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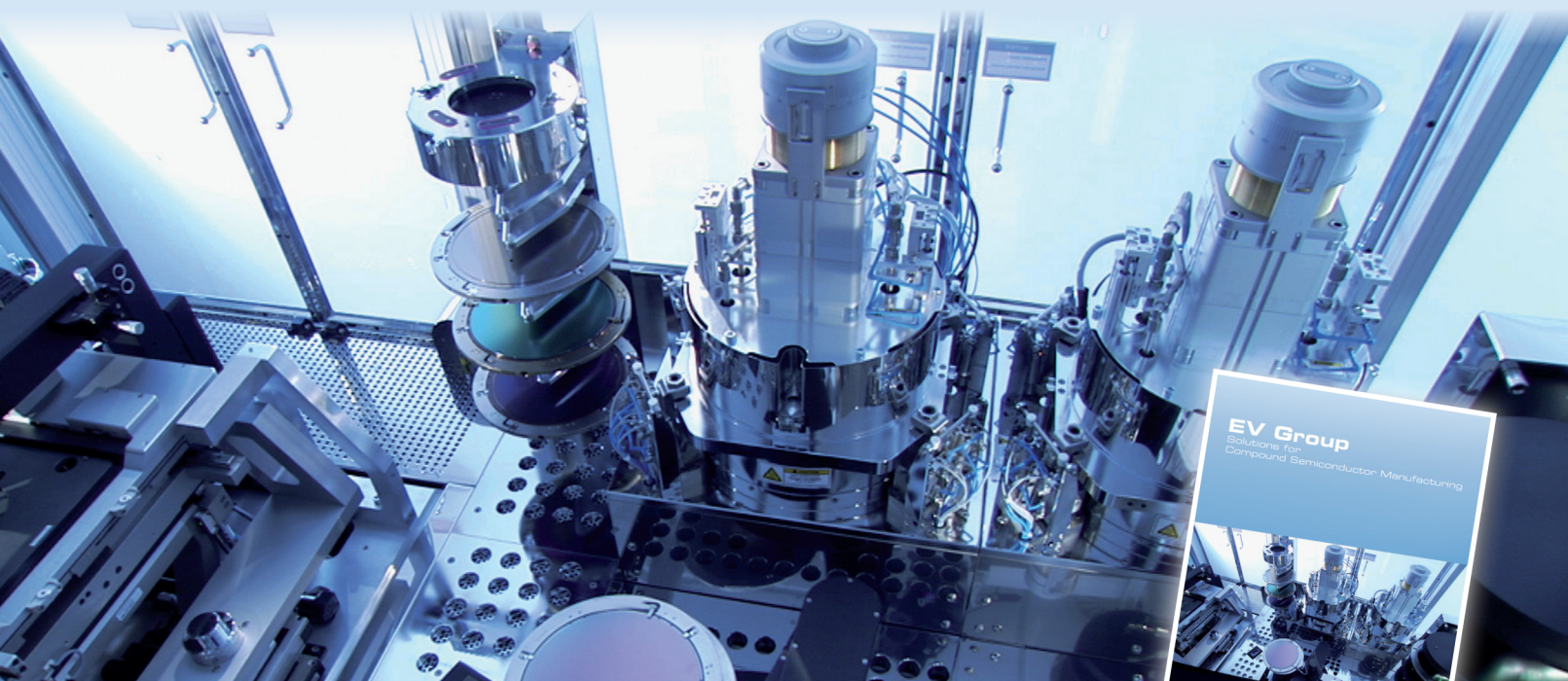
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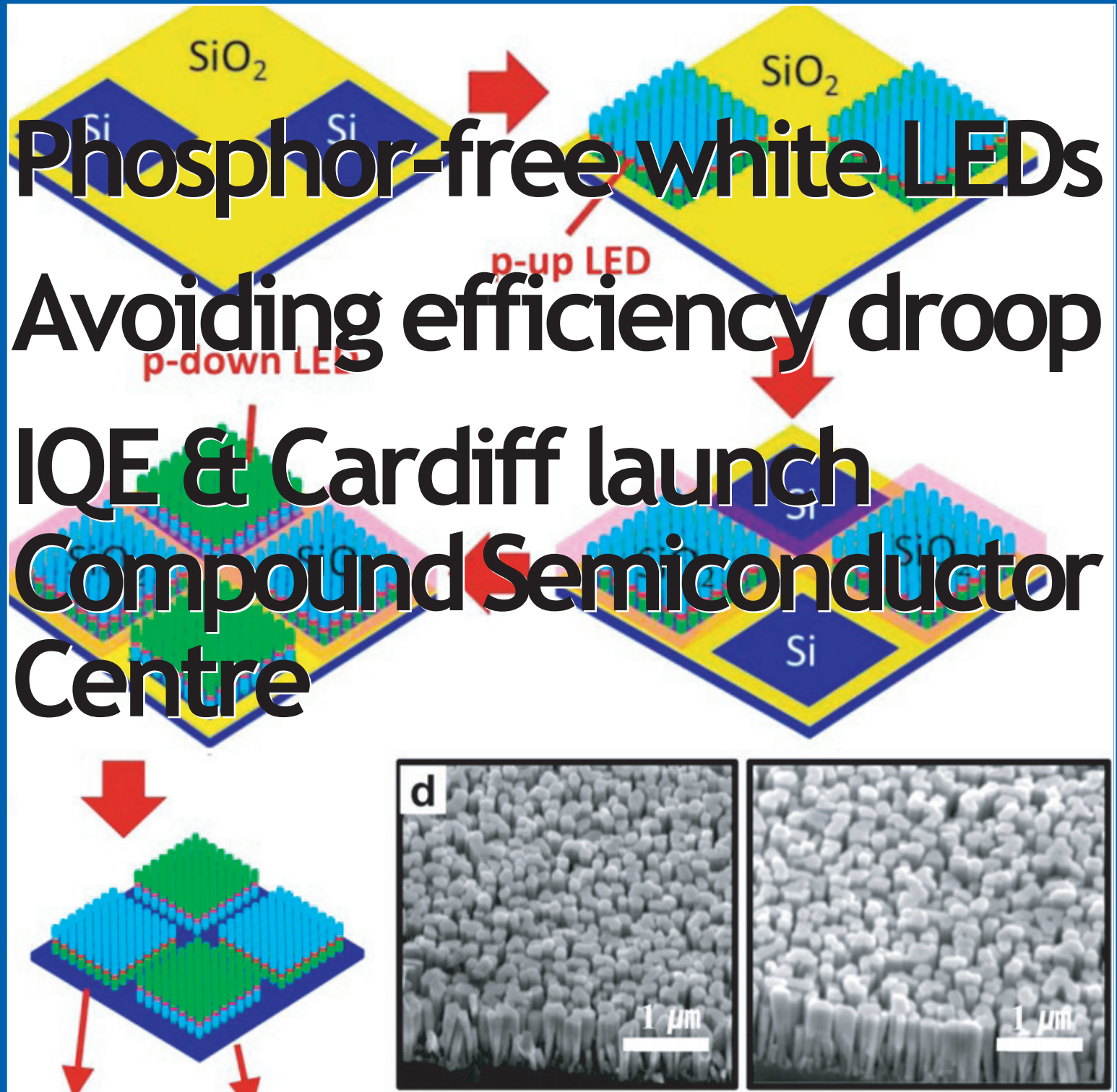
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GaAs Labs buys Anadigics • Sora to open New York LED fab
 Osram investing €3bn in lighting • ColorChip raises \$25m



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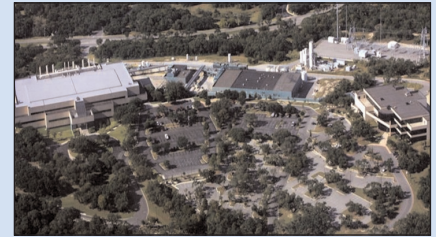
Contact us at www.veeco.com/EPIK700 to learn more.



Veeco's New TurboDisc EPIK700 GaN MOCVD System

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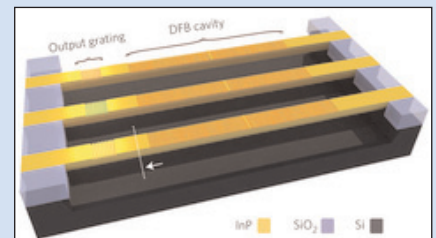
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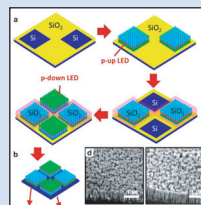
p18 TowerJazz is buying Maxim's analog 8" fab in San Antonio, Texas, where it will qualify its core specialty foundry technologies including RF-SOI.



28 IQE's CEO Drew Nelson (right) at the launch in the UK Houses of Parliament of Cardiff's Compound Semiconductor Centre, attended by Secretary of State for Wales Stephen Crabb MP (front left).



p44 Imec and Ghent University in Belgium have presented what are said to be the first arrays of InP lasers monolithically integrated on 300mm silicon substrates in a CMOS pilot line.



Cover: Two-step selective-area growth of p-GaN up and p-GaN down AC nanowire LEDs on silicon substrate, together with SEMs (45° tilted) of as-grown p-GaN up and p-GaN down nanowire structures, for AC-operation of phosphor-free white light-emitting diodes (courtesy of McGill University). **p62**

RFIC industry integrates further

After a longer-than-usual wait for the issue of its third-quarter financial results, in mid-November broadband and wireless communications component maker Anadigics announced its acquisition by venture firm GaAs Labs for \$32m (a premium of 38.2% on its share price) — see page 8.

Anadigics' Q3 revenue was just \$12.1m, down 23% on \$15.8m in Q2 and 36% on \$18.9m a year ago, and less than a third of the \$37m two years ago and a fifth of the \$61.3m five years ago. Anadigics' record revenue was \$80.5m in Q2/2008, when it had planned to resolve capacity constraints by building a 6" GaAs fab in China, which was subsequently cancelled. Net cash had fallen further during Q3/2015, from \$11.2m to just \$7.9m.

Founded in 1985, Anadigics pioneered production at the world's first 6" analog GaAs wafer fab in 1999, but diversified only a little, from its core gallium arsenide technology to add gallium nitride, and from mobile handset markets to wireless infrastructure. The firm's addressable market has hence diminished as traditional GaAs RFIC applications have been eroded by silicon technologies (such as RF silicon-on-insulator for switches and, more recently, RF CMOS for power amplifiers in 2G handsets).

In contrast, GaAs-based RFIC maker Skyworks Solutions has more than quadrupled its quarterly revenues from under \$200m in 2008 to \$810m in Q3/2015 (mainly through diversifying by acquisition into silicon technologies). Meanwhile, at the beginning of 2015 RF Micro Devices merged with TriQuint (becoming Qorvo), largely to exploit filter technology, which has been comprising an increasing proportion of component value — compared with GaAs RFICs — within increasingly multi-band 3G/4G mobile handsets. Both RFMD and TriQuint had also diversified into silicon technologies, and collectively have grown revenue similarly to Skyworks since 2008.

However, over the last year or so, Anadigics has been developing vertical-cavity surface-emitting laser (VCSEL) manufacturing technology at its 6" GaAs fab, and in August it announced an agreement to provide foundry services to POET Technologies (which integrates microelectronic and optoelectronic circuits monolithically on the same chip).

Acquisition will "provide a platform to accelerate innovation and product development in support of revenue growth in our key target markets of CATV, small-cell, WiFi and optical," believes Anadigics' chairman & CEO Ron Michels, adding that GaAs Labs brings "RF semiconductor industry knowledge and a proven track record of success that we expect will strengthen our ability to provide our customers with a broader portfolio of innovative and valuable product offerings."

Under president John Ocampo (who previously co-founded Sirenza Micro-devices, subsequently bought by RFMD). GaAs Labs acquired GaAs-based firms M/A-COM Technology Solutions in 2009 and Mimix Broadband in 2010 followed by GaN-based Nitronex in 2012. Since Mimix and Nitronex were subsequently absorbed by MACOM, Anadigics could follow, complementing MACOM's focus on GaN for base-station power amplifiers. But it remains to be seen what will come of Anadigics' VCSEL foundry deal with POET.

Meanwhile, NXP's divestiture of its RF Power business to China's JAC Capital has just cleared the way for its merger with Freescale Semiconductor, Microsemi has outbid Skyworks to buy PMC-Sierra (see page 15) and Avago shareholders have approved its acquisition of Broadcom (page 18).

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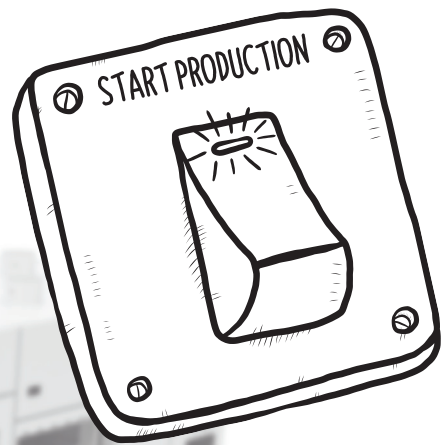
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Photonic integrated circuit market to grow at 25.3% CAGR to \$1.3bn in 2022

Hybrid integration to remain dominant but monolithic integration to grow fastest as module integration declines

The photonic integrated circuit (PIC) market was \$0.19bn in 2013 and is expected to increase at a compound annual growth rate (CAGR) of 25.3% from 2015 to \$1.3bn in 2022, according to the new market report 'Photonic IC Market — Global Industry Analysis, Size, Share, Growth, Trends and Forecast, 2015 — 2022' published by Transparency Market Research.

The main factors driving the photonic IC market are the reductions in cost and size achieved by integrating different optical components (including detectors, modulators and lasers) into a single distinct package. In addition, benefits offered in terms of efficiency, transfer speed, transmission capacity and power consumption have ensured market penetration into varied end-use verticals such as metrology, aerospace and defense, healthcare, telecommunications, industrial, and data communication. The lack of digitization — coupled with design and packaging challenges related to the photonic integration — have inhibited the swift growth of photonic ICs. However, the commercialization of quantum computing (expected by 2018) is predicted to offer tremendous growth opportunities for the photonic IC market.

Three integration techniques deployed in photonic ICs include hybrid integration, monolithic integration, and module integration. Hybrid integration was the major integration technique used for photonic integration, accounting for 56.8% of global market revenue in 2013. Although it is expected to remain the major integration technique over the forecast period, monolithic integration is expected

to exhibit the most rapid growth, at a CAGR of 26.5% during 2015–2022. On the other hand, the module integration technique is expected to see a fall in revenue due to its inferior integration capabilities compared with hybrid and monolithic integration.

Indium phosphide (InP) and silicon-on-insulator (SOI) collectively accounted for over half (60.9%) of market revenue in 2013. The dominance of InP is mainly due to its ability to integrate optoelectronic functions into an optical system chip monolithically.

In addition, the benefits offered in terms of size, speed, energy efficiency, and cost of fabrication and packaging have further ensured its dominance. Among different PIC components, lasers accounted for the biggest share (29.3%) of PIC revenue in 2013. Optical amplifiers (which help to realize high-level photonic integration by compensating for

Although it is expected to remain the major integration technique over the forecast period, monolithic integration is expected to exhibit the most rapid growth, at a CAGR of 26.5% during 2015–2022. On the other hand, the module integration technique is expected to see a fall in revenue due to its inferior integration capabilities compared with hybrid and monolithic integration

optical losses from individual photonic elements) are expected to show the most rapid growth, at a CAGR of 26.6% over 2015–2022.

The largest application segment of the PIC market in 2013 was optical communications, accounting for over half (58.6%) of revenue. It is expected to remain the largest application segment over 2015–2022 as a result of increasing demand from data-center applications. Currently, the other major application segments are sensing and biophotonics, which collectively account for around one-third (35.5%) of revenue. Although the existing contribution from the optical signal processing segment is the smallest, it is expected to see healthy growth following the commercialization of quantum computing.

The largest PIC market by geographical region in 2013 was North America, followed by Europe and Asia-Pacific. Although North America is expected to remain the largest market up to 2022, Asia-Pacific is expected to see healthy growth, outpacing North America and Europe. Growth in Asia-Pacific can be attributed mainly to rising demand from data-center and biophotonics applications.

The global PIC market is highly fragmented and is characterized by the presence of a large number of players, notes the report. Some of the leading players in the market are listed as include Infinera Corp (USA), Alcatel-Lucent S.A. (France), Huawei Technologies Co Ltd (China), JDS Uniphase Corp (USA), Avago Technologies Ltd (Singapore), Intel Corp (USA), and NeoPhotonics Corp (USA).

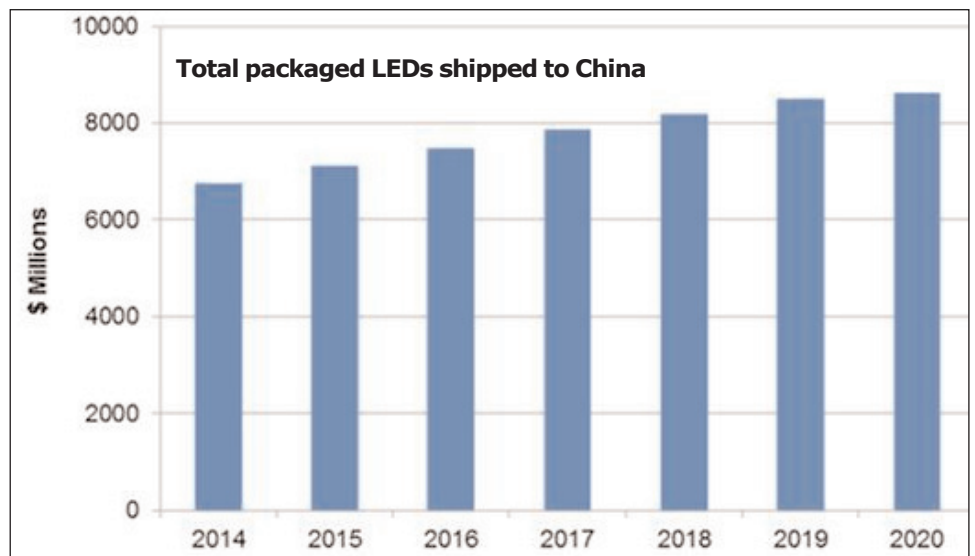
www.transparencymarketresearch.com/photonic-integrated-circuit.html

Chinese market for packaged LEDs to grow at single-digit annual rate

Oversupply & price competition between lighting LED makers hits ASPs

Due to oversupply and price competition between the suppliers of lighting LEDs, the total Chinese market for packaged LEDs will grow at a single-digit annual rate, forecasts market research firm IHS. The total Chinese market for packaged LEDs was \$6.7bn in 2014, including \$3.8bn for lighting applications, according to the latest data in the 'Packaged LEDs Report — China — 2015' (part of the IHS LED Intelligence Service).

Since too many suppliers produce almost the same LEDs for lighting (e.g. using the 2.8mm x 3.5mm 2835-type LED chip size), the average selling price (ASP) declined significantly in 2015. To ensure revenue growth, different companies therefore use different strategies. Larger companies tend to grow through capacity expansion and acquisition (for example, Hongli acquired Smalite, and Refond acquired Lingtao). Meanwhile, smaller companies are finding it difficult to survive without further



investment or a unique technical advantage.

In China in 2014, Nichia had the highest revenue, followed by MLS and Everlight. In addition to MLS, other local suppliers (such as Nationstar) have started to play an important role and are growing quickly, notes the report.

Look just at the revenue of China-based companies, MLS was

number one in 2014, followed by Nationstar and Jufei. MLS also had the highest revenue in lighting, signage and 'other' sectors, whereas Jufei led in the backlighting and mobile sectors. Eight Chinese companies had packaged LED revenue of more than \$100m in 2014, concludes the report from IHS.

<https://technology.ihs.com/552309>

Opto component sales to grow at 9.4% to \$55.5bn by 2020 China to grow the fastest at 11.14%

The optoelectronic component market was \$32.17bn in 2014 and is rising at a compound annual growth rate (CAGR) of 9.41% from 2015 to \$55.53bn by 2020, according to the report 'Optoelectronic Components Market by Component (LED, Laser Diode, Image Sensor), Application (Residential and Commercial, Consumer Electronics, Industrial, Healthcare), and Geography (North America, Europe, APAC, and RoW) — Global Forecast to 2020' from MarketsandMarkets.

LEDs comprised the largest share of the market in 2014 and should lead this market till 2020, whereas laser diodes are expected to exhibit the highest growth rate of 12.98%.

The report segments the opto component market by application into residential & commercial, consumer electronics, industrial, automotive, healthcare, telecoms, and aerospace & defense. The market is also segmented by component type into LEDs, image sensors, laser diodes, optocouplers, infrared (IR) components, and others. Due to their long operational life, efficiency and high durability, LEDs have a wide range of lighting applications. Image sensors are used widely in surveillance cameras, machine-vision cameras, and automotive cameras. Laser diode applications span telecoms, measurement instruments and consumer electronics.

The opto components market in the Asia-Pacific (APAC) region is expected to grow at a CAGR of 9.98% to \$22.31bn by 2020. The market in China should grow at the highest CAGR of 11.14%.

Major players in the optoelectronic components market are cited as Cree Inc in the USA, Germany's Osram Licht AG, Vishay Intertechnology Inc, ON Semiconductor and OmniVision Technologies Inc in the USA, Sony Corp and Sharp Corp in Japan, Samsung Electronics Co Ltd in South Korea, and Koninklijke Philips N.V. in The Netherlands.

www.marketsandmarkets.com/Market-Reports/optoelectronics-market-450.html

Anadigics agrees to be acquired by GaAs Labs for \$32m

Broadband wireless and wireline communications component maker Anadigics Inc of Warren, NJ, USA has agreed to be acquired by affiliates of GaAs Labs LLC for \$0.35 per share through a cash tender offer (worth \$32m in total), representing a premium of 38.2% on the average closing price of Anadigics' shares of common stock during the 30-day trading period ended 11 November.

Acquisition will "provide a platform to accelerate innovation and product development in support of revenue growth in our key target markets of CATV, small-cell, WiFi and optical," believes Anadigics' chairman & CEO Ron Michels.

"GaAs Labs brings a wealth of RF semiconductor industry knowledge and a proven track record of success that we expect will strengthen our ability to provide our customers with a broader portfolio of innovative and valuable product offerings," he adds.

"We are thrilled to add Anadigics, an innovator of RF solutions for infrastructure and optical market applications, to our RF semiconductor portfolio," says GaAs Labs' co-founder & president John Ocampo. "We look forward to leveraging Anadigics' products and technologies as a platform for growth in an array of exciting communications markets."

Prior to creating GaAs Labs, Ocampo co-founded Sirenza Microdevices Inc of Broomfield, CO, USA (a diversified supplier of RF semiconductors and related components for the commercial communications,

consumer and aerospace, defense & homeland security markets). After leading Sirenza through an IPO and eventual sale to RF Micro Devices Inc of Greensboro, NC in 2007, Ocampo served on RFMD's board of directors.

In 2009, GaAs Labs acquired M/A-COM Technology Solutions Inc of Lowell, MA, USA (a supplier of semiconductors, components and subassemblies for use in RF, microwave and millimeter-wave applications). In mid-2010, M/A-COM Tech acquired Mimix Broadband Inc of Houston, TX. In 2012, GaAs Labs bought GaN-based Nitronex (since merged into M/A-COM Tech in 2014)

GaAs Labs will commence a cash tender offer to purchase all of Anadigics' issued and outstanding shares of common stock at \$0.35 per share (net) to the seller in cash, without interest (less any applicable withholding taxes). Upon satisfaction of the conditions to the tender offer and after such time as all shares tendered in the tender offer are accepted for payment, the agreement provides for the parties to effect, as

Acquisition will provide a platform to accelerate innovation and product development in support of revenue growth in our key target markets of CATV, small-cell, WiFi and optical

promptly as practicable, a merger which would result in all shares not tendered in the tender offer being converted into the right to receive \$0.35 per share in cash. The tender offer is subject to customary conditions, including the tender of at least a majority of the outstanding shares of Anadigics' common stock on a fully diluted basis and obtaining certain regulatory approvals, and is expected to close in December 2015 or January 2016, after which will operate as a wholly owned subsidiary of GaAs Labs. The deal has been unanimously approved by Anadigics' board of directors.

