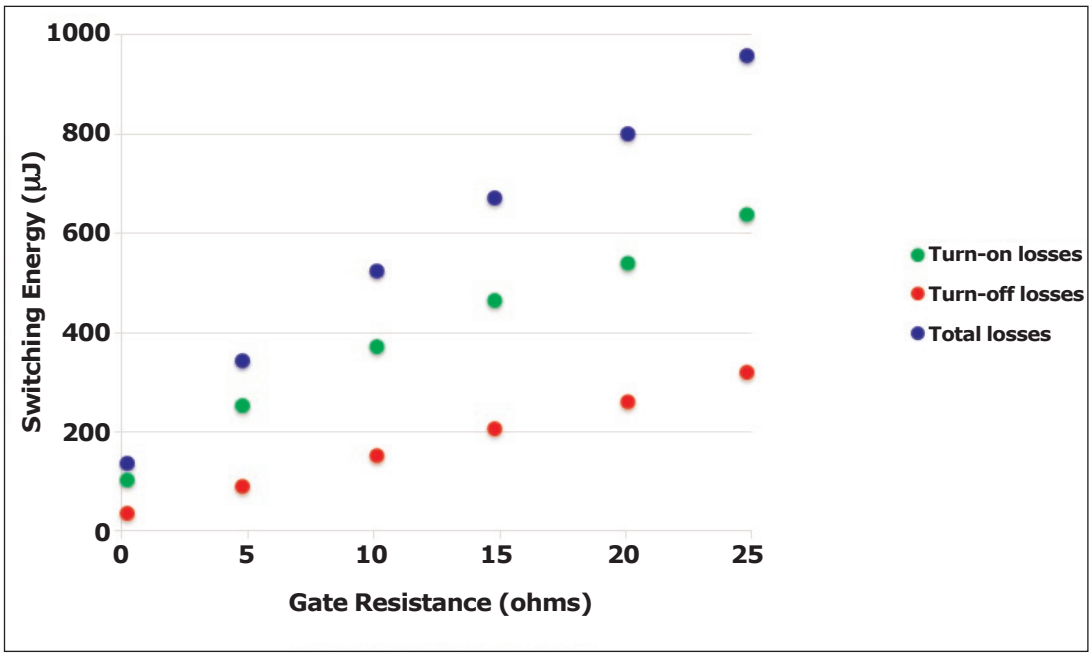

Figure 7. The devices exhibited less than 400µJ of switching loss at a gate resistance of 4.8Ω.

large quantity of devices from multiple wafers from different fab lots (Figure 8). This analysis showed that the process offers sufficient margin to accommodate a wide range of epilayer doping variations.

As part of our manufacturability analysis, we also analyzed $R_{DS(on)}$ or on-resistance (Figure 9). Note that the on-resistance distribution is quite tight despite the epitaxial layer doping variation.

Given that 150mm SiC wafers are not yet as common as 100mm SiC wafers, the diode leakage current of the fabricated devices was also investigated to assess defect density and device yields. Diode leakage wafer maps revealed only randomly located failures and >90% yields, which eliminated any concerns about the quality of 150mm wafers affecting device yields. Work on improving the epitaxial doping control aspect of the process continues. Doping variation has been taken into account in these designs and it is reflected in the wide breakdown voltage margin.

Assessing device ruggedness and reliability

A number of techniques were used to evaluate the ruggedness of the devices produced, including the avalanche energy of the device. Figure 10 shows the typical waveform from avalanche energy characterization of the device with an avalanche energy >1 Joule.

Because gate oxide quality is a common concern for SiC MOSFETs, the fundamental quality of the gate oxide process was studied previously using time-dependent dielectric breakdown (TDDB) measurement of capacitors at high temperatures [2]. Charge-to-breakdown (Q_{BD}) measurements in large-area DMOSFETs produced Q_{BD} values that were well above 10C/cm^2 (see Figure 11) and no defective tail that would indicate intrinsic failure modes. High-temperature gate bias (HTGB) testing at V_{GS} of −10V and +20V showed excellent stability of threshold voltage, as presented in [3]. The MOSFETs were also subjected to 1400 hours of high-temperature (175ºC) reverse bias (HTRB) testing at V_{DS} = 960V and V_{GS} = 0V, and stable breakdown voltage characteristics were observed.