Under the terms of the agreement, Anadigics may solicit superior proposals from third parties for a 'go-shop' period of 25 calendar days through 6 December. It is not anticipated that any developments will be disclosed with regard to this process unless Anadigics' board makes a decision to pursue a potential superior proposal. Anadigics' financial advisor Needham & Company LLC will assist with the go-shop process. The agreement provides GaAs Labs with a customary right to match a superior proposal. It also provides for certain break-up fees payable to GaAs Labs in connection with termination of the agreement under certain circumstances.

Greenbaum Rowe Smith & Davis, LLP is acting as legal adviser to Anadigics, and Perkins Coie LLP is acting as legal adviser to GaAs Labs. www.gaslabs.net

Net cash drops to \$7.9m after revenue falls 20.5% in Q3

For third-quarter 2015, Anadigics has reported net sales of \$12.1m, down 23.3% on \$15.8m last quarter and 36% on \$18.9m a year ago. Driven principally by the lower revenue, gross margin (on a non-GAAP basis) has fallen from 20.5% last quarter to 14.3% (down on 16% a year ago).

Operating expenses have been cut further, from \$8.7m a year ago

and \$7.7m last quarter to \$7.5m. Despite this, net loss was still \$5.7m (\$0.06 per share), level with \$5.7m (\$0.07 per share) a year ago but up on \$4.5m (\$0.05 per share) last quarter. During the quarter, cash and cash equivalents fell to \$11.7m, and net cash hence fell further, from \$11.2m to \$7.9m, excluding \$3.8m drawn under the firm's

credit facility with Silicon Valley Bank. SVB provided a waiver on the minimum earnings before interest, taxes, depreciation and amortization (EBITDA) covenant as of 3 October related to the three-month period then ended. Consequently, as of 3 October, Anadigics was in full compliance with the covenants of the SVB loan agreement.

www.anadigics.com

Bastani made senior VP of GlobalFoundries' RF unit

GlobalFoundries of Santa Clara, CA, USA (one of the largest foundries, with over 250 customers and operations in Singapore, Germany and the USA) has appointed Bami Bastani as senior VP of its Radio Frequency (RF) business unit.

With the acquisition of IBM's Microelectronics Division in July, GlobalFoundries says that it has solidified its technology position in wireless front-end module solutions. The firm has significantly broadened its existing high-voltage CMOS and RF MEMS technologies with differentiated RF silicon-on-insulator (RFSOI) and high-performance silicon germanium (SiGe) technologies geared to enable complex RF switches, high-performance power amplifiers, and integrated front-end applications in mobile devices.

With over 35 years of high-tech, semiconductor and RF experience, Bastani will focus on delivering the next generation of GlobalFoundries' RF roadmap, aiming to capture fur-

ther opportunities in the automotive, home and growing Internet of Things (IoT) markets. Bastani will lead a team with a history of providing high-performance solutions that address the increasing complexity of mobile radio devices.

"Bami is an experienced executive with deep knowledge of the RF industry," comments GlobalFoundries' CEO Sanjay Jha. "He brings to GlobalFoundries years of leadership and management capabilities that will enable us to grow our RF business," he adds. "Bami has been part of the semiconductor industry for several decades, and his experience spans beyond RF to wafer manufacturing operations and market growth strategies."

Prior to joining GlobalFoundries, Bastani was president, CEO and board member of global enterprise-grade Wi-Fi networks solution provider Meru Networks from 2012 to earlier this year. He transformed Meru from a hardware company to

a solution provider with emphasis on software, software-defined networks (winning the 2015 SDN Excellence Award) and subscription cloud offering (WaaS). He brought a vertical market strategic focus to the company, allowing it to broaden its offerings and customer base.

Before that, Bastani served in president & CEO as well as board member roles in the mobility, consumer, and broadband markets. These include president and CEO roles at Trident Microsystems Inc and Anadigics Inc. Bastani also served in executive positions at Fujitsu Microelectronics, National Semiconductor and Intel Corp.

Bastani earned his Ph.D. and MSEE in Microelectronics at Ohio State University. He holds three US patents, has several publications on semiconductor technology, and has given several invited keynotes on topics of innovation and corporate management.

www.globalfoundries.com

MACOM launches plug-in and surface-mount DOCSIS 3.1-compliant CATV diplex filters

M/A-COM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) has launched three families of diplex filters designed for DOCSIS 3.0 and 3.1 infrastructure equipment. Available in plug-and-play vertical and horizontal form factors along with surface-mount configurations, the new diplex filters are suited to use in CATV infrastructure spanning nodes, system amplifiers, line extenders, drop amplifiers and RF-over-glass (RFoG) optical networking unit (ONUs).

The new MAFL-0110XX series of diplex filter platforms cover the key industry frequency splits of 42/54, 65/85, 85/105 and 204/258MHz, and operate from 5MHz to 1218MHz.

The compact plug-and-play filters provide what is claimed to be superior insertion loss, return loss, rejection and cross-over-isolation performance, and are designed and tested to meet exacting infrastructure quality and reliability requirements. Each filter platform is easily expanded to cover other frequency splits.

The diplex filter platforms are the newest additions to MACOM's portfolio of RF components designed to comply with the DOCSIS 3.1 standard for high-bandwidth data transfer over hybrid fiber-coaxial (HFC) infrastruc-

ture. MACOM says that its domain expertise, coupled with a global sales and appli-

It is easy to lose sight of the importance of the filter and passive components in the cascade

cations support network, ensure that designers are afforded the products and support required for accelerated market deployments for DOCSIS 3.1-compliant equipment.

"MACOM's high-performance pluggable and SMD filter platforms provide network equipment designers with full turnkey solutions that facilitate accelerated amplifier developments," says Graham Board, senior director of Carrier Networks at MACOM. "With so much focus on amplifier performance for DOCSIS 3.1 infrastructure it is easy to lose sight of the importance of the filter and passive components in the cascade. MACOM's filters are designed to deliver superior RF performance, thus enabling optimal GaAs or GaN amplifier cascades for network equipment."

www.macom.com

Qorvo's quarterly revenue rises 5.2%, led by Mobile Products

Rebound at Chinese base-station customers to drive growth

For its fiscal second-quarter 2016 (ended 3 October 2015), Qorvo Inc, which provides core technologies and RF solutions for mobile, infrastructure and aerospace/defense applications, has reported revenue of \$708.3m, up 5.2% on \$673.6m last quarter and up 12% on \$634.8m a year ago for the combined September 2014 quarter revenues of RF Micro Devices Inc of Greensboro, NC and TriQuint Semiconductor Inc of Hillsboro, OR, USA (following the merger of the firms on 1 January).

The top three customers comprised about 60% of revenue, including two 10%-or-more customers. The largest, at 41%, represents the aggregate of multiple sub-contractors for this end customer. The second is China-based telecoms equipment maker Huawei Technologies Co Ltd (a customer for both Mobile Products and Infrastructure & Defense Products).

Both the Mobile Products and Infrastructure & Defense Products businesses did better than expected.

Despite rising 6% from \$122m last quarter, Infrastructure & Defense Products (IDP) revenue of \$129m was down 13% year-on-year, due to wireless infrastructure falling about \$24m on a year ago. However, outside of wireless infrastructure, IDP revenue grew 6% year-on-year.

Growth was led by Mobile Products, for which revenue grew 19% year-on-year and 5% sequentially (from \$551m last quarter) to \$578m, driven by large customer product ramps. However, following strong growth in China in the first two quarters of calendar 2015 (including a \$100m rise in the June quarter), despite continued strength from Qorvo's largest customer in the country, other Chinese customers have since slowed (not achieving their goals set at the beginning of the year), according to Mobile Products president Eric Creviston.

On a non-GAAP basis, gross margin was 49.7%, up on 47.4% a year ago but down from 51.5% last quarter (and slightly below the guidance of 50-51%) due to product mix.

Operating expenses (OpEx) were cut by nearly \$2m from \$158.7m last quarter to \$156.8m, reflecting synergies that have been realized. Year-on-year, operating expenses grew at half the rate of revenue growth. In particular, R&D expenses rose 14% sequentially as Qorvo pursued major growth opportunities, while sales & marketing and general administrative expenses rose 14% year-on-year. "The realization of synergies is allowing Qorvo to appropriately invest in product and process development, while driving towards our operating expense model," says Creviston.

Operating income was \$194.8m (an operating margin of 27.5% of revenue), up on \$187.8m last quarter and up 28% on a year ago. This was led by the Mobile Products business unit, which achieved operating income of about 30% on its 19% revenue growth. "In the nine months since Qorvo's formation, revenue has grown 25% from the same period in the prior year while non-GAAP operating income has nearly doubled," notes chief financial officer Steve Buhaly.

Net income rose from \$168.5m (\$1.09 per diluted share) last quarter to \$183.3m (\$1.22 per diluted share, exceeding original guidance of \$1.10).

Cash flow from operations was \$168.8m (up from \$141.4m last quarter). Capital expenditure (CapEx) was \$80.3m, primarily to

Our two largest synergy opportunities remain the in-sourcing of packaging, assembly & test, and in-sourcing of SAW filters

address growth and demand for premium filters. During the quarter, Qorvo repurchased about 9.1 million shares of its common stock at a total cost of \$500m. Overall, cash and investments have fallen hence from \$558m to \$195.6m. Since the end of the quarter, Qorvo's board of directors has just authorized a new one-year \$1bn share repurchase program (expiring on 4 November 2016).

"Design activity during the quarter was particularly robust, as we secured multiple opportunities to expand content in the marquee smartphones launching in calendar 2016 and 2017 and positioned IDP to accelerate growth across its target markets," notes president & CEO Bob Bruggeworth.

In mobile, Qorvo entered the BAW-based multiplexer market with a family of quadplexers for smartphones supporting carrier aggregation in China and Europe. Those parts are sampling at leading customers, with volume production expected in the spring.

Collaborating with leading channel partners in China, Qorvo also captured multiple next-generation LTE reference design wins for multimode power amplifiers (PAs), multimode transmit modules, switches, duplexers and multiplexers. "Qorvo has excellent long-term opportunities in China as smartphones continue to proliferate, as customers in China increase the number of phones they export, and as the RF content in China-based smartphones continues to expand," says Bruggeworth.

In IDP, Qorvo enjoyed strong design-win activity and signed multiple long-term supply agreements in defense & aerospace. In connectivity, the firm secured multiple high-value 5GHz PA and BAW filter slots in high-performance Wi-Fi enterprise applications and expanded mobile Wi-Fi content

with a leading LTE reference design provider. In transport, Qorvo captured an increasing percentage of DOCSIS 3.1 sockets with highly differentiated hybrid GaAs and GaN products delivering what is claimed to be best-in-class efficiency, bandwidth and power.

"In cable TV, Qorvo was especially strong with hybrid GaAs and GaN power doublers, saving operators 15–20W," says Bruggeworth. "These solutions mix and match our legacy technologies and capability, and they are especially strong in power efficiency and needed in applications where power consumption is everything," he adds. In wireless infrastructure, Qorvo was an active participant in pre-5G and 5G demos at major base-station OEMs, and it sampled GaN-based macro-cell high-power amplifier (HPAs) to the five leading base-station OEMs.

"We are introducing an expanded set of new products combining switches and filters and leveraging our broad set of competencies, including BAW filter and GaN process technologies, and all of this is creating exciting new growth opportunities for Qorvo," says chief financial officer Steven J. Buhaly.

"Our IDP organization has essentially repositioned itself to accelerate growth above what our legacy IDP businesses had achieved historically," notes Bruggeworth. "IDP is structured around a diverse portfolio of businesses, all leveraging Qorvo's shared core competencies and focused on winning with premium products using highly differentiated

internally developed technologies. We're increasing our focus on automotive, Internet of Things, data centers and Wi-Fi, and we're increasing our resources in those value streams. We're also targeting segments that don't appear to enjoy the same dynamic growth but have large niches that can be exploited with differentiated products based on Qorvo's technology," he adds. Examples include Qorvo's GaN-based products in the base-station market, and in the traveling-wave tube (TWT) replacement to defense and commercial markets using the firm's patent-protected Spatium solid-state products.

"We're continuing to penetrate the defense market with our expanding family of GaN-based products and we're increasing our leading market share, as measured by Strategy Analytics," Bruggeworth says.

"IDP is targeting the highest-growth segments within their diversified businesses with compelling premium solutions using highly differentiated internally developed technologies," continues Bruggeworth. "They're moving the organization forward from pre-merger levels, where both companies saw low growth trajectories [of 5–7 percentage points], to today where we see IDP on a path to grow their business two times to three times those legacy growth rates," he adds. "You'll start to see our growth rates pick up as we go into next year and certainly as we move into 2017 and 2018," adds IDP president James L Klein.

"In China, we saw industry funda-

mentals begin to improve and believe base-station customer activity bottomed in the September quarter," says Bruggeworth. "We remain cautious and believe we've embedded conservative expectations in our forward guidance related to China-based handset demand."

For its fiscal third-quarter 2016 (ending 2 January 2016), Qorvo expects revenue of \$720–730m. Gross margin should return to about 50%, aided by benefits from the consolidation of assembly & test in China accruing in the second half of calendar 2015. OpEx should again be in the mid-\$150m. Diluted EPS should be \$1.25–1.30.

"Synergy achievement is on track [expected to beat the \$75m annual target for both year one and year two post-merger], led by the consolidation of test & assembly into our China operations," notes Buhaly. "We're also uniquely positioned to reduce cost and enhance our operating model," reckons Bruggeworth. "Our two largest synergy opportunities remain the in-sourcing of packaging, assembly & test, and the in-sourcing of SAW filters. We estimate these represent greater than \$60m in annualized savings," he adds. "They're progressing on schedule and the benefit is expected to favorably impact results beginning early next year."

"We think calendar 2016 will be a strong year for Qorvo and believe we will fully achieve our target operating model of 30% operating margin over the full year," concludes Buhaly.

Qorvo closes offering of \$1bn of senior notes

Qorvo has completed its offering of \$1bn of senior notes, comprising \$450m of 2023 notes and \$550m of 2025 notes (maturing on 1 December 2023 and 1 December 2025), which will pay interest semi-annually at a rate of 6.75% and 7.00%, respectively.

The notes were issued to qualified institutional buyers and to certain non-US persons.

Qorvo aims to use the net proceeds of the offering for general corporate purposes, including share repurchases and repayment of any amounts outstanding under its revolving credit facility.

The notes are senior unsecured obligations of Qorvo and are initially guaranteed (jointly and severally) by each of the firm's existing and future direct and indi-

rect wholly owned US subsidiaries that guarantee Qorvo's obligations under its revolving credit facility.

The notes have not been registered under the Securities Act or any state securities laws and may not be offered or sold in the USA without registration or an applicable exemption from such registration requirements.

www.qorvo.com

Qorvo launches power amplifiers and duplexers to support small-cell network growth

Qorvo Inc of Greensboro, NC and Hillsboro, OR, USA, which provides core technologies and RF solutions for mobile, infrastructure and aerospace/defense applications, has launched seven new products — four new power amplifiers and three new duplexers — to support growth in small-cell base stations, helping to improve mobile network performance by expanding small-cell capacity.

“These small-cell products deliver the high levels of integration, transmit power, isolation and overall performance our infrastructure customers require to improve network coverage in dense environments, such as sports stadiums, airports, train stations and large enterprise buildings,” says James Klein, president of Qorvo’s Infrastructure and Defense Products group. “Qorvo is rapidly expanding our broad portfolio of premium products using internally sourced, differentiated technologies,” he adds. “Key strategic customers are requesting volume shipments.”

Qorvo’s newest power duplexers and amplifiers (PAs) cover major cellular infrastructure frequency bands, including bands 1 and 3, with superior band isolation.

The duplexers TQQ7101 (band 1, with passbands 1920–1980 and 2110–2170MHz), TQQ6103 (band 3, 1710–1785 and 1805–1880MHz) and TQQ6107 (band 7, 2500–2570 and 2620–2690MHz) are based on the firm’s premium bulk acoustic wave (BAW) technology and feature low insertion loss, high isolation and what is claimed to be industry-leading power handling.

Qorvo’s newest infrastructure PAs are the TQP9218 (1805–1880MHz), TQP9221 (2010–2170MHz), TQP9418 (1805–1880MHz) and TQP9421 (2110–2170MHz).

The TQP9218 and TQP9221 PAs provide –48dBc ACLR (adjacent-channel leakage ratio) at 24.5dB of linear output power, while the TQP9418 and TQP9421 PAs provide –48dBc ACLR at 27dB of linear output power (each with 20MHz

These small-cell products deliver the high levels of integration, transmit power, isolation and overall performance our infrastructure customers require to improve network coverage in dense environments

LTE signals). Each of the PAs deliver 16% efficiency at the rated power levels with 30dB gain in a 7mm x 7mm surface-mount package. The PAs are fully integrated with on-chip control bias and internal temperature compensation circuits to allow for operation from a 4.5 or 5V supply and do not require linearized system techniques such as digital pre-distortion.

Both the duplexers and PAs are integrated solutions, with a small footprint, eliminating external components. In addition, the TQP9221 PA can be utilized for bands 4, 10, 34, and 66; the TQQ6107 duplexer is intended to be used for band 7.

Qorvo says that it continues to expand its small-cell product portfolio to accommodate additional bands and provide seamless coverage across the entire front end. The firm’s broad portfolio of small-cell solutions includes low-noise amplifiers, filters, switches, duplexers and power amplifiers.

Samples of the above duplexers and power amplifiers are available now through global distribution channels.

www.qorvo.com

Qorvo receives first production orders for multiplexer solutions

Qorvo has received its first production orders for its recently launched highly integrated multiplexer solutions, which are designed to simplify and accelerate the adoption of carrier aggregation (CA) in 4G LTE-Advanced devices.

Qorvo’s quadplexer solutions leverage the firm’s proprietary LowDrift BAW (bulk acoustic wave) filter technology to deliver what are reckoned to be intrinsic performance advantages over other acoustic filter technologies. Its LowDrift and NoDrift BAW filter

technologies help network operators to optimize frequency spectrum and enable much improved mobile data services for users of next-generation smartphones.

“The rapid customer adoption of Qorvo’s multiplexer solutions reflects the strength of our premium filter technology portfolio and the benefit of our broad collaboration with the leading chipset suppliers on their highest-volume reference designs,” says Mobile Products group president Eric Creviston. “Qorvo will continue to expand our family of

multiplexers, and we anticipate broad adoption of our multiplexer solutions in calendar 2016.”

The firm says that its multiplexers deliver low insertion loss and high cross-isolation of receive and transmit paths to optimize receive sensitivity and extend smartphone battery life. Its first-generation multiplexer solutions are optimized for Europe and the Asia-Pacific region and integrate multiple BAW filters to cover the primary band combinations used in CA (carrier aggregation) deployments: bands 1+3 and bands 39+41.

Qorvo's 802.11ac Wi-Fi amplifier technology chosen for NETGEAR's new Nighthawk router

Qorvo Inc of Greensboro, NC and Hillsboro, OR, USA, which provides core technologies and RF solutions for mobile, infrastructure and aerospace/defense applications, says that its RFPA5542 5GHz wireless local-area network (WLAN) power amplifier (PA) module has been selected by consumer Wi-Fi router supplier NETGEAR Inc of San Jose, CA, USA for its Nighthawk X8 AC5300 smart WiFi router (R8500).

"The Nighthawk router series provides the best-in-class performance to fuel ever-increasing demands for Wi-Fi speed, coverage and throughput," claims Sandeep Harpalani, NETGEAR's senior director of product marketing. "Qorvo's high-power, high-efficiency Wi-Fi amplifier technology used on Nighthawk X8 helps us deliver the world's fastest wireless home network connection, giving our customers unparalleled wireless coverage and performance for the

growing number of connected devices in the home."

The Nighthawk X8 tri-band quad-stream 802.11ac WiFi router, with Qorvo's RFPA5542 PA, enhances throughput for every device in the home. The tri-band technology maximizes the number of multiple input, multiple output (MIMO) streams, and allows for high-definition video streaming, online gaming and roaming with a strong signal anywhere in the home. The Nighthawk enables eight streams of 5GHz Wi-Fi powered by the RFPA5542, providing extended

Qorvo's high-power, high-efficiency Wi-Fi amplifier technology used on Nighthawk X8 helps us deliver the world's fastest wireless home network connection

range and maximum throughput for multiple home devices.

Qorvo's 802.11ac Wi-Fi amplifier technology delivers "unparalleled speed and simultaneous coverage for multiple devices, paving the way for the Internet of Things (IoT) within the home," claims James Klein, Qorvo's president of Infrastructure and Defense products.

Qorvo says that, for the latest 4x4 and tri-band chipset solutions, the RFPA5542 PA provides power-added efficiency (PAE) of 17% for 802.11ac speeds and over 20% for 802.11n speeds. Moreover, available in 4mm x 4mm standard QFN packaging, the integrated module eliminates the need for external components, greatly reducing system design complexity, layout area, bill of materials, and manufacturing cost for the customer application.

www.qorvo.com

www.netgear.com/home/products/networking/wifi-routers/R8500.aspx

RF Fusion Mobile Wi-Fi iFEM selected for LG's Nexus 5X smartphone

Qorvo says that LG Electronics has selected its RF Fusion Mobile Wi-Fi integrated front-end module (iFEM) for the Nexus 5X smartphone. Contributing to the transition to highly integrated front-end modules for Wi-Fi, the TQF6174 (Qorvo's newest RF Fusion Mobile Wi-Fi iFEM) delivers higher performance than discrete components while saving space and simplifying design for smartphone manufacturers, the firm says.

"Qorvo is uniquely positioned to design and manufacture all the high-value components in the integrated front end, including high-performance filters, switching and amplification," reckons Eric Creviston, president of the firm's Mobile Products group.

Combining a Wi-Fi coexistence filter, 5GHz power amplifier, 5GHz low-noise amplifier (LNA), diplexer,

switch and coupler in a compact 4mm x 3mm package, the TQF6174 provides what is claimed to be a new level of integration and performance in the mobile Wi-Fi front end.

The Wi-Fi coexistence filter leverages Qorvo's proprietary LowDrift BAW (bulk acoustic wave) technology to address the design challenges related to interference between Wi-Fi and the adjacent LTE bands (7, 40 and 41) used in China, North America and elsewhere. The firm's coexistence filters deliver what is claimed to be superior insertion loss and improved power-added efficiency (PAE) and power output, helping smartphone makers to extend battery life and maximize data throughput across the full 2.4GHz Wi-Fi spectrum. All of Qorvo's LowDrift and NoDrift premium

BAW filters combine high performance and temperature stability to solve coexistence challenges unaddressed by other technologies, the firm adds.

"Qorvo worked closely with us to meet our requirements, while offering an enhanced solution to reduce the complexity of product development," comments an LG spokesperson.

Qorvo says that it co-architects and tunes the components in the TQF6174 to drive higher overall system performance. The firm employs proprietary wafer-level packaging (WLP) and CuFlip flip-chip technology to reduce module size, resulting in a footprint that is 24% smaller in a 2x2 MIMO configuration than comparable discrete solutions, it is reckoned.

www.triquint.com/products/p/TQF6174

Skyworks exceeds quarterly revenue and EPS guidance

For full-year fiscal 2015 (ending 2 October), Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) has reported record revenue of \$3.26bn, up 42% on fiscal 2014's \$2.29bn. For the fiscal fourth quarter, revenue was a record \$880.8m, up 8.7% on \$810m last quarter and up 23% on \$718.2m a year ago (and exceeding the guidance of \$875m).

"We delivered a strong close to fiscal 2015 producing Q4 financial results that once again significantly outpaced the growth of the broader semiconductor market," notes chairman & CEO David J. Aldrich.

Of Q4 revenue, power amplifiers (PAs) have fallen further, from 36% a year ago and 24% last quarter to 20%, while integrated mobile systems have risen from 39% a year ago and 53% last quarter to 59% (with revenue up 84% year-on-year). Broad markets fell slightly from 23% last quarter to 22% (compared with 25% a year ago).

On a non-GAAP basis, gross margin has grown again, from 45.9% a year ago and 49% last quarter to 50%. Full-year gross margin has risen from 45.2% for 2014 to 48.2% for 2015.

Operating expenses have risen further, from \$93.9m a year ago and \$101.3m last quarter to \$104.9m, consisting of research & development (R&D) expenses rising from \$65.1m last quarter to \$70.8m, while selling, general and administrative (SG&A) expenses fell back from \$36.2m last quarter to \$34.1m (compared with \$35.8m a year ago).

Operating income was \$335.2m (an operating margin of 38.1%), up from \$295.4m (a margin of 36.5%) last quarter and \$235.7m (a margin of 32.8%) a year ago. Full-year operating income has almost doubled from \$687m (operating margin of 30%) for 2014 to \$1170m (a margin of 36%) for 2015.

Net income was \$296.1m (\$1.52 per diluted share, \$0.01 better than guidance), up from \$262.5m (\$1.34 per diluted share) last quarter

and \$216.1m (\$1.12 of per diluted share) a year ago. Full-year net income has risen from 2014's \$623m (\$3.24 per diluted share) to 2015's \$1028m (\$5.27 per diluted share).

Cash flow from operations was \$230m (up from \$222m last quarter, and making about \$1bn for full-year fiscal 2015). Capital expenditure has increased from \$108m last quarter to \$151m. Depreciation was \$46m. During the quarter, Skyworks distributed \$160m to shareholders through its dividend and stock repurchase plans. Cash and cash equivalents hence fell from \$1106m to \$1044m (although this is still up from \$806m a year ago). "For fiscal 2015, we returned about 64% of free cash flow [\$360m] to shareholders, higher than our goal of 40%, based on our recent share repurchase activity," notes chief financial officer Donald W. Palette. For the most recent quarter, Skyworks' board of directors has declared a cash dividend of \$0.26 per share (payable on 10 December to stockholders of record at the close of business on 19 November). "Longer term, we continue to view an allocation of roughly 40% of free cash flow as an appropriate balance between internal investment for growth initiatives and shareholder returns," he adds.

"Fiscal 2015 was a record year for Skyworks across all metrics," says Palette. "We are capitalizing on favorable end-market trends — leveraging our differentiated systems solutions portfolio to expand our addressable opportunity and enhance our financial returns. We continue to strategically position our business to take advantage of the tremendous growth opportunity we see ahead in our served markets."

Business highlights cited for fiscal Q4/2015 include the following:

- captured Wi-Fi, Bluetooth and ZigBee content in the Google OnHub Connected Home Gateway with a suite of 20 devices;
- launched tuning and connectivity ICs in Huawei's Nexus 6P smart-

phone platform;

- extended momentum in the connected home with ZigBee front-end modules in Samsung's SmartThings suite of products;
- expanded Skyworks' presence in a small-cell base transceiver station (BTS) platform with \$25 of content;
- unveiled SkyOne and diversity receive modules in ZTE's Axon smartphone;
- secured display backlight and power management functionality in LG infotainment centers for upcoming Hyundai models;
- powered an Arris DOCSIS 3.0 cable modem for Time Warner deployments;
- supported the Moto X smartphone with five devices including the TrueFlash dual LED camera flash IC;
- introduced ZigBee solutions for Philips' latest smart lighting hub.

"Entering fiscal 2016, we are well positioned to continue delivering growth and profitability in excess of the broader semiconductor market," says Aldrich.

For fiscal Q1/2016, Skyworks expects revenue of \$925–930m, up 5.3% sequentially and 15% year-on-year. Gross margin should grow to 51%. Operating expenses should rise to about \$108m, driven by ongoing investments in engineering and development teams as Skyworks expands its footprint within new verticals and further enhances its integration capabilities. Operating margin should exceed 39%. Diluted earnings per share (EPS) should reach \$1.60.

Given that fiscal Q1 guidance exceeds the previous gross margin target of 50% and that Skyworks is within reach of its previous annual EPS target of \$7, it is introducing an updated mid-term model: to achieve (within 6–8 quarters) organic annualized EPS of \$8 at a revenue run-rate of about \$4.5bn with gross margin of 53%. Longer term, based on internal margin initiatives, Skyworks targets gross margin of 55% on an organic basis.

www.skyworksin.com

Skyworks announces new \$400m stock repurchase program

Skyworks' board of directors has authorized the repurchase of up to \$400m of the firm's common stock from time to time prior to 10 November 2017, on the open market or in privately negotiated transactions, in compliance with applicable securities laws and other legal requirements.

This newly authorized stock repurchase program replaces in its

entirety the \$300m stock repurchase program that was approved by the board on 11 November and had \$62.6m of repurchase authority remaining.

The timing and amount of any shares repurchased will be determined by the company's management based on its evaluation of market conditions and other factors. The repurchase program may

be suspended or discontinued at any time. Any repurchased shares will be available for use in connection with the firm's stock plans and for other corporate purposes.

Skyworks currently expects to fund the repurchase program using its working capital. As of 2 October, the company had cash and cash equivalents of about \$1043.6m.

Microsemi to acquire PMC-Sierra for \$2.5bn after outbidding Skyworks

PMC to pay \$88.5m fee after terminating Skyworks deal

Analog and mixed-signal semiconductor maker Skyworks Solutions Inc of Woburn, MA, USA says that it has decided not to modify its amended and restated merger agreement with PMC-Sierra Inc of Sunnyvale, CA, USA (which provides semiconductor and software solutions for storage, optical and mobile networks), entered into on 29 October. PMC has terminated the agreement (entitling Skyworks to an \$88.5m termination fee from PMC).

On 5 October, Skyworks offered to acquire PMC for \$10.50 per share. On 19 October, Microsemi Corp of Aliso Viejo, CA, USA (which makes chips for the communications, security, aerospace and industrial markets) made a rival unsolicited offer to acquire PMC for \$8.75 in cash and 0.0736 of a Microsemi share for each share of PMC common stock (amounting to \$11.35 per PMC share). Then, on 29 October, PMC announced an amended and restated merger agreement for Skyworks to acquire it for \$11.60 per share. In response, Microsemi made a revised offer of \$9.04 in cash and 0.0771 of a Microsemi share for each share of PMC common stock (amounting to \$11.88 per PMC share). PMC subsequently noted that this amounted to \$11.77 per PMC share based on the closing price of Microsemi com-

mon stock on 13 November (rather than 29 October) and that its board continued to recommend the amended and restated merger agreement with Skyworks to its stockholders.

However, a subsequent revised proposal from Microsemi offered \$9.22 in cash plus 0.0771x of a Microsemi share for each PMC share (amounting to \$12.05 per PMC share — a 77.4% premium to PMC's closing stock price as of 30 September — valuing PMC at \$2.5bn). On 19 November, Microsemi said it had been informed that its revised proposal to acquire PMC constitutes a 'Superior Proposal' under the terms of PMC's merger agreement with Skyworks, and that the PMC board had given written notice to Skyworks of its intent to approve or recommend the latest Microsemi proposal.

Skyworks now says that, at an increased valuation, PMC no longer meets Skyworks' financial criteria, adding that its increased mid-term target operating model remains unchanged from the annualized non-GAAP earnings per share of \$8.00 it provided on 5 November.

Microsemi says that the deal (which has been approved by the boards of both Microsemi and PMC-Sierra) did not require the approval of its shareholders. The offer "benefits shareholders of both

Microsemi and PMC," says Microsemi's chairman & CEO James J. Peterson. "We can now shift our focus to realizing the significant synergies," he adds. The firm expects the transaction to achieve more than \$100m in annual cost synergies (including more than \$75m in the first full quarter of combined operations) and estimates approximately \$0.60 of non-GAAP EPS accretion in the first full year after closing.

"This acquisition will provide Microsemi with a leading position in high-performance and scalable storage solutions, while also adding a complementary portfolio of high-value communications products," says Peterson. "As we integrate the team and drive profitability, our combined company will benefit from increased scale, industry-leading margins, diversified market exposure, consolidated infrastructure and substantial cost savings."

Microsemi intends to fund the transaction and repay its existing credit facility with existing cash, \$2.7bn in new transaction debt and \$0.6bn in Microsemi common stock. Shareholders of Microsemi and PMC will own about 85% and 15%, respectively, of the combined entity after completion of the transaction.

www.pmc.com
www.microsemi.com
www.skyworksinc.com

Toshiba unveils SOI-CMOS process claiming lowest-class insertion loss for RF switches in smartphones

Toshiba has announced the development of the next-generation TarfSOI (Toshiba advanced RF silicon-on-insulator) process, optimized for radio-frequency (RF) switch applications.

Sample shipments of a new SP12T (single-pole 12-throw switch) RF switch IC fabricated with the new process will start in January. Designed for use in smartphones, the SP12T RF switch IC features an integrated MIPI-RFFE controller for mobile applications (the RF front-end interface developed by the MIPI Alliance Inc), and is suitable for use in devices compliant with 3GPP GSM, UMTS, W-CDMA, LTE and LTE-Advanced standards.

RF switch ICs fabricated using the new TaRF8 SOI-CMOS TarfSOI front-end process achieve what is claimed to be the lowest-class insertion loss in the industry (0.32dB at 2.7GHz). Compared with products using Toshiba's

current TaRF6 process, insertion loss is improved by 0.1dB while maintaining the same level of distortion characteristics.

With the trend in mobile communications towards high-data-rate, high-capacity data transfers, RF switch ICs used in mobile devices and smartphones require multi-port support and improved RF performance. Lowering insertion loss is recognized as a particularly important factor in this, as it decreases RF transmission power loss,

With the trend in mobile communications towards high-data-rate, high-capacity data transfers, RF switch ICs used in mobile devices and smartphones require multi-port support and improved RF performance

which can support a longer battery life for mobile devices.

Toshiba is developing high-performance RF switch ICs using its in-house fab to apply SOI-CMOS technology, which is suitable for integrating analog and digital circuits. Toshiba says that, by handling all aspects of the production flow, from RF process technology development to the design and manufacturing of RF switch chips, it can swiftly improve SOI-CMOS process technology in response to feedback from the development results of its own RF switch IC products. The firm says that this integrated device manufacturer (IDM) approach allows it to quickly establish new process technologies that are suited to actual products and to enter the market with products fabricated with the latest process technology.

www.toshiba.co.jp

Anokiwave launches silicon-based low-noise-figure X-band AESA core IC

Anokiwave Inc of San Diego, CA, USA, a provider of highly integrated silicon core chips and III-V front-end integrated circuits for emerging millimeter-wave (mmW) and active electronically scanned array (AESA) markets, has announced the worldwide release of the second IC in a family of X-band silicon radar quad core IC solutions for commercial radar and 5G communications markets.

The AWS-0101 is an integrated 4-channel beamformer, low-noise amplifier (LNA) and power amplifier (PA). It supports four radiating elements with dual-beam Rx, single-beam Tx, and includes 6-bit phase and 6-bit gain control. The IC provides a low noise figure in Rx mode, allowing for a complete silicon RF solution for commercial

AESA systems. Additional features include gain compensation over temperature, temperature reporting, forward power telemetry with programmable delay power sampling, and fast beam switching using on-chip beam weight storage registers that can be accessed via direct address lines. Silicon technology enables very high integration of functionality, enabling planar antenna design at X-band with reduced system size, weight and cost.

The AWS-0101 is a highly integrated TDD (time-division duplex) transmit-receive chip in a commercial QFN-style surface-mount plastic package with dimensions of 7mm x 7mm x 0.9mm, easily fitting within the typical 15mm lattice spacing at 10GHz. The IC is con-

trolled through a 5-wire serial-to-parallel interface (SPI) bus.

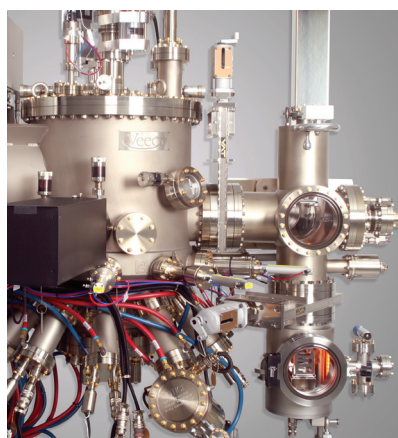
"Commercial AESAs are the future of radar and 5G systems and an all-silicon solution will enable the market to transition from expensive traditional military AESA technology to a commercial arena that requires very low cost," says CEO Robert Donahue. "These parts will set a new paradigm in the industry for commercial AESAs," he believes.

Anokiwave offers innovator kits and evaluation kits for early access to the technology. The kits include boards with the AWS-0101 device, USB-SPI Interface module with drivers, and all required cables. Pilot production deliveries are available in first-quarter 2016.

www.anokiwave.com

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TowerJazz to buy Maxim's Texas wafer fab for \$40m

TowerJazz to qualify analog fab for core specialty technologies including radio-frequency silicon-on-insulator

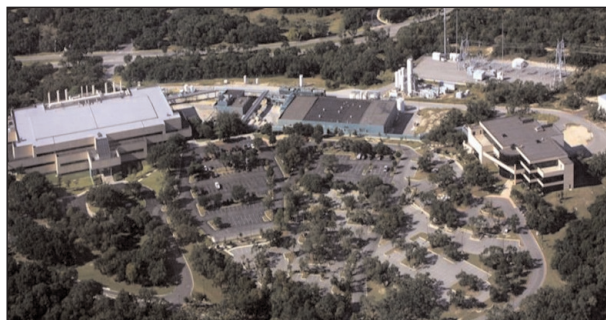
Specialty foundry TowerJazz (which has fabrication plants at Tower Semiconductor Ltd in Migdal Haemek, Israel, and at its subsidiaries Jazz Semiconductor Inc in Newport Beach, CA, USA and TowerJazz Japan Ltd) has agreed to buy the 8-inch fabrication facility in San Antonio, TX, USA belonging to Maxim Integrated Products Inc of San Jose, CA, USA (which provides analog integration to automotive, cloud data-center, mobile consumer and industrial applications).

The proposed purchase will expand TowerJazz's global manufacturing capacity, increasing production by about 28,000 wafers per month. Additional capacity is expected to be needed to serve TowerJazz's forecasted customer demand.

As part of the transaction (which is expected to close in January, subject to customary closing conditions), the firms have also signed a long-term supply agreement for TowerJazz to manufacture products for Maxim at San Antonio. The transaction is to be paid in ordinary shares of TowerJazz worth about \$40m.

All of the site's nearly 500 staff (production operators, support personnel, and process and integration engineers) will be retained.

The facility can support analog platforms using geometries down to



Maxim's fab in San Antonio, Texas.

130nm and can also manufacture third-party products using TowerJazz specialty process technologies. TowerJazz plans to qualify its core specialty technologies, including radio-frequency silicon-on-insulator (RF-SOI).

"It will provide a quick solution for our significantly growing customer demand, while gaining additional high-quality manufacturing capabilities and global flexibility with the incremental capacity," says TowerJazz's president Dr Itzhak Edrei. "The multi-year supply agreement with Maxim and the new available capacity will enable continuous growth with increased manufacturing scale to support our position as the worldwide leading specialty analog foundry," he adds.

"We know Maxim very well, having been their supplier for a family of high-end SiGe based products for

many years. During this period we have developed an appreciation for Maxim's technical capabilities, business vision and corporate culture," says TowerJazz's CEO Russell Ellwanger. "The San Antonio factory enables us to further strengthen our relationship with Maxim, in a true win-win business

model enabling TowerJazz incremental capacity supported by a proven high-performing technical and operational team," he adds.

"We needed a trusted partner to manage our proprietary process technology who also shared our commitment to the employees in San Antonio," comments Vivek Jain, senior VP of Maxim Integrated's Technology and Manufacturing Group. "Tower Jazz has a proven track record with Maxim and similar beliefs about employees, so this is a natural fit. I look forward to our continued partnership over the coming years," he adds. "With this arrangement, we will continue to support our customers for years to come, improve utilization in our Oregon fab, and advance our manufacturing flexibility."

www.maximintegrated.com

www.towerjazz.com

Shareholders approve Avago's acquisition of Broadcom

Avago Technologies Ltd of San Jose, CA, USA and Singapore (a designer and supplier of III-V-based analog components as well as digital and mixed-signal CMOS-based devices for communications, industrial and consumer applications) says that, at its shareholder meeting, its shareholders have voted overwhelmingly to approve its acquisition of Broadcom Corp of Irvine, CA, USA, with over 99% of the votes cast by Avago shareholders voted in favor.

Broadcom (which provides semiconductor solutions for wired and wireless communications) says that, at a special meeting, its shareholders approved all proposals necessary for the acquisition.

Avago and Broadcom announced their merger agreement on 28 May. The firms have received clearance on their proposed merger from the Committee on Foreign Investments in the United States and the anti-trust authorities in the USA,

Japan and Taiwan.

Among other customary conditions to closing, the transaction remains subject to regulatory approvals from the European Commission and anti-trust authorities in China and South Korea, all of which are progressing. Avago expects that these remaining approvals will be received and that the transaction will close late in 2015 or early in 2016.

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Lockheed Martin introduces GaN-based Digital Array Row Transceiver radar technology

At its regular radar users' conference in Orlando, FL (attended by representatives from more than 25 countries), security and aerospace company Lockheed Martin of Bethesda, MD, USA has unveiled its Digital Array Row Transceiver (DART) next-generation radar technology.

Based on the use of gallium nitride (GaN) technology, DART results in greater performance within existing Lockheed Martin radar products and lowers life-cycle costs due to an increase in energy efficiency. The company says that GaN is a low-risk solution, whether part of a systems upgrade or in a newly built system.

DART improves on Lockheed Martin's ground-based radar

products, which have a proven record of reliability for dozens of customers around the world. The new technology is available in the recently launched TPS-77 Multi Role Radar system and is fully compatible with legacy products (TPS-77, TPS-59, FPS-117) and can help to extend a radar's useful life.

"This technology is based in part on feedback we have received from customers with whom we've developed strong partnerships over decades," says Mark Mekker, Lockheed Martin's director, surveillance radar. "We are excited to offer this enhanced technology to all our ground-based radar customers," he adds.

Lockheed Martin has produced and maintains over 175 surveillance-range radars, which are operational around the world detecting targets at ranges up to 250 miles, 24 hours a day. These radars are capable of operating completely unmanned and many have performed for decades in remote, inhospitable areas and in a wide range of operational environments, says the firm.

Lockheed Martin notes that no FPS-117, TPS-77 or TPS-59 radar has ever been taken out of service, and the systems continue to operate well beyond their original 20-year service lives (many are planned to operate for more than 40 years).

www.lockheedmartin.com/gbas

MACOM receives first production order for SPAR tiles in Multifunction Phased Array Radar

M/A-COM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) says that, following the field trial of the Multifunction Phased Array Radar (MPAR) prototype system, the Massachusetts Institute of Technology (MIT) Lincoln Laboratory has placed an order for Scalable Planar ARray (SPAR) Tiles for use in the first full-scale MPAR system.

SPAR Tiles are RF assemblies containing antenna elements, gallium arsenide (GaAs) and gallium nitride (GaN) semiconductors, transmit and receive modules, and RF and power distribution networks. When combined with additional signal generation and receive and control electronics, the composite assembly forms the building block for the MPAR planar active electronically scanned antenna (AESA) for the radar system.

SPAR Tiles enable the transition from cumbersome traditional brick architectures to a more efficient planar approach. MACOM says that, by leveraging its commercial manufacturing expertise, SPAR Tiles will help to drive cost efficiencies that are required to propel MPAR to mainstream adoption and deployment in the latter part of this decade.

The MPAR radar system enables enhanced temporal and spatial precision for weather surveillance and air-traffic control applications. It is anticipated that the government proof-of-concept system will demonstrate a unique radar capability that simultaneously improves both aircraft and weather surveillance.

The data gathered by the MPAR radar can be used by the National Oceanic and Atmospheric Administration (NOAA) to more accurately forecast severe storm activity, providing the early warning needed to save lives. The Federal

Aviation Administration's (FAA) current air-traffic control network, built more than three decades ago, is approaching obsolescence. It is believed that replacing these systems with MPAR would provide improved awareness of air-traffic patterns, bringing dramatic efficiency improvements to FAA air traffic operations.

"The implementation of MACOM's SPAR Tiles as a critical element of a full-scale demonstration of MPAR represents a major milestone in the validation of this new approach for manufacturing AESAs," says Dr Doug Carlson, vice president, Strategy, at MACOM. "SPAR Tiles enable new levels of affordability and flexibility across a broad range of civil and defense applications," he adds. "Our ability to fulfill large orders of SPAR Tiles demonstrates the scalability of our manufacturing approach to achieve volume production of this highly integrated and complex RF product."

www.macom.com/activeantennas

WIN expands GaN portfolio by adding 0.45 μ m-gate GaN-on-SiC power process for 4G/5G macro-cell base-station power amplifiers

WIN Semiconductors Corp of Tao Yuan City, Taiwan — a pure-play provider of gallium arsenide (GaAs) and gallium nitride (GaN) wafer foundry services for the wireless, infrastructure and networking markets — has expanded its GaN technology portfolio by adding the NP45 gallium nitride on silicon carbide (GaN-on-SiC) process.

NP45 is a 0.45 μ m-gate MMIC technology enabling users to design fully integrated amplifier products as well as custom discrete transistors, and has been optimized for use in 4G macro-cell base-station power amplifiers operating at 2.7GHz and above, where bandwidth and linearity performance are key differentiators. The macro-cell base-station power amplifier market is projected to grow to over \$1bn annually by 2020, and GaN technology is expected to become the technology of choice, says WIN. Due to its efficiency, bandwidth and linearity, GaN devices outperform the incumbent LDMOS silicon technology, particularly in the higher-frequency bands utilized in 4G/4.5G networks, claims WIN.


The WIN NP45 process technology is fabricated on 100mm silicon carbide substrates and operates at a drain bias of 50V. In the 2.7GHz band this technology provides saturated output power of 7W/mm with 17dB linear gain and more than 75% power-added efficiency. These performance metrics make NP45 suitable for

The macro-cell base-station power amplifier market is projected to grow to over \$1bn annually by 2020, and GaN technology is expected to become the technology of choice

use in high-bandwidth 4G–5G high-power macro-cell transmitters and small cells, says WIN. NP45 sample kits are available and can be obtained by contacting the firm's regional sales managers.

WIN showcased its compound semiconductor RF and millimeter-wave solutions at the 2015 IEEE COMCAS Conference in Tel Aviv, Israel (2–4 November).


www.winfoundry.com



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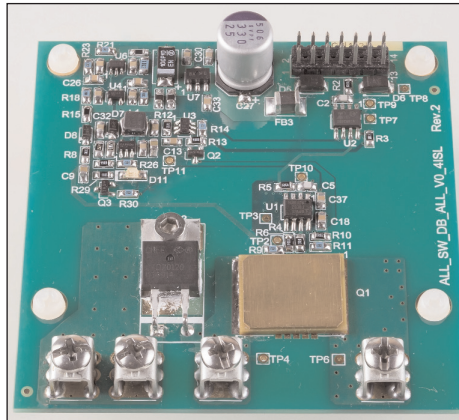
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VisIC makes available evaluation board and samples for lowest-resistance, fastest GaN power switches

After in June launching what it claimed was the lowest-resistance 650V-blocking-voltage transistor (specifying an R_{dson} as low as $15\text{m}\Omega$), VisIC Technologies Ltd of Rehovot, Israel, a fabless developer of devices based on gallium nitride (GaN) metal-insulator-semiconductor high-electron-mobility transistors (MISHEMTs) founded in 2010, has now delivered evaluation boards (EB) and samples of its ALL-Switch (Advanced Low-Loss Switch) to leading customers, allowing users to perform extensive testing confirming the switching parameters.

The evaluation board includes



ALL-Switch evaluation board.

gate driver and switching control logic based on commercially avail-

able components. ALL-Switch is configured for hard switching on the evaluation board and can switch a 400V load with greater than 30A currents at over 500kHz.

VisIC says that its technology solves problems that have limited devices from simultaneously achieving step-function reductions in conduction and switching losses for power conversion systems that can benefit from high switching speeds.

VisIC will soon also announce details of a half-bridge reference design.

www.visic-tech.com

GaN Systems' launches half-bridge evaluation board for GaN transistor circuit design

GaN Systems Inc of Ottawa, Ontario, Canada, a fabless developer of gallium nitride (GaN)-based power switching semiconductors for power conversion and control applications, has launched its Half-Bridge Evaluation Board, which demonstrates the performance of its GaN enhancement-mode power semiconductors in real power circuits.