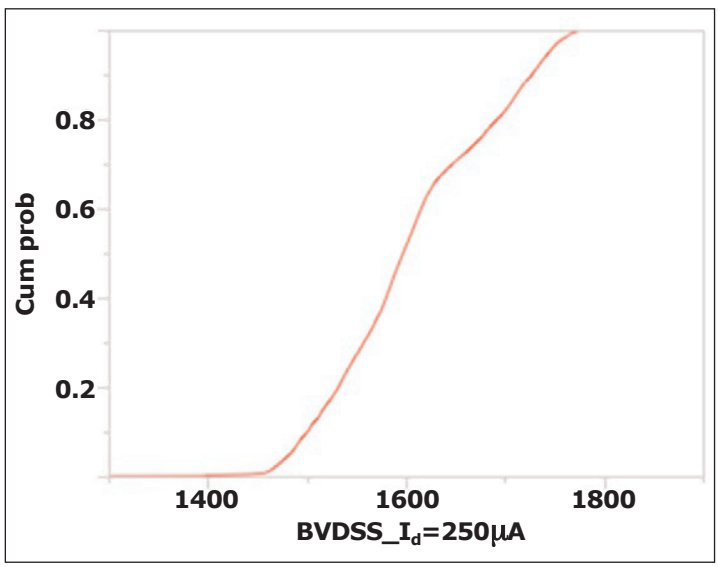

Figure 8. Breakdown voltage distribution of a large quantity of devices from multiple wafers from different fab lots.

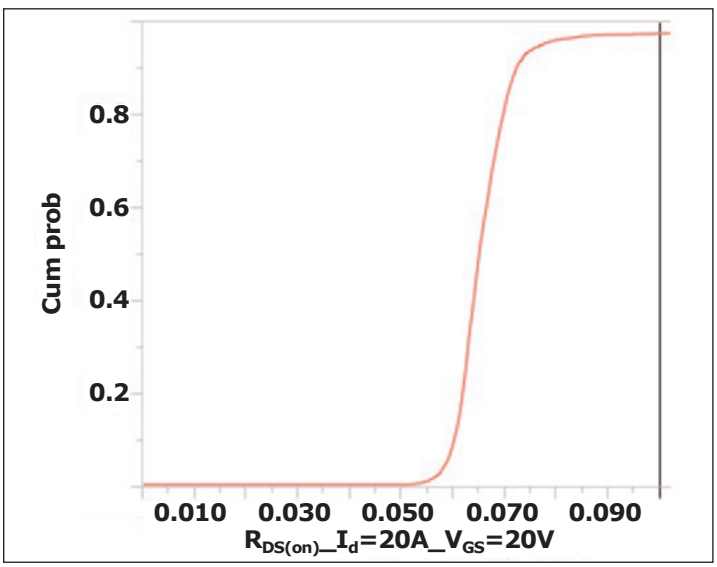

Figure 9. On-resistance distribution of a large quantity of devices from multiple wafers from different fab lots.