The fully functional GS66508T-EVBHB Eval Board can be configured into any half-bridge-based topology, including boost and buck modes. It comes with a Quick Start instruction guide and YouTube video links (<https://www.youtube.com/user/GaNSystems>) in order to have the installation up and running in minutes. The Eval Board can be used in synchronous boost or buck conversion, as well as pulsed switching to evaluate transistor waveforms. The kit has full documentation, including bill-of-materials component part numbers, PCB layout and thermal management, and gate drive circuit reference design, which is also useful for system engineers to use in their products.

Designed to provide electrical engineers with a complete working power stage, the evaluation board consists of two 650V, 30A GS66508T GaN FETs, half-bridge gate drivers, a gate drive power supply, and heat-sink. The GS66508T high-power transistors are based on GaN Systems' proprietary Island Technology and belong to its 650V family of high-density devices, which achieve efficient power conversion with fast switching speeds of $>100\text{V/nS}$ and ultra-low thermal losses, the firm says.

GaN Systems claims to be the only company to have developed and productized a comprehensive portfolio of GaN power transistors with voltage ratings of 100V and 650V and current ratings from 7A to 250A. Its Island Technology die design, combined with the very low inductance and thermal efficiency of GaNPX packaging, provides the GaN FETs with a 45x improvement in switching and conduction performance over traditional silicon MOSFETs and IGBTs, the firm adds.

The 30A/55m Ω GS66508T GaN power transistors are top-side

cooled and feature near-chip-scale thermally efficient GaNPX packaging. Power conversion efficiency of 98.7% at 1.5kW is shown in the product documentation and can be reproduced in the owner's lab.

The Eval Board provides footprints for output power inductors and capacitors to allow users to configure the board into desired boost or buck operational modes. Access to the transistor junction temperature is provided by both thermocouple pads and thermal camera imaging ports. Power input should be 9–12V_{DC}, with an absolute maximum of 15V. On-board voltage regulators create +5V for the logic circuit and +6.5V for the gate driver. There are three operational modes: pulse test mode; buck/standard half-bridge mode and boost mode.

The GS66508T high-current half-bridge Evaluation Board is available now worldwide and can be sourced by searching the GS66508T-EVBHB part number to find a local authorised distributor.

http://gansystems.com/evaluationboards/GS66508TEVBHB_UserGuide_rev2%20151020.pdf

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5N Plus' Q3/2015 sales hit by falling metal prices

For third-quarter 2015, specialty metal and chemical products firm 5N Plus Inc of Montreal, Québec, Canada has reported revenue of \$68.7m, down on \$114.4m a year ago, negatively impacted by continuing erosion in relevant underlying commodity prices that have on average fallen by 55% since the beginning of the year.

Margins were negatively impacted by falling metal prices including bismuth, indium, selenium and tellurium, which fell by 20%, 33%, 29% and 56% respectively in Q3/2015 alone.

Adjusted adjusted earnings before interest, taxes, depreciation and

amortization (EBITDA) was positive \$1.1m, down on \$8.1m a year ago. Net debt fell by \$11.7m, positively impacted by working capital management. At the end of September, net debt was \$46.7m, down from \$84m at the end of 2014.

Order backlog as at the end of September was 134 days of sales outstanding, up by 12 days from the end of 2014 and by 25 days from the end of September 2014. Backlog and bookings are also negatively impacted by the decreases in underlying commodity pricing.

"Demand for our products remained in line with expectations, with a slight decrease in shipments

following the usual pattern of the European summer slowdown," says president & CEO Jacques L'Ecuyer. "Continuing and persistent erosion in prices of almost all of our key metals continues to significantly weigh on our financial performance," he adds. "Until this trend stops or its magnitude decreases, we expect our financial performance to remain disappointing other than from a cash flow standpoint, which should stay relatively strong as we reduce our working capital requirements in line with underlying commodity pricing trends," L'Ecuyer concludes.

www.5nplus.com

5N Plus' co-founder, president & CEO L'Ecuyer steps aside

Jacques L'Ecuyer has informed the 5N Plus' board of directors of his intention to step aside from his current position of president & CEO. As a result, the board has initiated a process during the last quarter to identify a new president & CEO. L'Ecuyer will remain in post until the new president & CEO has been appointed.

"The board will be working closely with L'Ecuyer during this transition period and we are confident that we will be able to announce his successor in the coming weeks," says chairman Jean-Marie Bourassa.

5N Plus provides purified metals such as bismuth, gallium,

germanium, indium, antimony, cadmium, selenium and tellurium, and also produces related II-VI semiconducting compounds such as cadmium telluride (CdTe), cadmium sulphide (CdS) and indium antimonide (InSb) as precursors for the growth of crystals for solar, LED and eco-friendly materials applications.

"Throughout the years at the helm of 5N Plus, Jacques showed passion, determination and drive which has positioned the company as the worldwide leading producer in specialty metal and chemical products," comments Bourassa.

"The board wishes to express its gratitude for his enormous

contribution to the company's development and looks forward to continue to benefit from his extensive knowledge of the company and the industry at the board of directors level."

L'Ecuyer co-founded 5N Plus in 2000 and has been president & CEO since its inception. Under his direction, 5N Plus became a leading producer of specialty metal and chemical products with operations and sales offices in several locations in Europe, the Americas and Asia. During his 15 years at the helm of the company, 5N Plus' consolidated sales consistently increased to reach more than \$500m in 2014.

Indium Corp's new EZ-Pour gallium trichloride simplifies room-temperature processes

Materials manufacturing company Indium Corp of Clinton, NY, USA (which supplies to the electronics, semiconductor, thin-film, thermal management and solar markets) says that its new EZ-Pour gallium trichloride (GaCl₃) simplifies the use of gallium trichloride by allowing the user to easily transfer the

product from one container to another at room temperature.

Traditional gallium trichloride is solid at room temperature and often forms clumps or sticks together during storage and use, inhibiting the efficient and consistent materials transfer between vessels and processing equipment,

says Indium Corp. In contrast, the unique free form of EZ-Pour gallium trichloride solves this challenge by eliminating clumping and enabling fast, efficient, safe and accurate transfer, the firm claims.

www.indium.com/gallium-trichloride

Akhan opens HQ and production facility for diamond-based semiconductor technology

Akhan Semiconductor Inc of Chicago, IL, USA has formally opened its new global headquarters and production facility at 940 Lakeside Drive in Gurnee, Illinois, after beginning operations there in June. The firm's first commercial customer will take delivery of the first Akhan diamond semiconductor-based products in first-quarter 2016.

The opening ceremony was attended by Gurnee mayor Kristina Kovarik, US Senator Dick Durbin, Illinois State Senator Melinda Bush, US Representatives Randy Hultgren and Robert Dold, or designees, and other state, local and international dignitaries.

The opening of the production facility is the culmination of a decade of development and collaboration. Akhan Semiconductor Inc was formed in early 2013 as a subsidiary

of Akhan Technologies Inc, which was founded in 2007 by CEO Adam Khan to commercialize Diamond Lattice Technology for diamond-based semiconductor devices. The firm's IP portfolio combines Akhan's Miraj Diamond portfolio with low-temperature diamond deposition technology developed by Argonne National Laboratory's Center for Nanoscale Materials.

Akhan is now actively hiring to staff the new facility, which is expected to employ 100 people in the next two years.

"As a native of Gurnee, I am proud to help spur a new era of innovation and semiconductor technology in my hometown, in the state of Illinois, right here in the Diamond Prairie," said Khan. "Our diamond semiconductor based technology will enable a new generation of commercial,

industrial and consumer products such as flexible and transparent displays that can be used in wearables and thinner consumer devices that last longer," he adds. "On the commercial side, we expect to develop new products such as diamond windows for industrial, defense and aerospace applications."

Akhan's technology is based on a process that uses man-made diamond rather than silicon to produce new chip materials that are more cost effective, operate at higher temperatures, are thinner and require less power, it is claimed. The development is a result of the combination of two breakthroughs: the ability to use nanocrystalline diamond (NCD) films and a new doping process that makes it possible to use NCD as a semiconductor material.

www.akhantech.com

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AXT's revenue falls 12% in Q3/2015

InP growing 50% year-on-year, surpassing semi-insulating and semiconducting GaAs in sales

For third-quarter 2015, AXT Inc of Fremont, CA, USA, which makes gallium arsenide (GaAs), indium phosphide (InP) and germanium (Ge) substrates and raw materials, has reported revenue of \$18.4m, down 12.4% on \$21m last quarter and down 20% on \$23.1m a year ago (and below the expected \$19.5–20.5m). The drop in revenue is due largely to raw materials business falling by more than \$1.3m from Q2, as a result of continued declines in both price and volume for the firm's raw material joint ventures.

Of total revenue, 10% came from North America (down from 14% last quarter), 66% from Asia Pacific (up from 59%), and 24% from Europe (down from 27%). Two customers generated more than 10% of revenue, and the top five generated about 45% of total revenue, reflecting diversification of both products and customers.

"Our business has continued to evolve as a direct reflection of the transformation in our industry," says CEO Morris Young. "We are seeing a growing shift within our revenue base towards indium phosphide, which has surpassed both semi-insulating gallium arsenide and semiconducting gallium arsenide as the single largest segment of substrates in our sales composition," he adds. Year-over-year revenue growth rate for the last two years in indium phosphide has been more than 50% per year. "This shift is significant because indium phosphide is a specialized material used in strenuous environments and requires tight specifications," says Young. "In the last two years the primary driver in the demand for indium phosphide has been optoelectronic devices for fiber-optic communications and passive optical networks. More recently, data-center connectivity is gaining momentum as the strong driver for

indium phosphide demand," he adds. "The competitive landscape is limited with the number of meaningful barriers to entry. As a result, it commands a premium value and a stable pricing environment. Its growth as a percentage of revenue has a disproportionately favorable impact on our results. This was evident in Q3, as softness in other parts of our business caused us to fall short of our revenue guidance, but we outperformed our bottom-line guidance to achieve break-even profitability."

Due to the favorable product mix, gross margin was 25.1%, up from 20.9% last quarter and 23% a year ago. Despite operating expenses rising further, from \$4.7m a year ago and \$5.2m last quarter to \$5.3m, AXT made a net profit of \$42,000, compared with a net loss of \$3000 last quarter (although this is still down on a net profit of \$644,000 a year ago).

Depreciation and amortization

We are seeing a growing shift within our revenue base towards InP, which has surpassed both semi-insulating GaAs and semiconducting GaAs as the single largest segment of substrates in our sales composition. In the last two years the primary driver in the demand for InP has been optoelectronic devices for fiber-optic communications and passive optical networks. More recently, data-center connectivity is gaining momentum as the strong driver for indium phosphide

was \$1.4m. Capital expenditure (CapEx) was also \$1.4m (down slightly on \$1.5m last quarter). AXT also used \$733,000 of cash to repurchase its stock (making \$2.3m in total share repurchases through to the end of Q3/2015). During the quarter, cash and investments hence fell from \$46.3m to \$45.4m.

"As we look ahead to Q4, we expect to see continued weakness in certain areas of our business, in keeping with the near-term trends," says chief financial officer Gary Fischer.

"For semiconducting gallium arsenide, the market remains challenging," notes Young. "We continue to pursue higher-end [LED] applications such as backlighting, signage and automotive. However, we have made a conscious decision not to pursue certain lower-end applications as a result of serious competitive landscape in corresponding pricing environment. As a result, we are planning for continuous softness in this area in Q4," he adds.

Regarding raw material business, in Q4 AXT expects to see further decline. "This is a reflection of general weakness worldwide in commodities," notes Young. "Though revenues from our joint ventures have come down this year, they continue to provide us with profitable revenue and additional benefit to our vertically integrated business model," he adds.

For Q4/2015, AXT expects total revenue to fall slightly to \$17–18m, and the bottom line to show a loss of \$0.01–0.03 per share. "However, the longer-term shift in our business towards indium phosphide coupled with potential new opportunities across our portfolio gives us confidence in our renewed growth in the coming year," Fischer adds.

"We continue to grow our indium phosphide customer base

▶ amongst a number of customers who have recently had major wins in Taiwan and we are ramping up shipments with some of the largest indium phosphide epi customers in Europe. We are also in qualification with a major customer in Japan and we are just completing qualification with a large client in USA," says Young. Many of these customers are expanding their own capacity in anticipation of growing demand and new applications, he adds. "In total, our indium phosphide pipeline is robust and we're confident in our ability to continue to drive healthy revenue growth."

At the end of July, AXT acquired privately held firm Crystacomm Inc of Mountain View, CA, USA, which makes InP substrates using the liquid-encapsulated Czochralski (LEC) crystal growth technique, supplementing AXT's vertical gradient freeze (VGF) technique. "We are the only company to offer both VGF and LEC crystal growth technologies, which is giving us the flexibility to serve customers with varying technical requirements," says Young. The equipment is being installed in AXT's Fremont facility (where there are already staff that can

operate it, so the firm is not adding to the headcount or operating expenses), and the firm is currently bringing up the crystal growth and poly-synthesis processes.

Also, at the end of October, AXT acquired automated process equipment for wax mounting/demounting, edge grinding, wafer sawing, polishing and cleaning of GaAs substrates from Japan's Hitachi Metals (which exited its compound semiconductor substrate business in April, but remains in the GaAs epiwafer business). In addition, AXT licensed associated proprietary wafer processing technology and patents to enable it to use the equipment in full production and to enhance product quality and consistency. The equipment has been uninstalled in Japan and shipped to AXT's production facility in Beijing, China, where it is being installed. SCIOCS, the related spin-off from Hitachi Metals, is assisting in the installation and optimization process. The production line is suited to 4" and 6" GaAs and InP manufacturing processes, and AXT intends to supply GaAs substrates to SCIOCS and other customers. "So, for semi-insulating

GaAs, we continue to focus on developing our presence in both mobile and mobile applications," says Young. "We believe that the market is relatively stable around its current levels, having made a major transition in the past several years," he adds. "Now, we are conservative in ways that will forecast this area of our business, we're making strategic investments such as Hitachi Metals equipment purchase that we believe will position AXT to benefit from new opportunities and new applications for our products."

"We continue to actively invest in our future through focused R&D, technology M&A [mergers and acquisitions], the upgrade of our manufacturing infrastructure, and the continued build out of our leadership team," says Young. At the beginning of Q3 (in late June), former Emcore president & CEO Dr Hong Hou joined AXT as chief operating officer. "We are making the right investments in our technology, operations and management team to maximize our business opportunity," Young believes.

www.axt.com

AXT acquires automated processing and cleaning equipment from Hitachi Metals

Substrate maker to supply GaAs to Hitachi Metals spin-off SCIOCS

AXT Inc of Fremont, CA, USA, which makes gallium arsenide (GaAs), indium phosphide (InP) and germanium (Ge) substrates and raw materials, has acquired highly automated processing and cleaning equipment for GaAs substrates from Hitachi Metals.

The production line includes automated equipment for wax mounting/demounting, edge grinding, wafer sawing, polishing and cleaning. In addition, AXT licensed from Hitachi Metals associated technical information and applicable patents intended to enable it to use the equipment in full production. The

equipment has been uninstalled in Japan and shipped to AXT's production facility in Beijing, China, where it is currently being installed. SCIOCS, the related spin-off from Hitachi Metals, is assisting in the installation and optimization process. The production line is suited to 4" and 6" GaAs and InP manufacturing processes, and AXT intends to supply GaAs substrates to SCIOCS and other customers.

"This acquisition comes at a time when AXT is making a concerted effort to invest in automated manufacturing equipment to

increase sales of its InP substrates and 6" semi-insulating GaAs substrates," says CEO Dr Morris Young. "We plan to leverage the automation and manufacturing technology acquired to further enhance our product quality and consistency," he adds. "We are highly appreciative of the multi-faceted partnership between the two companies."

The terms of the acquisition are not being disclosed. However, it is not expected to have a meaningful impact on AXT's cost of operations going forward.

www.axt.com

Compound Semiconductor Centre formally launched as first compound semiconductor cluster

Joint venture to provide bridge between R&D at Cardiff University's Institute of Compound Semiconductors and pilot production at IQE

Hosted by Stephen Doughty (Member of Parliament for Cardiff South and Penarth), an event in the UK Houses of Parliament in Westminster, London, has formally launched the Compound Semiconductor Centre (CSC), formed at the beginning of August by epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, and Cardiff University (which will jointly own and control the venture). IQE is committing £12m worth of equipment as well as buildings and infrastructure, while Cardiff University has contributed a matching £12m in capital investment to the joint venture. IQE is also licensing certain intellectual property (IP) to the CSC.

Backed by funding from the Welsh Government, the partnership aims to build a center of excellence to lead the development and commercialization of compound semiconductor technologies in Europe. Four significant clusters based around silicon technologies already exist in Europe, but CSC — as a fifth semiconductor cluster in Europe, based in Cardiff — will be the first based specifically on compound semiconductors.

Due to their high-performance capabilities coupled with energy efficiency and photonic properties,

compound semiconductors have been identified as a Key Enabling Technology (KET) for the European Commission's 'Horizon 2020' economic growth strategy, which targets the re-industrialization of the European Union (EU). The planned compound semiconductor cluster is intended to represent a central base of operations for efforts in the UK (and wider EU regions) to reclaim high-value technology manufacturing from competitors in East Asia, and is reckoned to have the potential to create up to 5000 jobs within the region over the next five years.

The CSC, which was also launched at Cardiff Castle on 26 November, will see IQE working closely with Cardiff University's new £40m Institute of Compound Semiconductors (ICS), whose research aims to develop innovative new materials technologies enabling a wide range of new and emerging applications. The ICS forms part of Cardiff University's £300m investment in new research and innovation centers, and its potential is already recognized by the Welsh and UK governments, which have invested more than £29m towards its creation.

Professor Diana Huffaker, the Ser Cymru Chair in Advanced Engi-

neering and Materials, has been appointed from the University of California Los Angeles (UCLA) in the USA to become director of Cardiff University's ICS (starting in January). "The Compound Semiconductor Centre is a unique facility," notes Huffaker. "It brings together Cardiff University research in parallel with industrial-scale production from IQE and future industrial partners." Collectively, the ICS, the CSC and IQE's existing operation in Cardiff establishes the core elements of a compound semiconductor ecosystem in Wales to provide a complete capability value chain from early-stage research & development through product and process innovation prototyping, and pilot production, through to high-value, large-scale manufacturing. "In effect, the partnership builds a bridge from basic research to commercial technology transfer," Huffaker adds.

"Much of the compound semiconductor technology used in devices across the world is developed and manufactured in Wales," noted IQE's chief executive Dr Drew Nelson. "But technology evolves at a rapid pace. One of the big problems in the UK is that we frequently fail to take the steps needed to commercialize

Wyn Meredith named director of Compound Semiconductor Centre

Dr Wyn Meredith has been named director of the Compound Semiconductor Centre (CSC), the new joint venture between epiwafer foundry & substrate maker IQE plc of Cardiff, Wales, UK and Cardiff University.

IQE has a long-standing relationship with Meredith, who has been working on its behalf in a variety of roles, most recently developing links to education and funding bodies. In his new role he will be responsible for developing funding



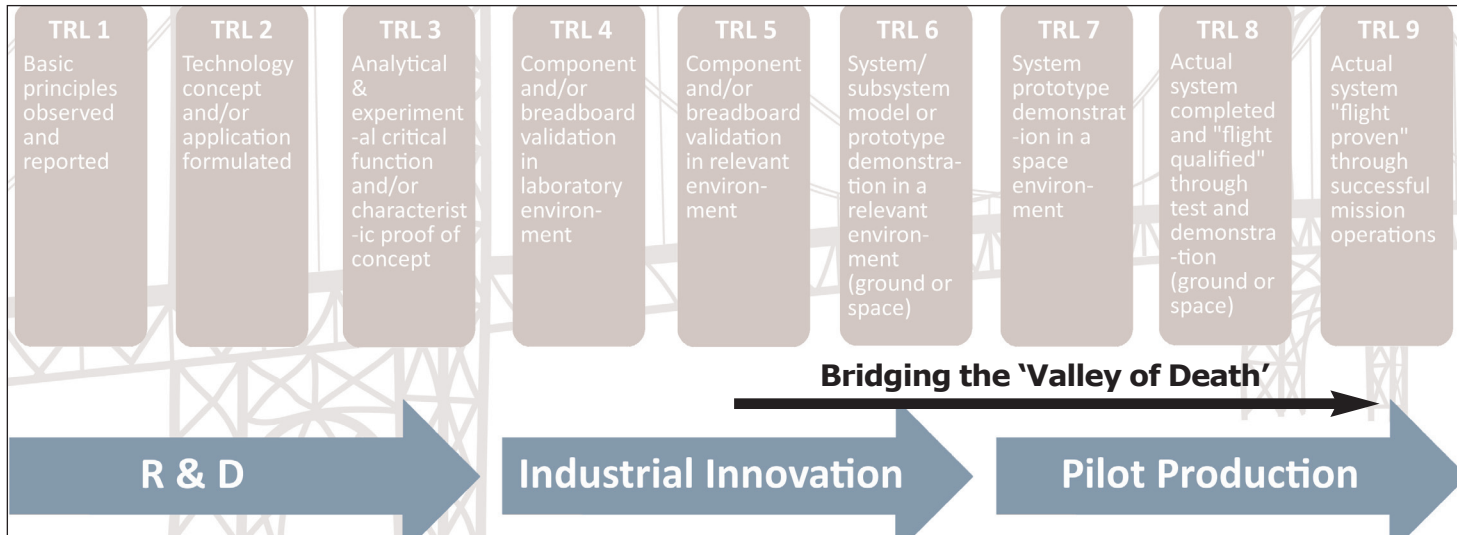
Wyn Meredith.

opportunities in external programs and will report to the CSC board of directors. Meredith, who holds a PhD in Optoelectronics from Heriot Watt University, joins IQE from his role as commercial director at optoelectronics device foundry Compound

Semiconductor Technologies Global Ltd (CST) of Hamilton, Scotland, UK.

The collaboration between IQE and Cardiff University that led to the formation of the CSC won the Partnership Award at the Insider Media Business and Education Partnership Awards ceremony in early November. The awards celebrate collaboration between companies, universities and colleges.

www.insidermedia.com/event/business-and-education-partnership-awards



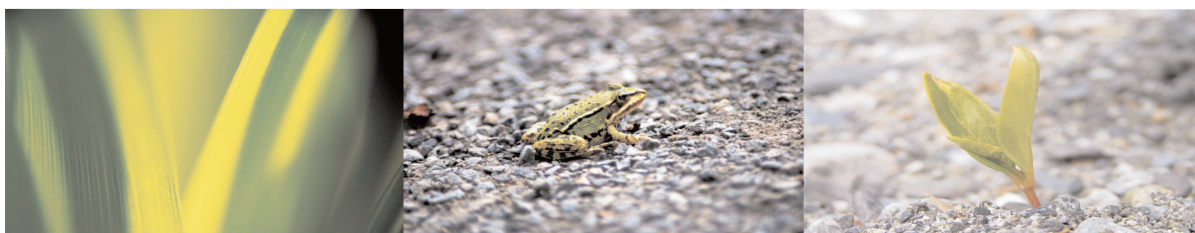
► research and development activities through innovation and manufacturing [the 'valley of death']," he adds. "This is why we are looking to create the world's first compound semiconductor cluster, and having Cardiff University and the UK academic infrastructure in place creates a very strong basis to enable this cluster to be formed."

The CSC will hence provide an essential pillar to span the entire Technology Readiness Level (TRL) scale, from TRL1-3 (R&D at ICS), via TRL4-6 (Industrial Innovation, at CSC) to TRL 7-9 (Pilot Production, at IQE).

The CSC will also "foster education at all levels and help create jobs within Cardiff and Wales," comments

Huffaker. "The venture allows IQE to try experimental ideas which they really think will be important, while Cardiff benefits from IQE's business direction," she adds. "CSC and ICS will be open for business for any interested industrial and academic users."

www.compoundsemiconductorcentre.com
www.iqep.com



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ClassOne opens new European office

Focus on 3- to 8-inch wafers yields increased interest from emerging markets and Europe

ClassOne Technology of Kalispell, MT, USA, which manufactures wet-chemical processing equipment (especially for emerging markets and other cost-conscious users of smaller substrates), has opened a new European sales and support office in Ulm, Germany.

"We are seeing a significant upsurge in our business in Europe," says Win Carpenter, ClassOne's VP of global sales. "This new office is a natural and very important expansion of our infrastructure; it's essential for giving our European customers the level of rapid response and first-class support we insist on."

The new Ulm office will be headed by sales director Roland Seitz, and the service engineering team will

be led by Helmut Schlenker (both veterans in the field with long experience in the equipment industry). The facility will also maintain a substantial parts inventory to enable rapid deployment to customers.

"At ClassOne we put a major emphasis on serving emerging markets who work on 3- to 8-inch wafers — many of whom are based in Europe," says ClassOne's president Byron Exarcos. "These companies have processes that would benefit from more advanced equipment, but they usually don't have huge equipment budgets. So we've developed tools that can deliver more performance for a more affordable price — often less than half of what similarly configured tools from the larger manufacturers

would cost," he reckons. "That's why we're getting increased interest from emerging markets and from Europe."

ClassOne's wet processing equipment includes the Solstice family of electroplating tools and Trident spin-rinse-dryers and spray solvent tools. The Solstice electroplating family includes the LT for process development; the 4-chambered S4 for mid-range production; and the 8-chambered, fully automated S8, which delivers up to 75wph (wafers per hour) throughput. The Solstice line is specifically designed to provide advanced yet cost-efficient plating for MEMS, sensors, LEDs, RF, interposers and other emerging technologies for $\leq 200\text{mm}$ wafers.

www.classone.com/products

TRUMPF Photonics buys ClassOne Solstice S8 electroplater for gold plating and metal lift-off

ClassOne Technology of Kalispell, MT, USA, which manufactures wet-chemical processing equipment (especially for emerging markets and other cost-conscious users of $\leq 200\text{mm}$ substrates), has sold a Solstice S8 plating system to semiconductor laser manufacturer TRUMPF Photonics Inc of Cranbury, NJ, USA (part of TRUMPF Inc, the North American subsidiary of TRUMPF GmbH near Stuttgart, Germany), which produces diode chips, optics and electronics as well as pump and direct-diode modules. The new system will be used for high-precision gold plating and metal lift-off.

"For these particular TRUMPF applications, process uniformity was extremely important, and fortunately the Solstice is very strong in that department," says ClassOne's chief technology officer Kevin Witt. "The unique elegance of the Solstice system design allows users to control processes



ClassOne's Solstice S8 Electroplater.

very precisely and consistently. In this case, we needed to be able to control the stress within the deposited films, and we were able to demonstrate that quite effectively," he adds. "We were also

able to prove ClassOne's expertise and support by helping TRUMPF develop their target processes," says Win Carpenter, ClassOne's VP of global sales.

The Solstice S8 is a fully automated eight-chamber electroplating tool that delivers capacity of up to 75wph (wafers per hour). Specifically designed for substrates with a diameter of less than 200mm (either transparent or opaque), Solstice can perform a range of electroplating and related processes (high-pressure metal lift-off, resist strip, UBM etch etc) using various metals and alloys. The product family also includes the Solstice LT for process development and the four-chamber Solstice S4 for mid-range production. ClassOne claims that Solstice pricing is less than half that of similarly configured 300mm plating systems outfitted for 200mm from the large manufacturers.

www.trumpf.com/en.html

Plasma-Therm acquires plasma processing technology from Nanoplas France

High Density Radical Flux low-temperature resist stripping to be integrated into plasma etching, dep and wafer-dicing products

Plasma process equipment maker Plasma-Therm LLC of St Petersburg, FL, USA has acquired a High Density Radical Flux plasma technology that enables low-temperature Bosch polymer removal.

High Density Radical Flux (HDRF) was developed by Nanoplas France as a plasma process for low-temperature removal of photoresists and organic polymer residues — capabilities that are especially important for device fabrication steps in the MEMS, LED and advanced packaging markets, says the firm.

Plasma-Therm is integrating HDRF technology into its existing suite of plasma etching, deposition, and wafer-dicing products. The Nanoplas-developed HDRF low-temperature photoresist stripping capability is also applicable to Bosch polymer removal after DRIE (deep reactive ion etch) processing.

“HDRF fits very well into our etch and deposition product line,

because this will allow Plasma-Therm to provide multi-step solutions to specialized device manufacturers for both R&D and production use,” says Ed Ostan, Plasma-Therm’s VP of marketing.

Plasma-Therm will also offer ongoing support to Nanoplas customers, which include global companies using the systems in volume production, as well as R&D and pilot line facilities. The Nanoplas installed base is primarily made up of DSB 6000 and DSB 9000 HDRF systems. Nanoplas introduced the semi-automatic DSB 6000 system in 2008, followed in 2011 by the fully automatic 200mm DSB 9000 system (which accommodates one or two process modules). Both systems are capable of chemical downstream etching, stripping and cleaning applications. The firm also designed the HDRF300 system for advanced cleans for 3D-IC fabrication.

HDRF enables removal of photoresist, as well as organic polymers left on trench sidewalls following DRIE processes (applications that are sought for advanced packaging, MEMS, and power devices). The systems incorporate a multi-zone, remote, inductively coupled plasma (ICP) source, which produces up to 1000 times greater chemical concentration than a conventional ICP source. HDRF is said to provide better performance than wet processing and regular plasma processing in terms of selectivity, low damage, flexibility, and high-aspect-ratio efficiency. It is also claimed to yield superior polymer removal efficiency for high-aspect-ratio (greater than 50:1) structures. With operating temperatures lower than 80°C, and with high selectivity to TiN, Al, Au, SiO₂ and Si₃N₄, HDRF provides damage-free residue removal for ultra-sensitive devices, the firm adds.

www.plasmatherm.com

Bruker completes acquisition of Jordan Valley

Bruker Corp of Billerica, MA, USA (a provider of scientific research instruments and analytical solutions for molecular and materials research as well as for industrial and applied analysis) has completed its acquisition of x-ray-based in-line metrology and defect inspection equipment maker Jordan Valley Semiconductors Ltd (JVS) of Migdal Haemek, Israel (which has subsidiaries in Durham, UK; Austin, TX, USA; Hsin-Chu, Taiwan; and Suwon, Korea).

The addition of Jordan Valley’s in-line x-ray metrology to Bruker’s existing x-ray metrology technologies is reckoned to position the Bruker Semiconductor Division as the leading x-ray metrology system provider for semiconductor produc-

tion applications at advanced nodes.

“The more demanding nanometrology requirements of ever smaller features and three-dimensional structures are being driven by increasing demand in data processing, cloud computing and mobile technologies,” says Bruker Semiconductor Division president David V. Rossi. “The combination of Jordan Valley’s core metrology strengths with Bruker Corp of Billerica, MA, USA (a provider of scientific research instruments and analytical solutions for molecular Bruker’s complementary x-ray technologies gives us a greater range of capabilities to best support the rapid development and production

challenges facing our customers,” he adds.

“We are excited by the access to Bruker’s increased global market reach and resources, and we look forward to delivering innovative metrology systems that will enable semiconductor manufacturers to meet the industry’s technology roadmap,” comments Isaac Mazor, founder & CEO of Jordan Valley Semiconductors, who has now become VP & general manager of Bruker’s X-ray Semiconductor business.

The acquired business is expected to add \$25–30m to Bruker’s 2016 revenue, and \$0.01–0.02 to its 2016 earnings per share (EPS).

www.bruker.com

www.jvsemi.com

CS Clean Systems and centrotherm clean solutions to merge in first-quarter 2016

CS Clean Systems AG of Ismaning (near Munich) and centrotherm clean solutions GmbH of Blaubeuren, Germany (both specialists in the treatment of exhaust gases) signed a memorandum of understanding (MoU) in October, in which they agreed on a roadmap to cooperate and merge their operational units and technologies in the near future. The firms' existing sites will continue as competence centers for specific exhaust gas purification technologies. Initial integration between the firms began at the end of October via a joint team workshop with international staff and partners. The merger should complete in first-quarter 2016.

Pending finalization of customary merger and acquisition procedures, the firms plan to combine products and technologies, and carry out global marketing activities through a shared sales channel. The collaboration represents "a synergy of

two technology leaders in exhaust gas purification", both with operations around the world. Also, as a firm focused on exhaust gas purification, the merger will result in a "one-stop provider with the ability to offer objective solutions to customer requirements based on an expanded suite of scrubbing technologies".

Founded in Munich in 1986, CS Clean Systems makes exhaust gas cleaning equipment for the semiconductor and solar industries. The dimensions and configuration of its units are tailored for individual customers, and all products are designed for lifelong serviceability and reuse. Hazardous waste gases are removed from the production process via specialist technology that uses dry absorption (CLEANSORB). Products (and the various granulates) are developed, tested and made ready for series production in Ismaning.

With an international marketing and

service network, the maintenance package includes refilling absorber containers and a waste disposal service for used granulates.

As an international firm operating in plant construction, centrotherm clean solutions has been designing, making and installing individual technical solutions for customer-specific challenges in environmental engineering for over 30 years. A key area is the development of systems and equipment for treating exhaust gases released in chemical vapor deposition, etch, epitaxy, implant and drying processes, including the use of thermal and wet chemical processes, filtration, condensation, and combinations of these methods. The firm also offers customized solutions for the treatment of waste water (e.g. from wet benches and exhaust air scrubbers).

www.centrotherm-cs.de
www.cscleansystems.com

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Knowledge is key

Trillium acquires Oxford Instruments-Austin Division

Trillium US Inc of Clackamas, OR, USA has acquired the Oxford Instruments-Austin division of Austin, TX, USA (formerly Austin Scientific). Focused on the helium-compression-based vacuum and temperature management and control sector, Oxford Instruments-Austin provides cryo pump, cold head and compressor service, a range of new cryogenic pumps, cold heads and helium compressors, as well as a full line of related spare parts and accessories.

UK-based Oxford Instruments plc sold its non-core Austin business for \$1.3m. In the six months to September, its revenue was £1.7m and operating loss was £0.4m.

Founded in 2002, Trillium has about 90 staff in the USA, addressing the semiconductor, R&D, metallurgy and coating markets via service and manufacturing locations in New Jersey, Texas and Oregon. It specializes in vacuum pump repair,

new and refurbished pumping systems, and spare parts. It also provides a temperature control unit repair service and new or refurbished chillers and heat exchangers. In addition the firm supplies exhaust gas abatement systems, as well as on-site maintenance programs.

"We acquire a significant range of complementary products while strengthening our existing service capabilities, allowing us to further leverage our customer relationships, while also taking us into new markets", says CEO Graham Stone.

Trillium operates a 12,000ft² facility in North Austin servicing primarily rough vacuum pumps and blowers, while the existing 23,000ft² Oxford Instruments-Austin facility is in South Austin. "Bringing them into the Trillium family will allow us to achieve significant synergies and a larger critical mass by consolidating our Texas operations to a single

South Austin location," says Trillium's general manager & VP-operations Glen Murray.

Over the past five years Trillium has grown from providing repair service and refurbished equipment to include new products and spare parts. This transition began via a merger with New Jersey's United Vacuum in 2011.

"Our new cryogenic customers can now rely on us to provide a broader range of vacuum products and services, and our existing customer base can take advantage of Oxford Instruments-Austin's world-class support for cryo pumps and helium compressors," says Trillium's VP-sales & marketing Rob Breisch.

Trillium is already transacting from South Austin. "Later phases in the process will include business system migration and consolidation of the facilities," says Stone. The transition should be completed by June.

www.trilliumus.com

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Rubicon's Q3 revenue hit by LCD TV backlighting slowdown and customers' excess inventory

Delayed PSS order to drive recovery in Q1/2016

For third-quarter 2015, 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 \$5.3m, down on \$7.1m last quarter and \$8m a year ago due to weaker sapphire demand.

Total revenue for sapphire cores is down from \$4.2m a year ago and \$4m last quarter to \$1.8m. This is due to revenue for 2" cores sold into the mobile device market dropping from \$2.6m last quarter to just \$0.55m (below the \$0.86m a year ago) as a result of higher inventory levels of finished 2" double-side-polished wafers (for the mobile device market) at customers.

Revenue from 6" cores has fallen back from \$0.17m last quarter to just \$0.04m. Revenue from 4" cores for the LED market was flat on last quarter's \$1.2m and down on \$3.3m a year ago, as pricing fell further. "This is also likely to be related to excess inventory in the LED supply chain due to reduced demand from the backlighting market," says president & CEO Bill Weissman. "While the LED general lighting market continues to grow, demand for LCD TVs has declined to their lowest levels since the global recession, according to industry analysts at IHS. This has resulted in excess supply of LEDs for the backlighting display market."

Wafer sales have risen from \$1.7m last quarter to \$2.1m (roughly level on a year ago). Since revenue for polished wafers has fallen further from \$1.8m a year ago and \$0.84m last quarter to \$0.76m, growth was due mainly to revenue for patterned sapphire substrates (PSS) rising again, from \$0.26m a year ago and \$0.9m last quarter to \$1.4m.

Optical and R&D revenues collectively were roughly level with last quarter at \$1.35m (due mainly to optical revenue being down from

\$1.6m a year ago to \$1.1–1.2m). "This market has also been relatively weak in recent quarters, but we are beginning to see some improvement," says chief financial officer Mardel Graffy. "We continue to focus on this business and expect revenue from this market to grow in coming years," he adds.

"The sapphire market remained very challenging in the third quarter as excess capacity in the market and fluctuations in inventory levels in the supply chain added additional downward pressure on pricing and volumes," comments Weissman. "The current oversupply in the sapphire industry has been driven by the anticipation of the mobile device market potentially converting to the use of sapphire for cover glass in smartphones. While we believe there is a good chance for the use of sapphire in that application, the timing for adoption and scale of that adoption — if it occurs — is uncertain. If sapphire cover glass is adopted on a large-scale, industry analysts suggest that the current excess sapphire capacity will be rapidly absorbed and significant capacity increases will be needed to support that application. While we are taking steps to assure that Rubicon is positioned to participate in the sapphire cover glass market if that application is adopted, we are also taking the actions necessary to diversify the business to reduce volatility [making the company less susceptible to the pricing swings in the bulk sapphire market] and drive stronger margins over the long term," Weissman adds. "Our key initiatives toward that aim include aggressively pursuing our PSS potential, targeting high-margin optical applications and developing new products. Our goal is to focus on products that require more intellectual property to produce, like large-diameter PSS wafers produced entirely in-house and optical products."

In the near-term, Rubicon is focusing on cost reduction to cut cash usage. Despite idled plant costs rising from \$1.6m last quarter to \$1.8m, total operating expenses were cut from \$3.2m to \$3m due to lower spending on reporting compliance (which last quarter included annual report costs).

Net loss has been cut further, from \$9.3m (\$0.36 per share) a year ago and \$8.6m (\$0.33 per share) last quarter to \$7.7m (\$0.29 per share). Net cash used in operating activities was \$1.9m, cut from \$5.1m last quarter. During the quarter, cash and short-term investments fell from \$36m to \$34.1m (with no debt).

However, these non-GAAP figures exclude a \$900,000 accrual for the pending settlement of securities litigation, plus a non-cash charge of \$39.6m for the impairment of long-lived assets. "Due to the protracted weakness in sapphire pricing, it was determined in the period that our long-lived assets [machinery, equipment, facilities] should be written down to current fair market value," notes Graffy.

During the quarter, inventory rose by \$1m, due mainly to increased work in process (WiP) consisting primarily of boules and cores as a result of the lower core sales.

In fourth-quarter 2015, Rubicon expects the market to be challenging. Given the high inventory in the supply chain, demand for 2" and 4" cores is weak. At current pricing, the firm hence plans to limit sales in Q4 to allow time for inventory to clear. "While we expect the market to improve, it is difficult to predict the timing and want to avoid building excess inventory," says Graffy. Rubicon has hence scaled-back crystal growth production further (now operating at 40% of capacity). "We will re-evaluate throughout the remainder of the quarter and look for improvement in demand going into the New Year," he adds. ➤

► Also, Rubicon's key PSS customer has delayed the start of its volume purchase order by a quarter, from 1 October to 1 January (based on revised end-customer demand), reducing wafer revenue in Q4. "We've agreed to produce PSS wafers for their consignment inventory, so they will be available as needed," says Graffy. Utilization at Rubicon's wafering operations in Malaysia hence rose with the extra PSS volume. "We continue to work on implementing the changes associated with the resource sharing agreement [with a leading sapphire polisher] that we announced last quarter," he notes. "Once the other party begins using a portion of the Malaysia facility, our utilization will increase further. Given the current market conditions, the timing of their use of our facility is uncertain. We continue to benefit from the knowledge transfer of their lower-cost polishing process, which was the main driver for entering into this agreement."

For fourth-quarter 2015, Rubicon's

revenue will hence likely be limited to \$2-3m. Net loss per share will rise slightly to about \$0.30, as the firm will be incurring the cost of producing PSS wafers in advance of recognizing revenue.

"The sapphire market is very challenging at the moment, with weakness in all markets," notes Weissman. "We expect improvement in the first quarter of next year, based on our visibility of PSS wafers sales [for consignment], and we also believe the LED and mobile device supply chain inventories should come down and anticipate some improvement in demand for 2" and 4" core in the first quarter," he adds.

"We are taking actions necessary to diversify the business to reduce volatility and drive stronger margins over the long term while putting intense focus on cost reduction to reduce cash usage in the short term," says Weissman. "Reducing the level of cash usage is a top priority, and we believe we will show sustainable improvements in cash flow starting

early next year as wafer costs decline and we reduce inventory levels," says Graffy. "Additional improvement is expected later in the year by increasing optical revenue," he adds. "However, given the expected inventory build in the current quarter for the wafer consignment inventory and limited core sales, cash used will be higher in the fourth quarter [back up to the \$5m range]... but obviously we expect cash burn to be significantly lower than that going into next year," Graffy continues.

"Our goal is to drive growth that is more balanced between large-diameter PSS, optical products, bulk crystal like cores and rectangular blocks, and new products," says Weissman. "The bulk crystal will likely continue to be volatile but has significant potential upside if the cover glass application is adopted. The rest of the business should offer good growth opportunities with less volatility and with good margins."

www.rubicon-es2.com

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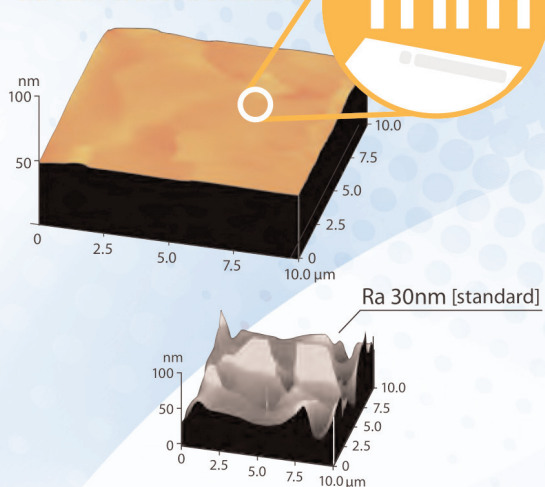


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Rensselaer's Michael Shur wins IET Achievement award for deep UV LED research

Rensselaer Polytechnic Institute (RPI) in Troy, NY, USA says that Michael Shur (its Patricia W. and C. Sheldon Roberts Professor of Solid State Electronics) is to receive an Achievement award from the UK's Institution of Engineering and Technology (IET) for pioneering contributions to deep-ultraviolet (DUV) LED technology.

The IET Achievement Awards recognize individuals from around the world who have made exceptional contributions to the advancement of engineering, technology and science in any sector, either through research and development in their respective technical field or through their leadership of an enterprise.

"It is a fitting recognition of his outstanding work at the intersection of advanced materials, devices and integrated systems," comments Rensselaer's dean of engineering



RPI's Michael Shur.

Engineering Department, which is home to several prominent research centers."

Shur's research in solid-state devices focuses on plasma wave excitation in submicron field-effect transistor (FET) and related device structures. His research has shown that a short-channel FET has a resonance response to electromagnetic radiation at the plasma oscillation frequencies of the two-

dimensional electrons in the device. The device that uses this resonance response should operate at much higher frequencies than conventional transit-time-limited devices — in the terahertz range — since the plasma waves propagate much faster than electrons.

Shur joined the Rensselaer faculty in 1996 and was named the Patricia W. and C. Sheldon Roberts Professor of Solid State Electronics. He has also held faculty positions at Wayne State University, Oakland University, and the University of Minnesota.

Recipients were honored at the IET's awards ceremony on 18 November, in conjunction with the announcement and presentation of the IET Volunteer Medal in London, UK.

www.rpi.edu/dept/phys/faculty/profiles/shur.html
www.theiet.org

Crystal IS adds TO-39 package with flat window to line of lattice-matched commercial UVC LEDs

Crystal IS Inc of Green Island, NY, USA, an Asahi Kasei company that makes proprietary ultraviolet light-emitting diodes (UVC LEDs) grown pseudomorphically (strained) on aluminum nitride (AlN) substrates, says that its newest Optan product is a deep UV LED in a TO-39 package with a flat window. Samples are available now.

Like the recently introduced Optan ball lens (BL) and surface-mount devices (SMD), the high-performance UVC LED is based on native AlN substrates using Crystal IS' proprietary technology. Claimed to be the only lattice-matched commercial UVC LED currently available, Optan provides a technology platform for increased detection sensitivity, proven to overcome limitations of other UVC LEDs in the market as well as traditional UV lamps including deuterium and xenon flash lamps,



the firm says.

Crystal IS says that the Optan Flat Window:

- has a wider viewing angle than other Optan packages (for easier alignment to fiber-coupled designs in analytical and life-science instruments);
- provides users with high reliability and performance, and lowers the cost of ownership in sensors for process monitoring (a requirement in applications in industrial processes and pharmaceutical manufacturing);
- does not focus the light from the chip (since the flat window packaging

preserves lambertian emission), so users have the maximum flexibility and full control over the optical path to fit their needs.

"As soon as we introduce a new Optan package, our customers come back with even more ways they'd like to replace traditional UV lamps with UVC LEDs," comments CEO Larry Felton.

The Optan Flat Window UVC LED can be used to monitor processes in industrial manufacturing; clean-in-place operations in the food and beverage processing industry; and in chromatographic processes used in protein purification and pharmaceutical manufacturing. In these processes and industries, UVC LED-based sensors have been shown to lower costs, increase productivity and meet regulatory and quality control requirements, the firm says.

www.cisuvc.com/products/optan

Seoul Viosys and Watersprint to provide UV-LED water purification technology for Bangladesh

UV LED firm Seoul Viosys plans to partner with Watersprint of Medicon Village, Lund, Sweden, which develops water purification products and systems for the disinfection of bacteria, viruses and protozoa. The system will be used to supply safe drinking water for people suffering from drinking water contamination in Bangladesh.

Water purification products and systems based on Watersprint's water control technology make it possible to keep water clean via sterilization using Seoul Viosys' Violeds technology. 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.

Realized through the collaboration between Seoul Viosys and Sensor Electronic Technology Inc (SETi) of Columbia, SC, USA (which makes deep-ultraviolet LED devices and modules), Violeds technology is available in a compact module, so it can be applied to industrial and commercial facilities as well as to home applications. In the water purification system, Watersprint is using a Wi-Fi system for 24-hour water quality monitoring and statistics (key for supplying clean water).

Even boiled water or sterilized vacuum-packed drinking bottled water cannot be kept several days without possible contamination by virus or bacteria, say the firms. Also, there have been many reports that tap water, shower mixers or water pipes are the main triggers of many diseases.

Violeds technology, which is used in sterilization systems in the International Space Station's (ISS) bio-laboratory equipment, is applied to the new clean water supply system with what is claimed to be a performance rate of 99.99% sterilization.

Muhammad Yunus, a Laureate of the 2006 Nobel Prize for Peace and co-pioneer of the project, has been running the Micro Production Center to supply clean and safe drinking water in order to help improve water quality in Bangladesh. Seoul Viosys' Violeds technology, combined with Watersprint's system, is applied at the Yunus Centre. The aim is to extend this system to water purification for the 750 million people without access to safe drinking water worldwide.

"UV-LED technology is at the core of our products," says Watersprint's CEO Anders Ruland. "A month ago, we announced a collaboration with Yunus Center and the launch of Micro Production Centers for water cleaning in Bangladesh, for which we are pleased to use the Seoul Viosys technology," he adds.