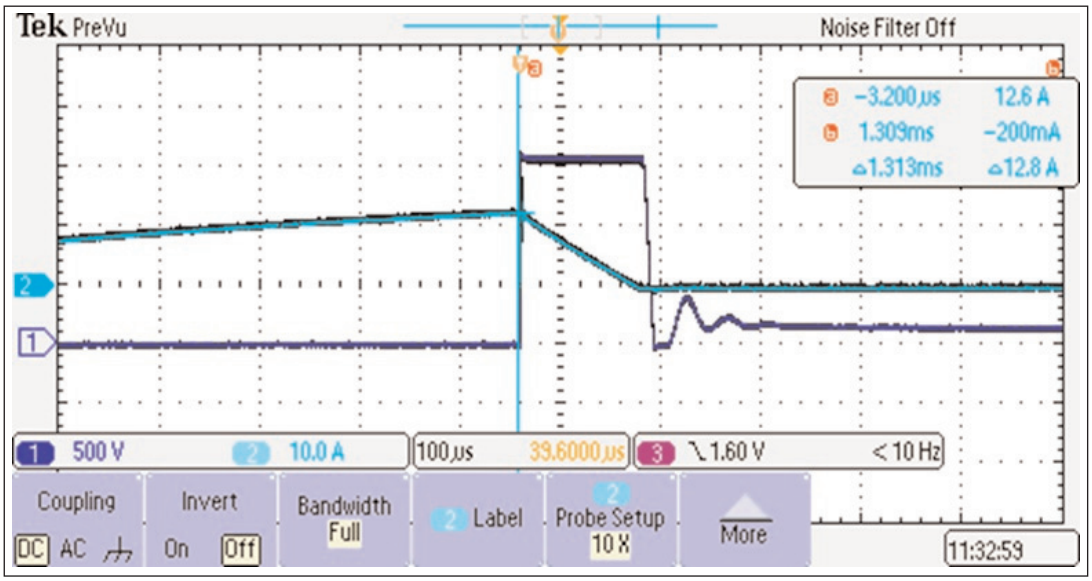

Figure 10. Avalanche energy characterization of the SiC MOSFETs, showing avalanche energy > 1 Joule.

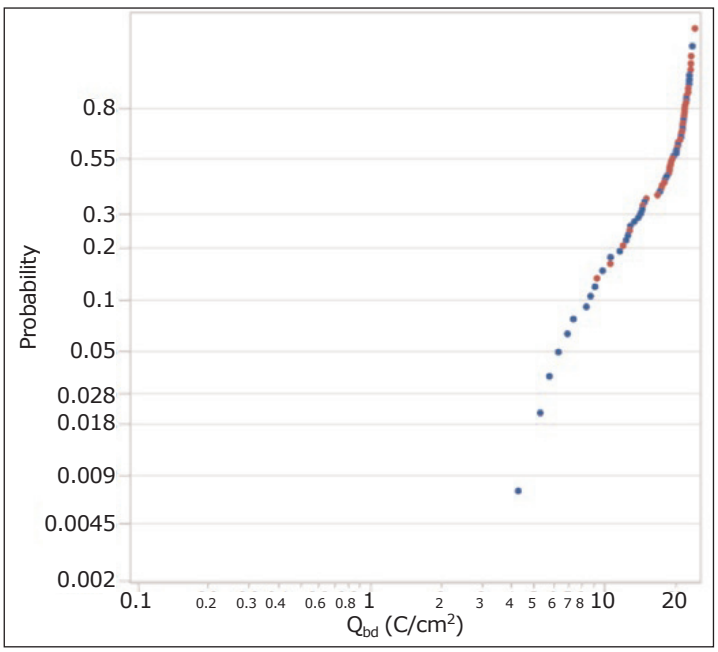

Figure 11. Results of charge-to-breakdown (Q_{BD}) measurements in large-area DMOSFETs.

Conclusion

In the coming years, the average selling price of commercial 1200V SiC MOSFETS is likely to continue to decrease, from the present price of ~50 cents/amp to somewhere around 10 cents/amp by the end of the decade. However, in order to achieve this price point and allow for widespread adoption of SiC power MOSFETs, suppliers must continue to explore opportunities to lower their costs without compromising device quality. Producing these devices in high-volume, automotive-qualified 150mm CMOS fabs has proven to be one way to achieve this goal [4]. ■

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Infineon's acquisition of Wolfspeed just the beginning of collaborations in SiC power electronics

After International Rectifier & Infineon, Fairchild & ON Semiconductor, Wolfspeed & APEI, and now Infineon & Wolfspeed, market analyst firm Yole Développement wonders who will be next to merge.

The agreement in mid-July for Infineon Technologies AG of Munich, Germany to acquire the Wolfspeed Power & RF division of Cree Inc of Durham, NC, USA for $850m has drawn a lot of attention in the compound semiconductor world. The deal also includes the related SiC wafer substrate business for power electronics and RF power electronics.

The power electronics industry landscape is evolving, and consolidation is increasing, noted Yole in its report 'Status of the Power Electronics Industry 2016' (issued in June). International Rectifier and Infineon Technologies, Fairchild Semiconductor and ON Semiconductor, Wolfspeed and APEI … Now, Infineon and Wolfspeed.