"The two companies will continuously cooperate to uplift the living conditions of people worldwide and capture business opportunities by developing and introducing new technologies," comments Seoul Viosys' CEO Jae-jo Kim.

www.watersprint.com
www.seoulviosys.com

Global Water and AquiSense sign memorandum of understanding for UV-LED water disinfection

Global Water Technologies has signed a memorandum of understanding (MOU) with UV-C LED system designer and manufacturer AquiSense Technologies, which is unveiling what is claimed to be the world's first UV-C LED production product for water disinfection at the Aquatech Amsterdam trade show at RAI Amsterdam, The Netherlands (3–6 November).

Both Global Water Technologies (based in Indianapolis, IN) and AquiSense Technologies (based in Florence, KY) are part of a regional water cluster formed by the US

Environmental Protection Agency (EPA) and US Small Business Administration to drive innovation and entrepreneurship in the water sector.

"We are honored to be one of just eight companies to exhibit in the Amsterdam Innovation Pavilion," says AquiSense's founder & CEO Oliver Lawal. "Our compact PearlAqua product marks a key milestone as the first production-volume UV-C LED water disinfection system. It is the result of eight years of development work, over \$5m of investment and hundreds of

hours of user interactions."

Global Water Technologies is an initial customer of the PearlAqua system, which began shipping this week and uses LED technology to provide water disinfection without the use of chemicals or mercury-based UV lamps. "We look forward to working with AquiSense to identify new opportunities to commercialize this innovative technology where traditional UV applications may not have been feasible," says Global Water's CEO Erik Hromadka.

www.aquatechtrade.com/amsterdam
www.gwtr.com

California-based Soraa to open LED fab in New York State, for production from second-half 2016

GaN-on-GaN LED maker's second fab to employ at least 300 staff

Soraa Inc of Fremont, CA, USA, which develops solid-state lighting technology built on 'GaN on GaN' (gallium nitride on gallium nitride) substrates, is to open a new fabrication plant in Syracuse, NY.

In partnership with the State of New York, the firm will construct a new GaN-on-GaN LED fabrication facility that will employ hundreds of workers. Working in coordination with State University of New York (SUNY) College of Nanoscale Science and Engineering (SUNY Poly CNSE), the new facility is on schedule for shell completion by the end of this year, with production beginning in second-half 2016. Soraa currently operates an LED fabrication plant in Fremont, California.

"Central New York's economic growth is due in large part to high-tech companies like Soraa that recognize the region's wealth of assets and resources," comments New York State Governor Cuomo. "Today's announcement not only means economic stability for the region, but it also strengthens Central New York as leader in the development of the clean technology

that will help light and power the future," he adds.

"Syracuse is an optimal location for the new fabrication facility for a number of reasons including the innovative high-tech vision and strategy of Governor Cuomo; the ability to attract some of the best and brightest scientists and engineers in the world; and the capacity to tightly control the product quality and intellectual property around our lighting products through our partnership with SUNY Poly CNSE," states Soraa's CEO Jeff Parker. "Since we launched our first product in 2012, global market reception for our high quality of light LED products has been phenomenal and sales have soared," he adds. "The new facility will significantly increase our manufacturing capacity to meet this growing demand."

It was announced in late 2013 that Soraa would expand its manufacturing operations to the Riverbend Commerce Park in Buffalo, NY. The plans outlined sharing the space with solar module manufacturer Silevo. However, following the acquisition of Silevo by SolarCity,

the facilities at Riverbend could no longer accommodate both Soraa's fabrication facility and the necessary square footage for SolarCity's expanded operations.

"Following the change with the Riverbend space, we remained focused on finding an optimal solution that worked for the State, Soraa and the talented workers that call upstate New York home," says Parker. "We're back on track with a great location and are targeting to employ at least 300 people to support a revenue stream of over \$1bn once fully functional," he adds.

"By taking Albany's nanotechnology-based public-private economic development model across New York State, Governor Andrew Cuomo has established an unmatched engine for long-term growth," comments SUNY Poly's president & CEO Dr Alain E. Kaloyeros, who adds that the new fab will present hands-on educational opportunities to New York's students, adjacent to the Film Hub in Syracuse, where the firm's lighting technology can be adapted for production purposes.

www.soraa.com

Plessey and 8Point3 to produce high-efficiency architectural lighting

Plessey has collaborated with fellow UK-based firm 8Point3 Ltd (a provider of energy-saving, solid-state lighting solutions for both private and public sectors, and a Value Add Partner of Philips Lighting) to develop and produce a high-efficiency architectural lighting product range. Plessey has signed a long-term commercial agreement with 8point3 to supply the lighting modules, including its Manufactured on GaN-on-Si I/C (MaGIC) LEDs.

"The improvements we have made on efficiency by using Plessey LEDs shows our continued commitment to developing and refining our products to deliver products of the highest quality and energy efficiency,"

says 8point3's managing director Ashley Bateup.

The Sabre linear lighting products combine the benefits of remote phosphor with a unique LED light engine, offering what are claimed to be unprecedented system efficiencies and an economic life-cycle. With a wide range of colour temperatures, Sabre provides a uniform and diffuse luminance and appearance, ensuring no reflections or pixilation, even when dimming the light, it is claimed. It offers designers a flexible solution for high-lumen areas and decorative lighting systems and is being widely used in the hospitality and retail sectors.

"Increased efficiencies have been achieved thanks to the close working partnership between our team of engineers and 8point3," comments Plessey's regional sales manager Mark Pinnock. "The Sabre architectural range shows what is possible when UK innovators join forces."

Plessey held product demonstrations presented by technical and design experts at LuxLive (the UK largest lighting show) at London's ExCeL arena (18-19 November), where the firm demonstrated its latest products and solutions for the commercial, industrial, consumer and wearable lighting segments.

www.8point3led.co.uk

www.plesseysemiconductors.com/

Plessey named 2015 Company of the Year by the NMI

At an annual awards ceremony in London attended by over 350 guests from the UK electronic systems industry, Plessey has been named Company of the Year by the NMI (National Microelectronics Institute), the industry trade body for electronic systems in the UK & Ireland.

"We present awards to recognize the achievements and behaviours that are conducive to a healthy and vibrant electronics industry in the UK and Ireland," says NMI's chief executive Dr Derek Boyd. "Our awards showcase excellence within the industry rewarding the innovation, expertise and ambition of businesses," he adds.

"We are entering a very exciting period with our new LED technology," said Plessey's chief technology officer Dr Keith Strickland at the event. "Our products are now gaining market traction in one of the



Receiving the award for Plessey: IC design manager George Ostaszewski, QA manager Robin Steele, product design director Neil Harper, financial director Chris Bailey, chief technology officer Dr Keith Strickland and commercial operations director Alan Colman.

fastest-growing technology markets, solid-state lighting. The expansion is highly significant not

only for Plessey, but also for British high-tech manufacturing," he adds. "We expect that our award-winning MaGIC [Manufactured on GaN-on-Si I/C] GaN-on-silicon technology with integrated electronics and optics will be soon be used around the world in a variety of lighting applications."

In September, Plessey announced a major expansion of its LED manufacturing facility in Plymouth, UK, after securing a £30m loan from Deutsche Bank AG to finance the expansion.

<https://nmi.org.uk>
www.plesseysemiconductors.com/led-plessey-semiconductors.php

Plessey demonstrates modular smart lighting system at LuxLive

At the LuxLive lighting trade show in London, UK (18–19 November), UK-based Plessey demonstrated the potential uses of its gallium nitride on silicon MaGIC (Manufactured on GaN-on-Si I/C) LED technology with a new smart lighting product called Totem, developed in collaboration with Manchester-based product design consultancy inventid. Totem is said to be an original concept based on the use of LED lighting solutions in the Internet of Things (IoT) — an increasingly favoured solution for the development of smart homes and cities.

"Our LED technology permits a far more integrated solution compared to traditional white LED components," claims Plessey's product line director Neil Harper. "Our integrated intelligent LEDs provide the design freedom to ensure end applications have greater functionality. Such things as dimming functions, light colour adjustment, automatic switch controls and remote operation can all be integrated into the



The Totem modular smart light bulb

silicon-based MaGIC LED," he adds.

"The team at inventid came up with a huge number of ideas and the first application we thought would resonate at the LuxLive event was the concept of the hands-free home," Harper continues. "The Totem could also include other modules like ambient light sensor,

sound and real-time clock whilst also fully controllable by consumers, providing dual functionality both as an addressable and reactive smart-lighting product. Together, we have designed Totem to deal with genuine human needs in the areas of safety and security, wellness, energy management and entertainment," he adds.

"The Totem is designed to be discreet and simple yet maintain strong ties with its heritage; the traditional light bulb," says inventid's co-founder Henry James. "Lights help change the use of a room and, because there are lights in every room in every home, they have the potential to reach people in a way that no other product can. In the same way that you can drive your car and speak on your mobile hands-free, you should be free to move about your house and talk hands free — the use of the light bulb to perform this function is a bit of genius."

<http://luxlive.co.uk>

DOE announces 2016 SSL R&D funding opportunity

The US Department of Energy (DOE) has announced the 'Solid-State Lighting Advanced Technology R&D — 2016' funding opportunity (DE-FOA-0001364), under which a total of up to \$10.5m in funding is directed toward all three existing DOE solid-state lighting (SSL) R&D program areas for both LED and organic LED (OLED) technologies:

- Core Technology Research — the application of fundamental scientific concepts to SSL technology;
- Product Development — using

the knowledge gained from basic or applied research to develop or improve commercially viable SSL materials, devices, or systems;

- US Manufacturing — accelerating SSL technology adoption through manufacturing innovations and improvements that reduce costs and enhance quality and consistency.

The objectives of this latest funding opportunity are to: maximize the energy efficiency of SSL products in the marketplace; remove market barriers through improvements to

lifetime, color quality, and lighting system performance; reduce costs of SSL sources and luminaires; improve product consistency while maintaining high-quality products; and encourage the growth, leadership and sustainability of domestic US manufacturing within SSL industry.

The DOE will select up to 10 projects. Concept papers are due by 20 November and full applications are due by 20 January 2016.

<https://eere-exchange.energy.gov/>

Solid State Supplies to distribute for Luminus in UK

Solid State Supplies Ltd of Redditch, UK has announced a UK franchise distribution agreement with Luminus Inc of Sunnyvale, CA, USA, which makes LEDs and solid-state light sources.

"Solid State Supplies has a growing reputation and understands the needs of lighting manufacturers. They have created important relationships with the major industry

players in the UK," comments Robert de Jonge, Luminus' senior director of sales for the EMEA region, said: "Our plan is to be a key supplier and business partner with Solid State Supplies to ensure that customers in the UK have access to our product portfolio as part of a comprehensive, competitive supply chain solution," he adds.

"Solid-state lighting is a major

opportunity and is becoming an increasingly important part of our business," says Solid State Supplies' managing director John Macmichael. "These highly versatile light source products and technologies from Luminus are a significant addition to our portfolio and will enable us to address an increased number of important applications."

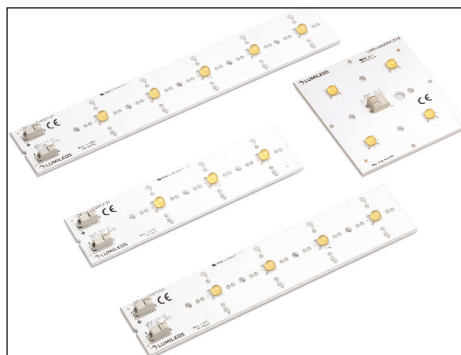
www.luminus.com

Lumileds launches XR-M LED as off-the-shelf addition to Matrix Platform to accelerate outdoor fixture design

Lumileds of San Jose, CA, USA has introduced the LUXEON XR-M line of Matrix Platforms, designed specifically as a turnkey solution for outdoor LED fixtures.

The versatile building blocks integrate 3, 4 or 5 LUXEON M LEDs on a metal core PCB, providing a platform that enables fixture manufacturers to accelerate their design of streetlights, high-bay and low-bay luminaires. For example, the 2-inch x 2-inch LED square version, in combination with industry-standard optics and driver, yields a complete IP66 solution.

"LUXEON XR-M incorporates LUXEON M, one of our most efficient and top-selling high-power LEDs," says Lumileds' Matrix Platform product manager Andrew Cohen.



"The boards can be connected in parallel or series for driver design flexibility, and the wide variety of lens options means designers have multiple turnkey options to release a full range of luminaires much faster to market," he adds.

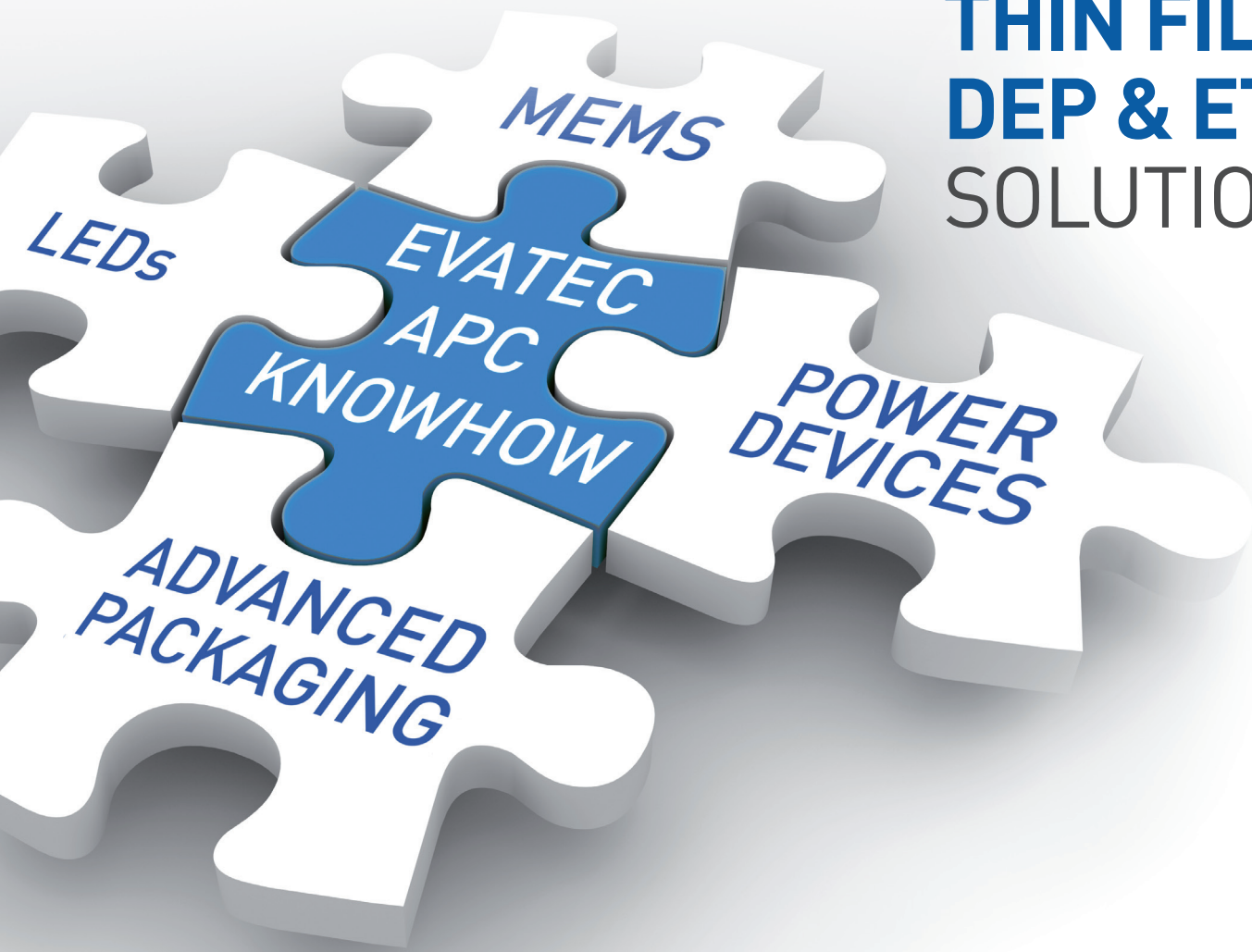
The LUXEON XR-M achieves luminous efficacy at the board level of 140lm/W at a color temperature of

4000K, color rendering index of 70CRI, junction temperature of $T_c=85^\circ\text{C}$, and 700mA drive current. Using constant pitch between the LEDs and PCBs, combining multiple LUXEON XR-M modules achieves uniform, distributed light patterns, says the firm. Each LUXEON XR-M module provides 3300–5500 lumens and is available in color temperatures of 4000K, 5000K and 5700K with a minimum CRI of 70.

The new product is part of the Lumileds Matrix Platform of infinitely configurable LED boards, linear flex and modules featuring LUXEON LEDs. The Matrix Platform comes in both off-the-shelf and built-to-spec options, offering a range of solutions for any application, says the firm.

www.lumileds.com/LUXEONXRM

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Osram investing €3bn in lighting by 2020

€2bn for R&D plus €1bn to construct 6-inch LED chip plant in Malaysia

In response to the shift in the lighting market toward semiconductor-based technologies creating new growth opportunities, lighting company Osram GmbH of Munich, Germany says it is to invest about €3bn in new technologies and applications by 2020. Of this amount, about €2bn will be spent on research and development in order to further strengthen Osram's technology and to expand into new markets. Additionally, Osram plans to spend a further €1bn in constructing a new LED chip plant in Malaysia, in order to unlock additional growth potential in both dynamic, technology-driven general lighting markets and niche markets, where Osram is already present.

"With a focus on profitability, flexibility and entrepreneurship, following a phase of strategic realignment, we are now launching the 'Diamond' innovation and growth initiative," says Osram Licht AG's CEO Olaf Berlien. "This means we are switching the focus to sustainable growth, benefitting even stronger from the potential offered by semiconductor-based technologies."

'Diamond' comprises several strategic measures. In a first step, Osram will invest about €370m in its Opto Semiconductors (OS) segment for a new LED chip plant in Kulim, Malaysia. Since further expansion measures are already being planned, the firm expects to invest a total of about €1bn there by 2020. The new plant is expected to represent the largest 6" LED chip production site worldwide. Osram expects that the additional production capacity and its technology should enable it to significantly increase its market share in the fast-growing general lighting market (which is currently about €5.7bn). Given average annual growth rates of 7.5%, the firm reckons that this offers the greatest potential up to 2020. It also reckons that, through economies of scale and synergies,

it can also reduce its costs in other market activities such as automotive lighting as well as applications for mobile devices, in which Osram already has a strong presence.

Osram is also planning additional investments in the Specialty Lighting (SP) segment to facilitate the broad-based rollout of new technologies in the market and to realize further growth potential. The firm has been the global leader in automotive lighting for many years, and intends to strengthen activities with innovative lighting modules. For example, Osram is claimed to be the only company in the world currently offering laser modules for headlamps ready for series production. Also for automotive lighting, organic light-emitting diode (OLED) technology is about to be rolled out for broad-based use in the rear lights of vehicles. Osram expects the market for laser and OLED applications in the automotive sector to amount to about €1.1bn in 2025.

In the recently created Lighting Solutions & Systems (LSS) segment, Osram says it will roll out many different measures in the coming years to realize "intelligent, technologically demanding lighting solutions". Following the review of the Luminaires and Solutions business (LS) announced recently, Osram is aligning this segment towards profitable growth. In particular, the market entry and range of integrated solutions offered are to be improved, adds the firm. Given the increasing importance of complex lighting solutions, Osram is also shifting the focus to expanding its electronics and software expertise. Over the next two years, new capacities for electronic ballasts and light management systems will be created for this purpose.

Boost to research

In line with the initiatives declared, Osram aims to increase its R&D budget significantly, aiming in particular to promote development

of smart-city applications, wireless lighting control, and laser and OLED technology.

Osram says that, despite consolidation and focusing measures, it has kept its research at a high level of just over 6% of revenue in recent years. After the sell-off of its general lighting lamps business that was initiated recently, the increased research expenditure will account for about 9% of revenue by fiscal-year 2016.

"Investments in research and development have paid off for the company in the past by taking it to a clear number-one position in the automotive sector and leading to groundbreaking applications with opto semiconductors," says Berlien. "Through the intended increase in research intensity, Osram wants to further strengthen its technical expertise for semiconductor-based technology and extend its market position."

'Diamond' targets growth

The 'Diamond' innovation and growth initiative aims to increasingly focus the company on balanced growth. In addition to high-revenue areas that hold large growth potential, lucrative niche areas — where Osram is already in a good position — will continue to make a valuable contribution to overall returns, the firm reckons. Osram has hence set the following targets, to be achieved in fiscal 2020:

- revenue of €5–5.5bn (corresponding to an average annual growth rate of 8%, after the sell-off of the lamps business);
- earnings before interest, tax, depreciation, and amortization (EBITDA) of €0.9–1bn (corresponding to an average annual growth rate of about 9%); and
- earnings per share of about €5 (equal to average annual growth of 25% compared with fiscal 2015) — the announced share buyback program is included in this target.

www.osram-os.com



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Imec and UGent demonstrate first InP laser arrays monolithically grown on 300mm silicon

Nanoelectronics research center Imec and Ghent University (UGent) in Belgium have presented (for the first time, it is claimed) arrays of indium phosphide (InP) lasers monolithically integrated on 300mm silicon substrates in a CMOS pilot line (published in Nature Photonics).

The development is reckoned to provide a path toward high-volume manufacturing of cost-effective photonic integrated circuits (PICs) with monolithically integrated laser sources. Such laser-powered PICs could revolutionize data transfer between future logic and memory chips.

Over the past few years, demand for data communication between servers in cloud data-centers has been growing exponentially, following strong growth in social networking, cloud computing and big-data applications. Silicon photonics technology enables cost-effective manufacturing of fiber-optic transceivers, which in turn provides continued scaling of server and data-center capacity with improved power efficiencies. However, widespread adoption of this technology has been hampered in part by the lack of monolithically integrated laser sources. However, the integration on silicon of efficient InP-based light sources, currently

driving long-range telecom networks, is challenging due to the large mismatch in crystal lattice constants between the materials.

Imec and Ghent University say they have overcome these structural differences and largely suppressed the detrimental crystal defects that typically form at the interface between silicon and InP. Utilizing a production-grade metal-organic vapor-phase epitaxial (MOVPE) growth reactor, InP was selectively grown on silicon in a pre-patterned oxide template, realizing InP waveguide arrays across the entire 300mm substrate. Subsequently, periodic grating structures were etched in the top layer of these waveguides, providing the optical feedback required for laser operation.

Lasing operation was demonstrated for all tested devices, consisting of an array of ten InP lasers. Typical lasing threshold powers of around 20mW were observed at room temperature under optical pumping. Lasing performance showed small variability along the array, illustrating the high material quality of the heteroepitaxial grown InP. In addition, accurate control of the distribution of lasing wavelengths in the array was demonstrated by modifying the grating parameters.

The new approach for integrating lasers with silicon has been carried out in Imec's 300mm CMOS pilot line, providing a path to high-volume manufacturing. Ongoing research efforts focus on growing more complex layer stacks to enable electrical injection of the lasers and emission in the 1300nm wavelength range, along with integration with silicon-based waveguide devices.

This work was undertaken as part of Imec's industry affiliation program (IIAP) on Optical I/O, which aims to develop a scalable, silicon-based optical interconnect technology for high-bandwidth chip-level I/O. The work was also partly supported by the European Commission through an ERC starting grant awarded to professor D. Van Thourhout of Ghent University for research on Ultra Low Power Photonic ICs (ULP-PIC). This five-year project aims to develop novel active photonic devices with lower power consumption, for integration on next-generation electronic and photonic ICs.

Imec's R&D work on Optical I/O is performed in cooperation with key partners in its core CMOS programs, including Huawei, GlobalFoundries, Intel, Micron, Panasonic, Qualcomm, Samsung, SK Hynix, Sony and TSMC.

<http://photonics.intec.ugent.be>
www.imec.be

LandMark Optoelectronics expanding capacity by 20% Two of four new MOCVD systems to be used for silicon-based epitaxy as partner of Intel's Silicon Photonics project

LandMark Optoelectronics Corp, which makes gallium arsenide and indium phosphide based laser diode and photo-detector epitaxial wafers for optical communications, industrial applications and special-purpose usage, is to expand production capacity by 20% by adding four metal-organic chemical vapor deposition systems to reach 18 in total in fourth-quarter 2015, reports Taiwan's Digitimes.

As a partner of Intel's Silicon Photonics research project, LandMark started production of silicon-based epiwafers at the end of third-quarter 2015. Two of the new MOCVD systems will be used to produce such wafers, the firm says. Of its total 2015 revenue, LandMark expects GaAs- and InP-based epiwafers to account for 80-85% and Si-based epiwafers to account for 15-20%.

LandMark recorded revenue of NT\$552m (US\$16.8m), gross margin of 66.8%, net operating profit of NT\$320m, net profit of NT\$279m and net EPS of NT\$3.08 in third-quarter 2015. This has led to total year-to-date revenue (January-September) of NT\$1.407bn, gross margin of 65.3%, net operating profit of NT\$801m, net profit of NT\$678m and net EPS of NT\$10.30.

www.lmoc.com.tw/en/e-index.html



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SystemOnGlass optical communications firm ColorChip raises \$25m in growth-funding round

Funding to be used to scale up operations and accelerate product development roadmap

Privately held integrated optical communications component and sub-system developer ColorChip of Yokneam, Israel has raised \$25m in a round of growth funding.

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 and photonic 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-based lasers and photo-detectors) and passive optical components (PLCs).

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

ColorChip is also claimed 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 in Israel. The fab utilizes the firm's unique IP and is a critical component of its core technology, allowing the industrialized manufacturing of optical assemblies.

The new financing round was led by tech-focused growth equity fund Israel Growth Partners with participation from Vintage Investment Partners and existing investors Gemini Israeli Funds and BRM Group. IGP co-founder & general partner Haim Shani is joining ColorChip's board of directors. "I look forward to benefiting from his experience in scaling up our businesses," comments ColorChip's CEO Yigal Ezra. To date, the firm has raised \$60m with Gemini and BRM leading the previous rounds.

Ezra says that the new funding will be used to scale up operations and accelerate its product development roadmap for data-centers that need to increase their traffic capacity. With Internet services becoming more data intensive due to streaming HD video, virtual reality, cloud computing, and IoT devices, there is

a growing need for new technologies to help data-centers manage all of the exponentially growing traffic, says ColorChip, adding that its optical communication solutions are positioned to help solve the growing bandwidth demand of the web.

"ColorChip is currently in high-growth mode, with production expected to increase 15 times in the next 24 months," says Ezra. "We are already serving top-tier customers in the USA and China, and this new funding will support our efforts to scale further and meet the accelerating demands of the market," he adds.

"We believe that ColorChip's unique inter-disciplinary optical and networking technology addresses a major pain in an industry that is experiencing exploding bandwidth and speed demands and is looking for breakthrough innovations," says Shani. "IGP believes that ColorChip's technology provides a unique opportunity to better serve the growing demands of the datacom market, and this round will enable the company to scale its operations to meet those demands."

<http://color-chip.com>

Emcore expects 8.5% quarterly revenue growth to \$23m

Gross margin up from 36.3% to about 40%

In preliminary financial results for its fiscal fourth-quarter 2015 (to end-September), Emcore Corp of Alhambra, CA, USA (which provides compound semiconductor-based chip-level devices, optical components, subsystems and systems for broadband and specialty fiber-optics markets) says that it now expects revenue of about \$23m (consistent with August's guidance of \$22-24m), up 8.5% on \$21.2m last quarter.

"We saw strong demand for our chip-level products, with shipments

of our chips exceeding \$4m, up from approximately \$2m in the prior quarter," notes president & CEO Jeffrey Rittichier. "In fiscal year 2015, we shipped more than \$8m of chips, up from zero in 2014."

Gross margin is expected to be up from 36.3% last quarter to about 40%, due mainly to a favorable product mix and increased volume. However, this will be partially offset by higher operating expenses, due largely to increased legal and headcount costs.

"While we are pleased with our preliminary fourth quarter financial results and are encouraged about the long-term industry outlook, we remain cognizant of the dynamics in the CATV market and consolidation in the industry at both the OEM and MSO levels," Rittichier says. Emcore hence expects revenue for fiscal first-quarter 2016 to be roughly level at \$22-24m.

Emcore is announcing full results for fiscal Q4/2015 in December.

www.emcore.com

Firecomms adds 5Mb RedLink optical receivers with temperature range extended to 95°C for industrial use

Firecomms Ltd of Cork, Ireland and Tongxiang, China (which manufactures fiber-optic solutions and optical transceivers for communications networks) has launched a range of 5Mb RedLink fiber optic receivers with an extended temperature operating range of up to 95°C for the industrial command, control and communications markets. The company debuted the new receivers at the SPS IPC Drives 2015 Electric Automation (Systems and Components) international exhibition & conference in Nuremberg, Germany (24–26 November).

The new receivers have been specifically designed to be compatible with the ever increasing component operating temperatures of 21st century insulated-gate bipolar transistor (IGBT) driver and control modules. The FM05MHIR and FM05MVIR receivers extend the operating range of plastic optic fiber (POF) receivers up to +95°C, enabling the optical component to remain part of the next-generation IGBT technology backbone.

"Customer feedback, like extending our temperature range, constantly informs and directs our product roadmap," notes VP of marketing Michael O'Gorman. "This new product represents the first step in a comprehensive NPI [new product introduction] roadmap which will ensure Firecomms customers have optical solutions compatible with the demands of next-generation drives," he adds.

"Our customers' products operate in the harshest of environments and are regularly exposed to temperature extremes," says chief technology officer John Lambkin. "For example, a locomotive sitting in the searing heat of the desert will experience internal ambient temperature at the top end of the standard industrial range of -40°C to 85°C," he adds. "We are now challenged to meet a component specification beyond the traditional industry norms."

Firecomms says that its RedLink devices are in use by some of the largest industrial conglomerates in applications such as electric trains, high-voltage grid stations, and wind and solar energy converters. The firm uses in-house designed photonics as well as transmitter and receiver ICs together with an

internal production facility to control its supply chain. Firecomms says that its vertical integration around the core technologies used in fiber-optic transceivers enables it to respond flexibly to demands while maintaining tight control of major cost drivers.

www.firecomms.com



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MACOM to acquire optical sub-assembly supplier FiBest High-performance packaging to expand addressable market via 100G in data centers

M/A-COM Technology Solutions Holdings Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) has entered into a definitive agreement to acquire Japan-based FiBest Ltd (a merchant-market component supplier of optical sub-assemblies) in an all-cash transaction valued at about \$60m (2.4 times trailing 12-months revenue).

MACOM expects benefits of the transaction to include:

- extending MACOM's position in 100G, 200G and 400G optical networking;
- expanding the serviceable addressable market (SAM) in data centers;
- providing localized leadership and a robust sales channel into the

Japanese market; and
● being accretive to MACOM's adjusted earnings per share.

"The FiBest acquisition augments MACOM's preeminent position in optical networking components, adding high-performance packaging capability," says MACOM's president & CEO John Croteau. "This will enable us

The quality of the optical sub-assembly is a major factor in achieving the performance, power efficiency and cost targets necessary for 100G in data centers — and becomes mission critical at 200G and 400G data rates

to deliver more refined and validated component solutions to our transceiver customers," he adds.

"The quality of the optical sub-assembly is a major factor in achieving the performance, power efficiency and cost targets necessary for 100G in data centers — and becomes mission critical at 200G and 400G data rates," continues Croteau. "Adding FiBest will significantly expand MACOM's addressable market with high-growth potential for 100G in data centers, as we anticipate an inflection point in demand in 2017," he adds.

MACOM expects to fund the acquisition with available cash. Closing is subject to customary closing conditions and is expected to occur during the firm's fiscal first-quarter 2016.

www.fibest.com

MACOM launches chipset for QSFP28 modules for data-center applications

M/A-COM Technology Solutions has announced availability of its complete chipset for CWDM and PSM4 applications in the data-center. The chipset includes the complete lineup of electronic and optical integrated circuits to achieve the lowest power consumption in a QSFP28 form factor.

As new mega-datacenters continue to expand to service the demand for high-speed data communications, the volume of 100G transceivers is expected to grow exponentially with the parallel need for lower-power, smaller-size and lower-cost components. MACOM has consolidated the high-speed semiconductor content in 100G transceivers and now offers the complete solution including lasers, drivers, CDRs (clock & data recovery) and TIAs (transimpedance amplifiers) —

all optimized to provide highly differentiated performance, power, size and cost benefits.

The M37046 and M37049 are claimed to be the lowest-power and smallest quad-channel receive and transmit CDRs. The MAOM-002301 and MAOM-002304 are single- and quad-channel directly modulated laser (DML) drivers that offer what is claimed to be the lowest-power solution in the market. They are also said to be widely adopted in the market due to ease of assembly inside the transmitter optical sub-assembly (TOSA). In addition, the 127/129/131/133D-25C-LCG11 family of distributed feedback (DFB) lasers covers CWDM and PSM4 wavelengths, offering high performance over a broad operating temperature range. The M03002 and M03102 are

single- and quad-channel TIAs offering what is claimed to be the industry's lowest noise and power consumption for 28G applications. The bundle is fully supported by MACOM's expert applications team to provide faster time to market for transceiver designers. Economies of scale also provide significant cost benefit to manufacturers building transceivers based on the MACOM chipset, the firm reckons.

"By providing the complete solution in a neat bundle, we can provide cost and power efficiency benefits which solve our customers' high-speed networking challenges," says Vivek Rajgarhia, MACOM's VP of strategy, Networks.

All of the products in MACOM's 100G data-center bundle are now shipping in volume.

www.macom.com

GigOptix launches single- and quad-channel limiting 28Gbps direct modulated laser drivers

GigOptix Inc of San Jose, CA, USA has launched a highly integrated, low-power-dissipation, small-form-factor single- and quad-channel limiting 28Gbps direct modulated laser (DML) driver chipset for 25 and 100Gbps Ethernet data-center and cloud computing applications.

The single-channel HXT42100 and quad-channel HXT42400 DML drivers enable the next generation of lower-power 28G SFP28+ and 100G QSFP28+ Ethernet modules or active optical cable (AOC) solutions, as well as providing 32GFC and 128GFC support for fiber channel storage solutions.

The HXT42100 and 42400 share the same architecture, with a high level of integration, low power dissipation, and small form factor. The HXT42100 single-channel driver footprint is sufficiently small to use within a TOSA (TO-can) solution.

Both DML drivers support low-voltage-supply operation as low as 2.5V with modulation and bias currents of 50mA, enabling the next generation of low-power modules, and can be driven with supply voltages up to 3.3V if higher modulation and bias currents are required. A single channel operating at 2.5V will dissipate less than 200mW of chip power. Neither of the two devices require any external digital-analog convertors (DACs) for operations.

With both HXT42100 and 42400, a high level of integration is provided by incorporating the modulation, bias and pulse-shaping DAC into the devices with an integrated I²C interface for control, monitoring, fault, and status detection. The 1MHz I²C interface enables full control of additional functionality such as signal detect and squelch, bandwidth adjust, mask-able fault

and interrupt generation, internal temperature monitor selection, channel polarity inversion, and programmable CTLE input equalization.

"Next to our market-dominating 40Gbps short-reach (SR) and long-reach (LR) ICs, and the 100Gbps SR ICs and CDR, the DML driver will substantially enhance our 100Gbps long-reach market penetration," reckons datacom marketing director Tom Kapucija.

"With integrated bias and modulation current control via our standard I²C interface, low power and small form factor, TOSA TO-can form factor integration is now possible," comments Emad Afifi, senior director of engineering and the lead designer of these parts.

The HXT42100 and 42400 are sampling now and will ship in full production volumes in Q2/2016.

www.gigoptix.com

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Oclaro achieves positive adjusted EBITDA and non-GAAP operating income

Revenue growth driven by 100G for China, but capacity constrained while Asian production lines qualified

For its fiscal first-quarter 2016 (ended 26 September 2015), Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications) has reported revenue of \$87.5m, down 2% on \$89.2m a year ago (which included \$7.5m of since-divested Industrial & Consumer business) but up 7% on \$82.2m last quarter (and at the high end of the forecast range of \$82–88m).

Revenue from 40G products has fallen further, from \$22.2m (25% of sales) a year ago and \$14.1m (17% of sales) last quarter to \$10.8m (12% of total sales). However, while line-side 40G telecom product revenue was down by \$4m from last quarter, revenue for end-of-life legacy products was higher than forecasted by about \$1m.

Although down on \$38.2m (43% of total sales) a year ago, revenue from 10G-and-lower products has rebounded by 6% from \$33.8m last quarter to a slightly higher-than-expected \$35.7m (remaining 41% of total sales), benefitting from higher-than-expected revenue from final sales of end-of-life products.

Revenue growth was primarily driven by 100G products (both client-side and line-side), almost doubling from \$21.3m (24% of total sales) a year ago and rising by 20% from \$34m (41% of sales) last quarter to \$40.7m (47% of sales).

"We have now firmly put the turnaround challenges behind us and are entirely focused on growing the company based on the strength of our 100G-and-beyond business," says CEO Greg Dougherty. "In the March quarter, we increased our capacity for 100G client-side transceivers. This includes our CFP, CFP2 and CFP4. We realized the benefit of this investment initially in Q4 and for the full first quarter of fiscal 2016."

Driven by 100G sales, datacom applications have grown further, from \$37.7m (42% of total sales) a year ago and \$41.9m (51% of total sales) last quarter to \$47.5m (54% of total sales), while telecoms applications have fallen from \$44m (49% of total sales) a year ago and \$40.3m (49% of total sales) last quarter to \$40m (46% of total sales).

By region (compared with last quarter), China grew further, from 36% to 38% of total revenue, while the Americas fell back slightly from 31% to 30% and Europe from 22% to 19%, and there were slight rebounds for Southeast Asia from 10% to 11% and for Japan from 1% to 2%. Oclaro's two greater-than-10% customers each contributed 16% of revenue.

On a non-GAAP basis, gross margin has risen further, from 16.5% a year ago and 19.9% last quarter to 26.4% (well above the high end of the forecasted 18–22%). This was driven by revenue flow-through, improved execution (leveraging fixed manufacturing overhead on higher sales), a richer mix of products for both 100G and 10G, and a one-time benefit from final sales of higher-margin end-of-life

In addition to reaching our first milestone of generating positive adjusted EBITDA, we also achieved non-GAAP operating income. This was done ahead of schedule and demonstrates the ongoing success we are achieving with our 100G products and a transition to a richer mix of 10G products

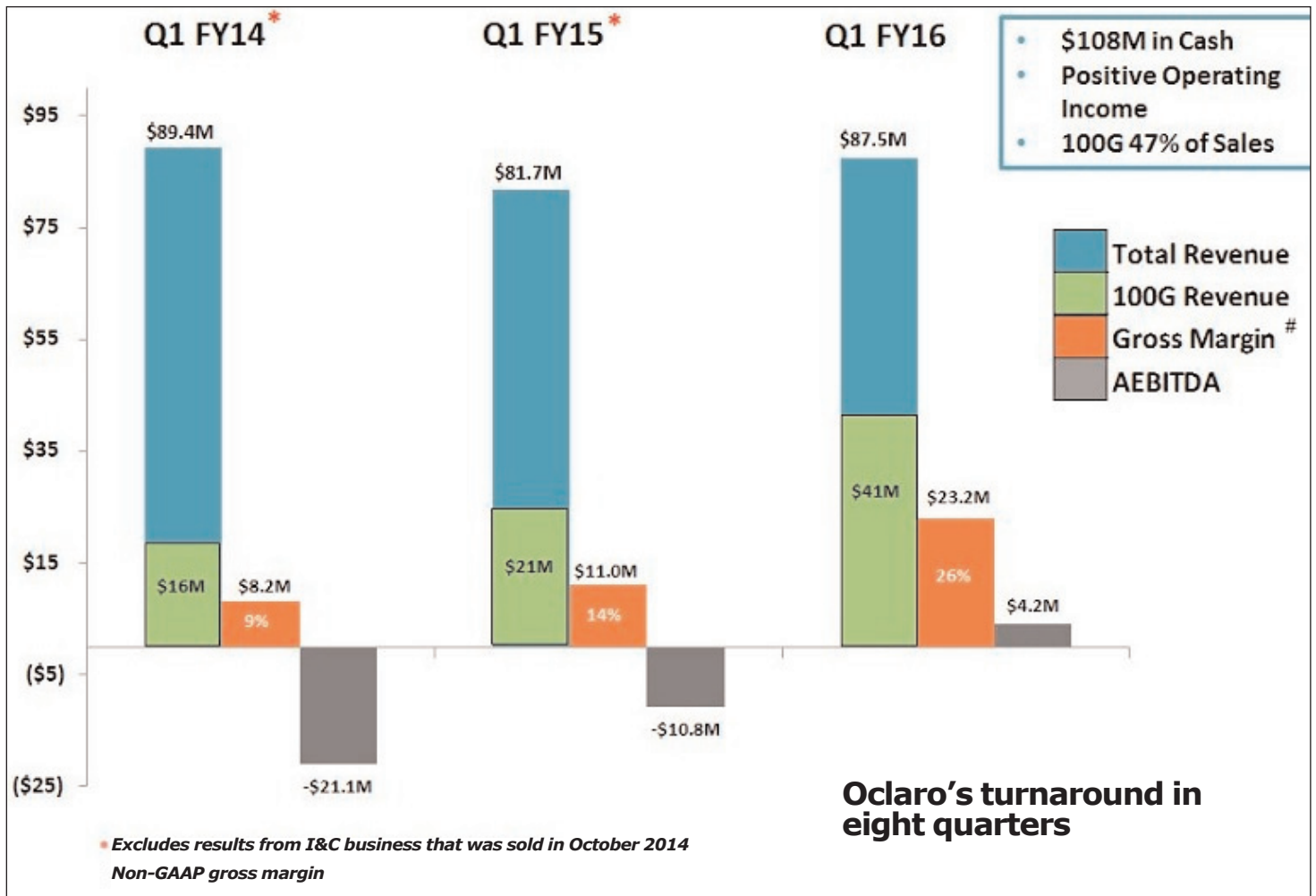
products (equating to 1% of gross margin).

Operating expenses leveled off at about \$23m (26% of revenue), cut by 20% (\$5.6m) from a year ago due mainly to restructuring programs implemented last year. Oclaro has hence reported an operating income of \$0.4m, compared with a loss of \$5.4m last quarter and \$13.6m a year ago.

Compared with –\$8.9m a year ago and –\$1.2m last quarter, adjusted EBITDA (earnings before interest, taxes, depreciation and amortization) was +\$4.2m (much better than the forecasted range of between –\$3m and breakeven, and an improvement of \$25m on the –\$21m of fiscal 2014 when comparing continuing operations).

During the quarter, cash, cash equivalents, restricted cash and short-term investments fell from \$115.1m to \$107.7m. The primary use of cash was from working capital of \$5.4m, driven primarily by higher sales and capital expenditure (CapEx) of \$3.8m.

"In addition to reaching our first milestone of generating positive adjusted EBITDA [the firm's first in over four years], we also achieved non-GAAP operating income," notes CEO Greg Dougherty. "This was done ahead of schedule and demonstrates the ongoing success we are achieving with our 100G products and a transition to a richer mix of 10G products," notes chief financial officer Pete Mangan. "These accomplishments resulted primarily from planned cost reductions, operational improvements, and strong growth across our 100G product portfolio over the past two years," adds Dougherty. "We now believe that the foundation is in place to further grow our 100G product revenues and enable continued financial improvement." ➤



► For fiscal second-quarter 2016 (ending 26 December 2015), Oclaro expects revenue to grow to \$88–94m, boosted by growth in 100G revenue of 10–20% (\$4–8m), offset slightly by a drop of \$3m collectively for 10G (to about \$34m) and 40G (to about \$10m, then remaining at that quarterly level throughout fiscal 2016). Gross margin should be 24–27% (roughly level quarter-to-quarter, excluding fiscal Q1's one-time contribution from end-of-life products). Adjusted EBITDA is expected to be \$3–7m.

"Recently, we began to see very strong demand signals from China as it appears that our customers are preparing for awards for 100G systems from both China mobile and China telecom," says Dougherty. "The demand is for both our client-side and line-side 100G products," he adds. "We expect to see continued 100G sales growth in China and believe that revenue in Q2 and Q3 of fiscal 2016 will continue to be constrained by our ability to increase

capacity." For full-year fiscal 2016, Oclaro still anticipates investing \$30–40m of CapEx (mostly for assembly & test equipment) to support additional capacity for both 100G client-side and line-side growth.

Oclaro has been qualified and begun shipping CFP2-ACO coherent transceivers for field deployment in the December 2015 quarter. "We have achieved the qualification for products manufactured at our UK production facility, and have begun our builds for qualification of our Asian production lines [expected in the March quarter]," notes Dougherty. Demand continues to exceed supply and Oclaro will be capacity constrained (continuing to ship out of the UK) for several quarters while it waits for Asian lines to start production and to ramp. "The challenges in ramping the production of our ACO product are mostly centered on test and software now, which are difficult given the variety of customer-specific feature sets and test conditions. Once these feature sets and algo-

rithm have been finalized, we expect to see a steady increase in our capacity and production output," he adds.

"We have now started sampling our QSFP28 transceivers for use in data centers which are upgrading to 100G and to single-mode fiber infrastructures. Early feedback from customers who have tested our parts has been very positive," says Dougherty. "The QSFP family of transceiver leverages the technology of our CFP products and utilizes what we believe are the world's best high-speed DFB and EML lasers to offer industry-leading performance at 100G," he adds. "We believe that we have best-in-class performance especially in power consumption, which is particularly important to data centers." Oclaro expects to start seeing early revenue from QSFP28 shipments in first-half calendar 2016, and estimates that the potential available market for QSFP28 products is \$100–150m in full-year 2016.

www.oclaro.com

NeoPhotonics reports higher-than-expected Q3 revenue, despite product pruning

100G long-haul build-out in China to drive growth

For third-quarter 2015, 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 \$83.6m, down 2.1% on \$85.4m last quarter but up 2.4% on \$81.6m a year ago (and above the projected range of \$77–83m) despite having pruned products that contributed \$23m in annual revenue in 2014.

High Speed Products (for 100G-and-beyond) represented 56% of total revenue (falling back from last quarter's record of 59%). Network Products and Solutions (<100Gb/s) represented 44% of total revenue (up from 41% last quarter), with sales of products for access networks demonstrating strength in China.

The two 10%-or-greater customers were China's Huawei Technologies (41% of total revenue, up from 40% last quarter) and US-based Ciena (26% of total revenue, up from 22%). Of total revenue, China fell slightly from 50% to 49% as the Americas rose from 28% to 30%. Japan and the rest of the world were roughly flat, at 4% and 18% respectively.

On a non-GAAP basis, gross margin was 29.8%, up from 26.5% a year ago but down on 32.3% last quarter. However, excluding inventory-related charges from discontinued products, gross margin would have equaled the midpoint of the projected range of 29–32% despite the higher-than-expected mix from Network Products and Solutions.

Operating expenses were \$20.7m, up on \$20.3m a year ago but cut from \$21.1m last quarter (remaining about 24.8% of revenue). "Quarterly operating expense run-rate continues to reflect the vigilant management and controls we established for the year, to be consistent with our target model and as we drive for increased profitability,"

notes senior VP & chief financial officer Ray Wallin. For the last five quarters, NeoPhotonics has operated at its target operating expense model of 25% of revenue.

Net income was \$4.6m (\$0.11 per diluted share), down from \$5.3m (\$0.14 per diluted share) last quarter but up from \$1.4m (\$0.04 per diluted share) a year ago (and above the expected range of \$0.01–0.09). Net income is 6% of revenue (level with last quarter, and up from just 2% a year ago). Likewise, although down from \$11.4m (13% of revenue) last quarter, adjusted EBITDA (earnings before interest, taxes, depreciation and amortization) of \$10.2m (12% of revenue) is up on \$7.3m (9% of revenue) a year ago.

"We are pleased to report our fourth straight quarter of GAAP profitability and year-over-year revenue and margin expansion, which resulted in our generating \$43m of adjusted EBITDA over the last four quarters," says chairman & CEO Tim Jenks.

During the quarter, cash and cash equivalents, short-term investments and restricted cash and investments fell slightly from \$104.4m to \$103.6m.

To support anticipated 100G China awards in Q4, net inventory has been increased by \$1.1m to \$70.7m (106 days of inventory on hand).