Indeed, the Infineon's acquisition of Wolfspeed occurs amidst a power electronics industry where silicon carbide (SiC) technology benefits are well known and where business opportunities have been clearly identified by industrial companies. In its latest compound semiconductor technology & market analysis report 'Power SiC 2016: Materials, Devices, Modules, and Applications', Yole Développement forecasts that the market is rising at a compound annual growth rate (CAGR) of 19% from $200m in 2015 to $550m in 2021.

"Wolfspeed and Infineon Technologies are leaders in the SiC power devices industry. The combination of both players will clearly strengthen the leading position of Infineon Technologies in the SiC power business," notes technology & market analyst Dr Hong Lin. "This is a win–win acquisition." According to Lin, Infineon's market share should rise by more than 50% if the full acquisition is confirmed.

Lin gives the following analysis:

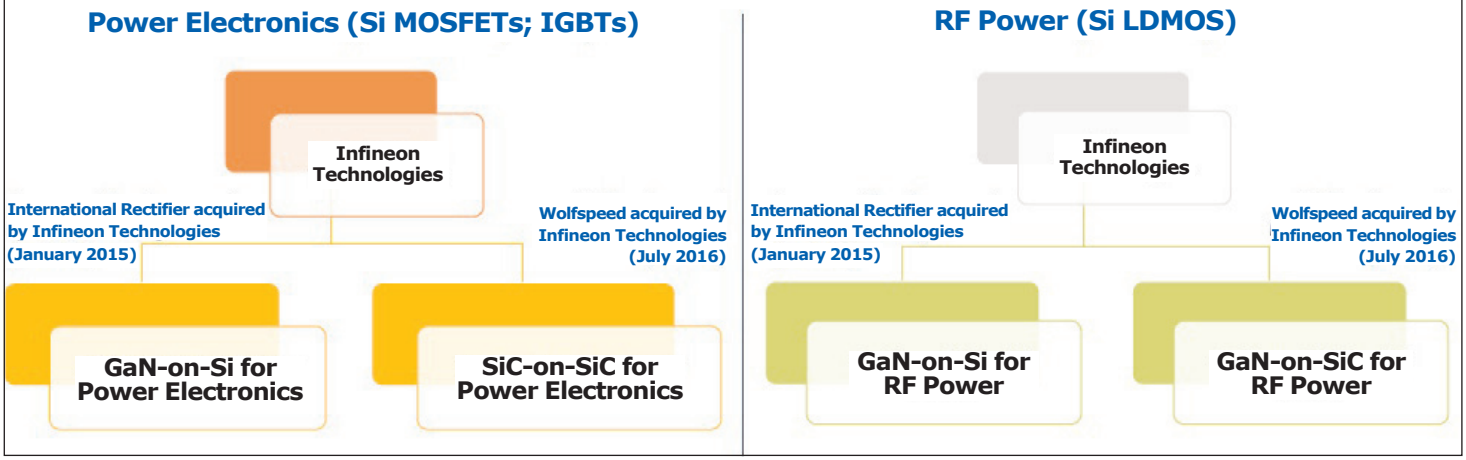
- Infineon and Wolfspeed are both established players in SiC diode manufacturing.
- Wolfspeed has developed a powerful SiC MOSFET solution, which is clearly more advanced than Infineon's, i.e. within the commercialization phase: Wolfspeed's Gen 3 has already been commercially available for two years and has a good reputation. From its side, Infineon just released its MOSFET component in May. Within a SiC MOSFET market that is just taking off, Infineon's acquisition of Wolfspeed ensures its development in this market segment.
- In parallel, as number 1 in the incumbent silicon power business, Infineon has a well-established client portfolio. The firm has a strong understanding of the market's needs, its players, and the technical specifications related to power electronics applications.
- Infineon also has significant experience in power packaging for semiconductors, which is considered to be the main business bottleneck for SiC power electronics currently. Last year, to reinforce its packaging capability, Wolfspeed acquired Arkansas Power Electronics International Inc (APEI) of Fayetteville, AR, USA, a provider of SiC power modules and power electronics applications. Now, with the support of Infineon, Wolfspeed can further accelerate its product development and reaffirm the leadership of its technology approach.
- Finally, Infineon's investment and large-scale production capability could support Wolfspeed in ramping up production and expansion.

As well as Wolfspeed's SiC devices for power electronics applications, the acquisition also includes activities focused on GaN-on-SiC for RF applications. According to Yole's report 'GaN RF Devices Market: Applications, Players, Technology, and Substrates 2016–2022' (issued in June), the GaN RF devices market will double in the next five years, due to widespread adoption within various market segments. As a result, the acquisition of Wolfspeed gives Infineon direct access to the emerging GaN RF market.

With the two acquisitions over an 18-month period (from January 2015 to July 2016), Infineon has reaf-

Power Electronics & RF Power: Infineon Technologies' acquisitions & market positioning

(Sources: Power SiC 2016: Materials, Devices, Modules, and Applications report — Status of the Power Electronics 2016 report — GaN RF Devices Market: Applications, Players, Technology, and Substrates 2016–2022 report)



firmed its market-leading position, says Yole, strengthening its activities in the emerging wide-bandgap (WBG) semiconductor technology sector.

The several recent mergers and acquisitions, such as Infineon Technologies and International Rectifier, ON Semiconductor and Fairchild Semiconductor, have launched a phase of consolidation in the power electronics industry, notes Yole. "We see this acquisition [of Wolfspeed] as the beginning of a series of impressive collaborations within the SiC power business in the coming years," says Yole business unit manager Dr Pierric Gueguen. "This industry trend is likely to continue and to further increase in the future." ■

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Tel: +49 (0)911 650 78 650 90
Fax: +49 (0)911 650 78 650 93
E-mail: info@crystal-n.com
www.crystal-n.com

Crystal IS Inc
70 Cohoes Avenue
Green Island, NY 12183, USA
Tel: +1 518 271 7375
Fax: +1 518 271 7394
www.crystal-is.com

Freiberger Compound Materials
Am Junger Loewe Schacht 5,
Freiberg, 09599, Germany
Tel: +49 3731 280 0
Fax: +49 3731 280 106
www.fcm-germany.com

Kyma Technologies Inc
8829 Midway West Road,
Raleigh, NC, USA
Tel: +1 919 789 8880
Fax: +1 919 789 8881
www.kymatech.com

MARUWA CO LTD
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Japan
Tel: +81 572 52 2317
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Fax: +1 408 492 0633
www.sp3inc.com

Sumitomo Electric Semiconductor Materials Inc
7230 NW Evergreen Parkway,
Hillsboro, OR 97124,
USA
Tel: +1 503 693 3100 x207
Fax: +1 503 693 8275
www.sesmi.com

III/V-Reclaim
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84568 Pleiskirchen, Germany
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Fax: +49 8728 911 156
www.35reclaim.de
III/V-Reclaim offers reclaim (recycling) of GaAs and InP wafers, removing all kinds of layers and structures from customers' wafers. All formats and sizes can be handled. The firm offers single-side and double-side-polishing and ready-to-use surface treatment.

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Watertorenstraat 33,
B-2250 Olen, Belgium
Tel: +32-14 24 53 67
Fax: +32-14 24 58 00
www.substrates.umicore.com

Wafer World Inc
1100 Technology Place, Suite 104,
West Palm Beach, FL 33407,
USA
Tel: +1-561-842-4441
Fax: +1-561-842-2677
E-mail: sales@waferworld.com
www.waferworld.com

4 Epiwafer foundry

Spire Semiconductor LLC
25 Sagamore Park Drive,
Hudson, NH 03051,
USA
Tel: +1 603 595 8900
Fax: +1 603 595 0975
www.spirecorp.com

Albemarle Cambridge Chemical Ltd
Unit 5 Chesterton Mills,
French's Road, Cambridge CB4 3NP,
UK
Tel: +44 (0)1223 352244
Fax: +44 (0)1223 352444
www.camchem.co.uk

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

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

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

5 Deposition materials

Akzo Nobel High Purity Metalorganics
www.akzonobel.com/hpmo
Asia Pacific:
Akzo Nobel (Asia) Co Ltd,
Shanghai,
China
Tel. +86 21 2216 3600
Fax: +86 21 3360 7739
metalorganicsAP@akzonobel.com
Americas:
AkzoNobel Functional Chemicals,
Chicago,
USA
Tel. +31 800 828 7929 (US only)
Tel: +1 312 544 7000
Fax: +1 312 544 7188
metalorganicsNA@akzonobel.com
Europe, Middle East and Africa:
AkzoNobel Functional Chemicals,
Amersfoort, The Netherlands
Tel. +31 33 467 6656
Fax: +31 33 467 6101
metalorganicsEU@akzonobel.com

Cambridge Chemical Company Ltd
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French's Road,
Cambridge CB4 3NP,
UK
Tel: +44 (0)1223 352244
Fax: +44 (0)1223 352444
www.camchem.co.uk

Dow Electronic Materials
60 Willow Street,
North Andover, MA 01845,
USA
Tel: +1 978 557 1700
Fax: +1 978 557 1701
www.metalorganics.com

Matheson Tri-Gas
6775 Central Avenue,
Newark, CA 94560,
USA

Tel: +1 510 793 2559
Fax: +1 510 790 6241
www.mathesontrigas.com

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

Praxair Electronics
542 Route 303, Orangeburg,
NY 10962,
USA
Tel: +1 845 398 8242
Fax: +1 845 398 8304
www.praxair.com/electronics

SAFC Hitech
Power Road, Bromborough,
Wirral, Merseyside CH62 3QF,
UK
Tel: +44 151 334 2774
Fax: +44 151 334 6422
www.safchitech.com

Materion Advanced Materials Group
2978 Main Street,
Buffalo, NY 14214,
USA
Tel: +1 716 837 1000
Fax: +1 716 833 2926
www.williams-adv.com

6 Deposition equipment

AIXTRON SE
Dornkaulstr. 2,
52134 Herzogenrath,
Germany
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Fax: +49 2407 9030 40
www.aixtron.com

AIXTRON is a leading provider of deposition equipment to the semiconductor industry. The company's technology solutions are used by a diverse range of customers worldwide to build advanced components for electronic and optoelectronic applications (photonic) based on compound, silicon, or organic semiconductor materials and, more recently, carbon nanotubes (CNT), graphene and other nanomaterials.

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www.evatecnet.com

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www.svta.com

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7 Wafer processing materials

Air Products and Chemicals Inc
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Tel: +1 610 481 4911
www.airproducts.com/compound

MicroChem Corp
1254 Chestnut St. Newton,
MA 02464, USA
Tel: +1 617 965 5511
Fax: +1 617 965 5818
www.microchem.com

Praxair Electronics
(see section 5 for full contact details)

8 Wafer processing equipment

EV Group
DI Erich Thallner Strasse 1,
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Austria
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Fax: +43 7712 5311 4600
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Tel: +44 (0) 1389 875 444
Fax: +44 (0) 1389 879 042
www.logitech.uk.com

Oxford Instruments Plasma Technology
(see section 6 for full contact details)

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

SAMCO International Inc
532 Weddell Drive,
Sunnyvale,
CA,
USA
Tel: +1 408 734 0459
Fax: +1 408 734 0961
www.samcointl.com

SPTS Technology Ltd
Ringland Way,
Newport NP18 2TA,
UK
Tel: +44 (0)1633 414000
Fax: +44 (0)1633 414141
www.spts.com

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

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

9 Materials & metals

Goodfellow Cambridge Ltd
Ermine Business Park,
Huntingdon,
Cambridgeshire
PE29 6WR,
UK
Tel: +44 (0) 1480 424800
Fax: +44 (0) 1480 424900
www.goodfellow.com
Goodfellow supplies small quantities of metals and materials for research, development, prototyping and specialised manufacturing operations.

10 Gas and liquid handling equipment

Air Products and Chemicals Inc
(see section 7 for full contact details)

Cambridge Fluid Systems
12 Trafalgar Way, Bar Hill,
Cambridge CB3 8SQ,
UK
Tel: +44 (0)1954 786800
Fax: +44 (0)1954 786818
www.cambridge-fluid.com

CS CLEAN SYSTEMS AG
Fraunhoferstrasse 4,
Ismaning, 85737,
Germany
Tel: +49 89 96 24 00 0
Fax: +49 89 96 24 00 122
www.cscleansystems.com

SAES Pure Gas Inc
4175 Santa Fe Road,
San Luis Obispo,
CA 93401,
USA
Tel: +1 805 541 9299
Fax: +1 805 541 9399
www.saesgetters.com

11 Process monitoring and control

k-Space Associates Inc
2182 Bishop Circle
East, Dexter,
MI 48130,
USA
Tel: +1 734 426 7977
Fax: +1 734 426 7955
www.k-space.com
k-Space Associates Inc specializes in in-situ, real-time thin-film process monitoring tools for MBE, MOCVD, PVD, and thermal evaporation. Applications and materials include the research and production line monitoring of compound semiconductor-based electronic, optoelectronic, and photovoltaic devices.

KLA-Tencor
One Technology Dr,
1-2221I, Milpitas, CA 95035, USA
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Fax: +1 408 875 4144
www.kla-tencor.com

LayTec AG
Seesener Str. 10–13,
10709 Berlin,
Germany
Tel: +49 30 89 00 55 0
Fax: +49 30 89 00 180
www.laytec.de
LayTec develops and manufactures optical in-situ and in-line metrology systems for thin-film processes with particular focus on compound semiconductor and photovoltaic applications. Its know-how is based on optical techniques: reflectometry, emissivity corrected pyrometry, curvature measurements and reflectance anisotropy spectroscopy.

WEP (Ingenieurbüro Wolff für Elektronik- und Programmentwicklungen)
Bregstrasse 90, D-78120
Furtwangen im Schwarzwald,
Germany
Tel: +49 7723 9197 0
Fax: +49 7723 9197 22
www.wepcontrol.com

12 Inspection equipment

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

13 Characterization equipment

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

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

14 Chip test equipment

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

15 Assembly/packaging materials

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

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

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

Materion Advanced Materials Group
2978 Main Street,
Buffalo, NY 14214,
USA
Tel: +1 716 837 1000
Fax: +1 716 833 2926
www.williams-adv.com

16 Assembly/packaging equipment

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

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

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

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

17 Assembly/packaging foundry

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

18 Chip foundry

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

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

19 Facility equipment

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

20 Facility consumables

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

21 Computer hardware & software

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

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

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

22 Used equipment

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

23 Services

Henry Butcher International
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High Holborn, London WC1V 6EG,
UK
Tel: +44 (0)20 7405 8411
Fax: +44 (0)20 7405 9772
www.henrybutcher.com

M+W Zander Holding AG
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Germany
Tel: +49 711 8804 1141
Fax: +49 711 8804 1950
www.mw-zander.com

24 Consulting

Fishbone Consulting SARL
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E-mail: jean-luc.ledys@neuf.fr

25 Resources

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SEMI Global Headquarters
3081 Zanker Road,
San Jose, CA 95134, USA
Tel: +1 408 943 6900
Fax: +1 408 428 9600
www.semi.org

Yole Développement
45 rue Sainte Geneviève,
69006 Lyon, France
Tel: +33 472 83 01 86
www.yole.fr

event calendar

If you would like your event listed in *Semiconductor Today*'s Event Calendar, then please e-mail all details to the Editor at mark@semiconductor-today.com

4–9 September 2016
19th International Conference on Molecular Beam Epitaxy (MBE 2016)
Montpellier, France
E-mail: contact@mbe2016.com
http://mbe2016.sciencesconf.org

5–9 September 2016
18th European Conference on Power Electronics and Applications (EPE 2016)
Karlsruhe, Germany
E-mail: info@epe2016.eu
www.epe2016.com

6–7 September 2016
2nd International Forum on Sapphire Market & Technologies
Shenzhen Convention & Exhibition Center (SZCEC), China
E-mail: veyrier@yole.fr
www.i-micronews.com/events/yole-events/eventdetail/142/-/2nd-int-forum-on-sapphire-market-technologies.html
alongside:

6–9 September 2016
18th China International Optoelectronic Exposition (CIOE 2016)
Shenzhen Convention & Exhibition Center (SZCEC), China
E-mail: cioe@cioe.cn
www.cioe.cn/en

7–9 September 2016
SEMICON Taiwan 2016
Taipei Nangang Exhibition Center, Taiwan
E-mail: semicontaiwan@semi.org
www.semicontaiwan.org

12–15 September 2016
25th International Semiconductor Laser Conference (ISLC 2016)
Kobe Meriken Park Oriental Hotel, Kobe, Japan
E-mail: islc2016@ics-inc.co.jp
www.islc2016.org

12–15 September 2016
46th European Solid-State Device Research Conference (ESSDERC 2016)
Swisstech Convention Centre, Lausanne, Switzerland
E-mail: essderc2016@epfl
http://esscirc-essderc2016.epfl.ch

19–22 September 2016
LED China 2016
Shanghai New International Expo Centre (SNIEC), China
E-mail: led-trust@ubm.com
www.LEDChina-sh.com

25–29 September 2016
ECSCRM 2016:
11th European Conference on Silicon Carbide and Related Materials
Halkidiki, Greece
E-mail: ECSCRM2016@symvoli.gr
www.ecscrm2016.org

2–6 October 2016
29th IEEE Photonics Conference (IPC 2016)
Waikoloa, Hawaii, USA
E-mail: c.c.scott@ieee.org
www.ipc-ieee.org

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3–7 October 2016
European Microwave Week (EuMW 2016), incorporating:
46th European Microwave Conference (EuMC)
11th European Microwave Integrated Circuits Conference (EuMIC)
13th European Radar Conference (EuRAD)
ExCel London, UK
E-mail: eumw2016@manchester.ac.uk
www.eumweek.com

10–13 October 2016
2016 IEEE SOI-3D-Subthreshold Micro-electronics Technology Unified Conference (S3S SOI/3D/SubVt) — 'Energy Efficient Technology for the Internet of Things'
Hyatt Regency San Francisco Airport, Burlingham, CA, USA
E-mail: manager@s3sconference.org
http://s3sconference.org

23–26 October 2016
2016 IEEE Compound Semiconductor Integrated Circuit Symposium (CSICS)
Austin, TX USA
E-mail: hpmoyer@hrl.com
https://csics.org

25–27 October 2016
SEMICON Europa 2016
Grenoble, France
E-mail: eweller@semi.org
www.semiconeuropa.org

26–28 October 2016
6th Annual World Congress of Nano Science & Technology (Nano S&T-2016) — ' Theme: Small is All, The Future of Nanotechnology'
Singapore
E-mail: stella@bitconferences.com
www.bitcongress.com/nano2016

7 November 2016
ITF2016 Japan
New Otani Hotel – Tokyo, Japan
E-mail: Annouck.Vanrompay@imec.be
www.itf2016.be/page.aspx/2218

7–9 November 2016
4th IEEE Workshop on Wide Bandgap Power Devices and Applications (WiPDA 2016)
Fayetteville, AR USA
E-mail: mantooth@uark.edu
www.wipda2016.org

13–16 November 2016
11th International Conference on Advanced Semiconductor Devices & Microsystems (ASDAM '16)
Smolenice, Slovakia
E-mail: asdam@savba.sk
http://elu.sav.sk/asdam

3–7 December 2016
62nd annual IEEE International Electron Devices Meeting (IEDM 2016)
San Francisco Union Square Hilton Hotel, CA, USA
E-mail: info@ieee-iedm.org
www.ieee-iedm.org

14–16 December 2016
SEMICON Japan 2016
Tokyo International Exhibition Center (Tokyo Big Sight), Japan
E-mail: jcustomer@semi.org
www.semiconjapan.org

28 January – 2 February 2017
SPIE Photonics West 2017
Moscone Center, San Francisco, CA, USA
E-mail: customerservice@spie.org
http://spie.org/SPIE-PHOTONICS-WEST-conference

19–23 March 2017
Optical Fiber Communication Conference & Exhibition (OFC 2017)
Los Angeles Convention Center, CA, USA
E-mail: OFC@compusystems.com
www.ofcconference.org

9–13 April 2017
SPIE Defense + Commercial Sensing 2017 (DCS)
Anaheim Convention Center, CA, USA
E-mail: customerservice@spie.org
http://spie.org/SPIE-DCS-conference

18–21 April 2017
SNEC's 11th International Photovoltaic Power Generation Conference & Exhibition (SNEC PV Power EXPO 2017)
Shanghai, China
E-mail: info@snec.org.cn
www.snec.org.cn

1–3 May 2017
13th International Conference on Concentrator Photovoltaics (CPV-13)
University of Ottawa, Canada
E-mail: info@cpv-13.org
www.cpv-13.org

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