"We continue to expect steady growth in China market over the next two years," says Wallin. "The 100G long-haul build-out in China will span upwards of 30 provinces. Fiber-to-the-home [FTTH] roll-outs continue along with 4G wireless installations (albeit at a reduced pace versus the past year) and adding new data-center construction. In particular, we have seen some uptick in demand over the past 4–6 weeks, which gives us more confidence in these forecasts," he adds. "We are excited about the renewed momentum we are seeing in the 100G market and the progress we are making with our

strategy of increasing our content per 100G port and extending our products to 400G and beyond."

Taking into account the product pruning completed in mid-2015 (representing \$23m in 2014 annual revenue) plus typical impacts on average selling price (ASP) from annual price negotiations (mainly with the firm's largest customers), for Q4/2015 NeoPhotonics expects revenue of \$82–86m. "While we anticipate solid fourth-quarter volume growth in China for 100G products, we also expect the demand to carry into the first quarter of next year," notes Wallin. Gross margin should rise to 30–34%, despite increases in R&D spending as key new products are moving towards general availability. Diluted earnings per share should be \$0.05–0.13.

"As we look to the growth drivers of our business through 2016, High Speed 100G-and-beyond coherent developments and deployments (including in China) will remain a primary contributor," says Jenks. "To ensure NeoPhotonics is best positioned to take advantage of these technology transition cycles, we continue to introduce new products and solutions. Our 100G solutions include new compact receivers and ultra-narrow-linewidth tunable lasers and address both high baud rate and higher-order modulation approaches to 400G," he adds.

"For data-center applications we joined with Inphi at the European Conference on Optical Communications (ECOC) in September to demonstrate a 100G PAM4 10km link, and we believe our capability here will further complement NeoPhotonics' existing line of client-side transceivers, including CFP2-LR4, CFP4-LR4," says Jenks. "We see the metro market as the next significant opportunity for 100G coherent solution growth in 2016 and beyond."

www.neophotonics.com

NeoPhotonics appoints industry veteran to board

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) says that Ihab Tarazi has been appointed to its board of directors, effective 27 October. Tarazi replaces Allan Kwan, who is stepping down after serving on the board since 2008.

Tarazi is chief technology officer at Equinix Inc, where he is responsible for Equinix International Business Exchange (IBX) network opera-

tions, data-center platform strategy, leading the next-generation technology and innovation function, and contributing to the company's cloud initiatives. Tarazi has 25 years of experience in the telecom business.

Before joining Equinix, Tarazi was Verizon's VP of Enterprise Network Services, where he helped to drive product strategy, life cycle management, technology and development for its network products including IP, Ethernet and transport to support retail and wholesale customers. He was also the chairman

of the Metro Ethernet Forum (MEF).

Tarazi received his Master of Engineering in Telecommunications Management from Southern Methodist University and a Bachelor of Engineering in Telecommunications Engineering from the University of Maryland.

"His extensive background in the telecommunications industry and deep technology experience will provide the board with valuable insights into the ongoing evolution of our addressable markets," says chairman & CEO Tim Jenks.

www.neophotonics.com

NeoPhotonics receives Huawei's Excellent Core Partner Award for fifth consecutive year

For the fifth consecutive year, NeoPhotonics has received the Excellent Core Partner Award for 2015 from China-based telecom network provider Huawei Technologies. NeoPhotonics was honored for its contributions as a supplier of innovative optical technology and products for high-speed and access communications networks.

The award is given only to companies that consistently deliver innovative technology with the highest performance and quality to meet Huawei's special-

ized requirements. NeoPhotonics has been recognized yearly as a Huawei Excellent Core Partner since 2011.

"We are proud to have been an integral part of Huawei's success," said NeoPhotonics' chairman & CEO Tim Jenks at the awards ceremony at Huawei's corporate headquarters in Shenzhen.

"We believe that we provide the highest performance and quality in our products and also add value through collaboration with our customers to leverage our technology, engineering and supply chain

strengths to anticipate their needs."

Huawei is reckoned to be the largest network equipment provider in the world, serving about one-third of the world's population through more than 400 telecom operators in 170 countries.

Huawei was one of the earliest customers of NeoPhotonics, and NeoPhotonics has supported Huawei's growth and technology advancement for more than a decade.

www.huawei.com

Applied Optoelectronics launches 100G optical engine

Applied Optoelectronics Inc (AOI) of Sugar Land, near Houston, TX, USA, a manufacturer of fiber-optic access network products (including components, modules and equipment) has announced a new optical engine for use in 100Gbps transceivers for data-center applications.

The new optical engine combines four 25Gbps laser diodes (manufactured in AOI's MBE fab in Texas), a receiver array, an optical fiber array and the associated integrated laser-diode drive electronics and

trans-impedance amplifiers into a single optical subassembly that is the major building block required for assembly of a 100Gbps parallel single-mode (PSM4) transceiver. The light engine also features a high-reliability non-hermetic design for cost efficiency as well as a proprietary housing design for improved heat dissipation. The transceivers are designed to address the growing market demand for 100G optics and are expected to be used in next-generation data-center inter-

connects to facilitate higher data throughput between servers and switches.

"We expect this device to be a critical building block for QSFP-28 transceivers using the PSM4 optical interface," says Dr Fred Chang, AOI's senior VP of the Optical Component business unit.

Both MSA-compatible and fiber-pigtail versions of the light engines are available now in sample quantities, with volume production expected this year.

www.ao-inc.com

First Solar to supply another 400MW of modules to Strata over 2017–18

First Solar Inc of Tempe, AZ, USA, which makes thin-film photovoltaic modules based on cadmium telluride (CdTe) as well as providing engineering, procurement & construction (EPC) services, has signed an agreement with US-based Strata Solar LLC (which provides utility-scale, commercial and industrial solar PV systems) for the procurement of an incremental 400MW_{DC} of First Solar's modules, with delivery expected from 2017 into 2018. Strata expects to install the modules

in a series of solar projects in the southern and eastern USA.

With this agreement, Strata will have purchased more than 1000MW_{DC} from First Solar in a long-standing relationship between the two firms. "We are pleased to be extending our relationship with First Solar," says Strata Solar's CEO Markus Willem.

"This deal shows confidence in the continued strength of the utility-scale solar market in the US," says Georges Antoun, First Solar's

president, US. Antoun said the agreement demonstrates the sustainability of utility-scale project development. "We see ongoing opportunity for continued growth over the next several years," he adds.

Antoun noted that First Solar has now sold more than 1.8GW of modules in the USA Southeast, with modules either sold to outside developers, EPC contractors, or used in First Solar's own projects.

www.firstsolar.com

First Solar connects Luz del Norte to Chilean central grid

First Solar says that the first two blocks of its Luz del Norte solar project have been connected to the Chilean central grid. The interconnect includes about half of the project's total 141MW capacity.

The milestone is "proof of how utility-scale solar is a viable energy alternative for Chile right now," says First Solar's Chile country manager Cristian Sjogren. "Luz del Norte harnesses one of the region's richest resources, allowing Chile to reduce dependence on fossil-based fuels and meet renewable energy targets set by the national Energy Agenda," he adds. Sjogren pointed out that the project is also an example of how the global energy transition towards clean renewable energy alternatives is taking place in Latin America.

Construction of the Luz del Norte power plant, located 58km north of the city of Copiapó, began in August 2014 and is expected to enter full commercial operation by January 2016. At that time, it will be the largest solar plant in Latin America, generating enough electricity to meet the needs of more than 174,000 homes (avoiding over 185,000 metric tons of CO₂ emissions per year). As the developer and owner of Luz del Norte, First Solar is actively

seeking a permanent off-taker of power generated by the project, which is currently being sold on the open market.

"We are eager to work with other solar developers with projects in Chile," says Joe Kishkill, First Solar's president, International. "There is great opportunity to continue solar development at the scale of Luz del Norte."

Sjogren said First Solar's presence in Chile has expanded this year, with a permanent office in Santiago that includes over 30 employees supporting more than 1GW of regional solar development projects and partnership opportunities.

"First Solar is positioned to offer comprehensive PV energy solutions to meet the needs of our customers from high-efficiency modules and mounting solutions to turnkey utility solar solutions," says Sjogren. "Strong, mutually beneficial partnerships are critical to the continued growth of a reliable, sustainable solar energy market," he believes. "Projects like Luz del Norte represent only the beginning of what is to come of solar energy in this region."

Sjogren notes that First Solar has also worked to be an active member of the communities in which it is doing business. Last year,

the firm developed and funded a job training program in Copiapó intended to help young people obtain technical skills for careers in renewable energy. Also, following the storms and flooding that occurred last March in the Atacama region, First Solar's Luz del Norte team arranged for a US\$50,000 donation directed towards rebuilding damaged infrastructure and service in the region. Through Desafío Levantemos Chile, the donation was focused on providing assistance to the town of Diego de Almagro, one of the most heavily damaged communities.

Upon completion, Luz del Norte will generate power using 1.7 million of First Solar's high-energy-yield thin-film photovoltaic modules. The firm's PV modules have set the industry benchmark with over 10GW installed worldwide and have recently achieved a record energy conversion efficiency of 18.6% for thin-film modules (more efficient than the best multi-crystalline module). First Solar says that, with both a superior temperature coefficient and superior spectral response, its PV technology has been independently certified for reliable performance in high temperature, high humidity, extreme desert, and coastal environments.

First Solar and Austin Energy sign 119MW power purchase agreement for East Pecos Solar Project

First Solar has signed a power purchase agreement (PPA) with Austin Energy (the City of Austin's electric utility) allowing the municipally owned electricity provider to obtain low-cost solar power generated by First Solar's 119MW_{AC} East Pecos Solar Project.

Austin Energy's general manager Larry Weis said the partnership will directly benefit the citizens of Austin — as well as the entire state of Texas — as the utility takes a step towards meeting its solar development goals. "In committing to procuring 600MW of solar energy in the coming years, the City of Austin has once again taken a leadership role in Texas,"

Weis says.

"There is an irrefutable trend of solar becoming competitive in more geographies," says Georges Antoun, First Solar's president, US. "Texas, in particular, shows great promise as an attractive market for solar-generated electricity," he adds.

"The East Pecos Solar Project is proof of solar's real-world cost competitiveness." Antoun added that Texas' business-friendly environment, combined with the largest solar resource in the USA, makes it an excellent market for utility-scale solar.

With a robust pipeline of projects in Texas and across the US southeast,

First Solar reckons it is strategically positioned to bring its execution capabilities to capitalize on opportunities throughout the region where the firm's modules are competitively advantaged.

East Pecos, which First Solar owns and is developing in Pecos County, Texas, is expected to begin construction in early 2016, with commercial operations anticipated in late 2016. The project will create about 500 construction jobs. East Pecos will generate about 300,000,000 kilowatt-hours annually (enough to power 27,000 average homes in Austin Energy's service area).

www.austinenergy.com

MiaSolé inks sales rep deal with Whitehead & Associates

MiaSolé of Santa Clara, CA, USA (which was founded in 2004 and acquired by Beijing-based renewable energy firm Hanergy Holding Group Ltd in December 2012) has entered into a sales representative agreement for Whitehead & Associates Inc of Atlanta, GA, USA (which provides tailored power and energy services to the electrical industry) to sell its FLEX copper indium gallium diselenide (CIGS) thin-film photovoltaic (PV) solar photovoltaic modules in Georgia, Alabama, Florida, Tennessee, South Carolina and North Carolina.

Established in 1968, Whitehead & Associates says that it services cover the electric utility, commercial and industrial, large power users, and all lighting markets.

MiaSolé's FLEX modules are claimed to be the most efficient thin-film lightweight flexible modules on the market, with an efficiency rating of more than 16%. The FLEX-02 Series module is available in two formats. The FLEX-02W module is 39.3-inches x 102.3-inches and is rated at 360W, and designed for low-slope commercial single-ply roof systems. The FLEX-02N mod-



there are no penetrations, eliminating the worry of leakage and damage to contents of the building. The FLEX-02 also blends into both metal and

ule is 14.6-inches x 102.3-inches and is rated at 120W, and designed specifically for standing-seam metal roofs. Both bond to the roof surface with a simple peel-and-stick adhesive. This eliminates the need for racking and reduces labor and logistics cost to provide a 20% lower balance-of-system (BoS) cost than traditional glass solar systems, it is claimed. The FLEX-02 Series module is IEC 61646 & IEC 61730 and UL 1703 certified.

The low weight of the FLEX-02 module (<0.7lb/ft²) allows installation on roofs that cannot support the weight of traditional glass solar panels. Because the FLEX-02 panels adhere directly to the roof surface,

TPO roofs, preserving the original look of the roof, it is said. In addition, the low-profile module aids wind resistance and is claimed to provide an advantage over traditional rack-and-panel systems where their higher profile increases the likelihood of damage in a hurricane or earthquake.

"This high-performance solar roofing in such a lightweight form can serve a variety of markets including commercial, industrial, auto, and off-grid," notes Whitehead & Associates' president Scott Whitehead.

www.WhiteheadAssoc.com

www.hanergy.com

<http://miasole.com>

PLAT4M silicon photonics supply-chain project develops three mature platforms

Four-year European Union FP7 project reaches mid-point.

Micro/nanotechnology R&D center CEA-Leti of Grenoble, France and its partners say that they have built three silicon photonics platforms, as they reach the mid-point of the four-year European Union Seventh

Framework Program (EU FP7) project PLAT4M (Photonic Libraries And Technology for Manufacturing, launched in 2013), which aims to build a European-based supply chain in silicon photonics, speeding industrialization of the technology. Funded by a European Commission (EC) grant of €10.2m and based in Grenoble, PLAT4M includes 15 European R&D institutes and CMOS companies, key industrial and research organizations in design and packaging, as well as end-users in different application fields, in order to build the complete supply chain.

The consortium has developed advanced technologies and tools by building a coherent design flow, demonstrating manufacturability of elementary devices and process integration, and developing a packaging toolkit. The supply chain is based on technology platforms of Leti, Imec and STMicroelectronics, supported by a unified design environment. The high level of maturity of the technology offered by these platforms makes them readily accessible to a broad circle of users in a fabless model, it is said.

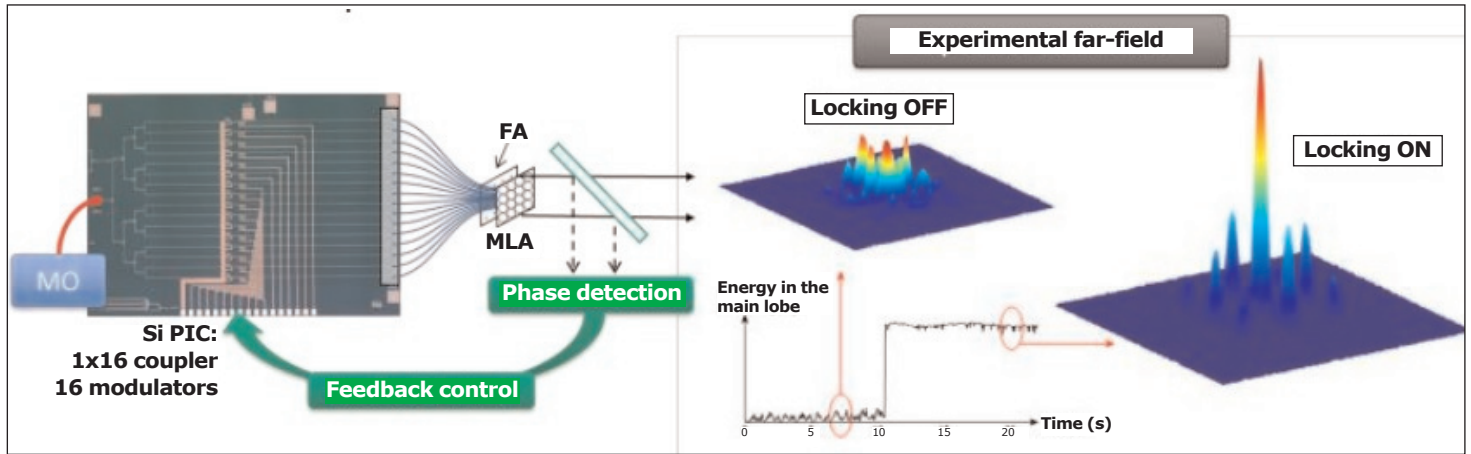
Imec's silicon photonics platform (based on 200mm substrates) has matured as a result of the PLAT4M project. The platform is based on silicon-on-insulator (SOI) substrates with 220nm crystalline silicon on a 2000nm buried oxide. During the project the existing fabrication processes and integration flow have been fine tuned to have stable and repeatable performance for all photonics building blocks (couplers, waveguides, phase shifters, photodetectors). This feeds the process design kit's robust performance specifications and guarantees quality and first-time-right designs for the platform's fabless users for high data-rate telecom and non-telecom applications, it is said. PLAT4M partners Thales, Polytec and TNO are already using the technology.

Beyond the 200mm platform, Imec has pushed the limits of silicon photonics, exploiting advanced optical lithography via its 193nm immersion lithography scanner. It has also demonstrated very low propagation

loss ($\sim 0.6\text{dB/cm}$) for fully etched waveguides, with excellent within-wafer linewidth control (standard deviation $< 3\text{nm}$ for 450nm-wide waveguides) and sub-100nm features. Deep sub-wavelength features can be made in a manufacturable process, avoiding the use of electron-beam lithography.

Using the Imec platform, Thales demonstrated a coherent combination of laser beams (CBC). Ultimately, this application aims to produce high-power, high-energy laser sources for sensing, industry or fundamental physics. The CBC rationale is to push the limits of single laser emitters (typically fiber amplifiers) by using a large number of amplifiers and coherently adding the output beams. The coherent addition requires locking the phase of all the amplifying channels. With the number of channels (potentially very large, from tens to thousands), an integrated technology is a major concern in terms of possible industrial products. The first-generation CBC demonstrator of PLAT4M, which was packaged by Tyndall UCC (University College Cork) in Ireland, included a 1-to-16 channel splitter tree, plus 16 independent thermal phase modulators. The CBC experiment has demonstrated the successful coherent addition of 16 laser beams at $1.55\mu\text{m}$.

Leti has developed a new photonic platform based on 200mm SOI wafers. This process offers multi-level silicon patterning that allows the design of various passive and active devices (e.g. a modulator and a photodiode) with thermal tuning capability. Two AlCu metal levels are available for routing. A process design kit (PDK) is available for circuit design and a multi-project wafer (MPW) service will be proposed in 2016. State-of-the-art performance has been demonstrated: insertion losses are below 2dB/cm for a mono-mode waveguide and below 0.2dB/cm for multimode devices. Germanium photodiode responsivity is $> 0.75\text{A/W}$ for a bandwidth $> 30\text{GHz}$. The Mach-Zehnder modulator $V_p L_p$ product is in the 2V.cm range for 2V operation with an E/O bandwidth of $> 25\text{GHz}$. Moreover, Leti and III-V Lab have developed integrated hybrid III-V lasers and electro-absorption modulators (EAMs) on silicon using a wafer-bonding technique. The hybrid lasers operate in the single-mode regime and the EAMs exhibit an extinction ratio higher than



(Left) Schematic of the CBC experiment layout with the PIC. MO: master oscillator; FA: fiber array; MLA: microlens array. **(Right)** Experimental measurement of the output combined beams in the far field, in closed loop and open-loop configurations. The plot shows the evolution in time of the energy encircled in the main central lobe.

20dB with a drive voltage lower than 2V. A clear eye-diagram has been achieved at a bit-rate of 25Gb/s, confirming the strong potential for telecom applications.

During the project, ST developed an additional silicon-photonics platform in 300nm technology to be used as an R&D tool for proof-of-concept purposes. Designed for evaluating new devices and subsystems for demonstration, DAPHNE (Datacom Advanced PHotonic Nanoscale Environment) is a flexible platform that fits R&D needs. While developing it, ST demonstrated wavelength division multiplexing (WDM) solutions using arrayed waveguide gratings (AWGs), echelle gratings, cascaded Mach-Zehnder interferometers and a side-coupled integrated spaced sequence of resonators. Some of the configurations are designed for the 100GBase-LR4 standard, and the experimental characterization results show insertion losses below 0.5dB and channel cross-talk above 25dB for a band flatness of 2nm. Furthermore, proper operation of receiver-and-transmitter blocks to be interfaced to optical devices above them has been demonstrated at 28Gbps, making use of 65nm-node technologies.

The PLAT4M WP2 work has led to a qualitative leap in the design flow for silicon photonics, allowing the photonics community to design more complex and more robust circuits. The electronics OpenAccess standard for data sharing between design-automation tools includes an extension for silicon photonics in a beta phase today. Simulation capabilities were leveraged thanks to an extensive characterization effort from the three partner fabs and the statistical data gathered for variability prediction. Paris-Sud University has studied theoretically the behavior of different phase shifters and photodetectors for time-efficient and precise modeling. The partners Mentor Graphics and Phoenix Software have improved phase-aware routing and tool interoperability. Verification and manufacturability have reached industry-requirement standards due to the development of new techniques based on the Mentor Graphics Calibre platform that delivers layout-versus-schematic comparison (Calibre nmLVS), photonic rule checks (PRC) and curvilinear-aware design-rule checks (Calibre nmDRC). Mask preparation is also improving, with better pattern-density control and mask correction.

www.leti.fr

PLAT4M consortium members

Coordinated by Leti, the PLAT4M consortium consists of technology providers, research institutes, end-users and small- and medium-size enterprises (SMEs) with track records in photonics technologies. At the design and process level, Leti and Imec have been the most prominent European players in silicon photonics for a decade. Together with University of Paris-Sud, III-V Lab and TNO, they have

demonstrated many scientific and technological breakthroughs. For building a complete design flow, electronic design automation (EDA) tool suppliers Mentor Graphics, Phoenix BV and Si2 have worked together to develop a common reference platform.

STMicroelectronics (of France and Italy) has been engaged for the past year in developing silicon photonics at the industrial level.

Tyndall-UCC and Aifotec are experts in opto-electronic packaging and work together on the implementation of packaging technologies developed within PLAT4M in a manufacturing environment.

End-users like Polytec and Thales Research & Technology are driving the demonstrators' development and assess the use of silicon photonics in their applications fields.

<http://plat4m-fp7.eu>

Slanted trench approach to side-mode suppression in Fabry–Perot laser diodes

A cost-effective solution shows promise as a replacement for conventional distributed feedback, according to researchers.

Researchers based in China and Canada have developed single-mode ridge waveguide Fabry–Perot (RW FP) laser diodes using a pair of etched trenches that are slanted to reflect out unwanted wavelengths [Xun Li et al, *Appl. Phys. Lett.*, vol107, p091108, 2015]. Side-mode suppression ratios (SMSRs) up to 35dB were achieved.

The team from Huazhong University of Science and Technology in China, McMaster University in Canada, and Shandong University in China comment: “As a cost-effective solution, this device is promising as a replacement for conventional distributed feedback laser diodes in specific applications where single-mode operation is indispensable but precise control of the lasing wavelength and/or very high SMSR (e.g. >40dB) are not required.”

Standard FP laser diodes can be mass produced, but suffer from multi-mode operation. This creates noise problems in high-speed moderate-span passive optical networks. Cleaning up the emission spectrum with distributed feedback techniques suffers from low manufacturing yields, increasing cost.

The etched-trenches create a coupled cavity that acts as an extra band-pass filter (BPF), while the slanting

ensures that other modes do not compete with the selected mode inside the laser cavity.

The researchers fabricated 1310nm ridge-waveguide Fabry–Perot lasers using strained-layer indium aluminium gallium arsenide/indium phosphide (InAlGaAs/InP) multiple quantum well material. Based on simulations, a pair of deep trenches were etched into the structure (Figure 1). The optimum trench design was for 1.1 μm width with 10 μm separation at 4° slant. The researchers found that varying the trench parameters allowed them to lock into one of the many FP modes so that precise control of this aspect of the fabrication was not required.

The FP cavity length was 250 μm . The devices were packaged in standard transistor outline packages without cooling.

In theory, the trenches should be as deep as possible to suppress side-modes, but the researchers were concerned about reliability issues and limited the depth to the etch-stop layer used for the ridge etching. The researchers add: “As such, the crossing trenches can be formed in the same step as the ridge waveguide itself, so that no extra burden is introduced to the conventional RW FP laser fabrication process other

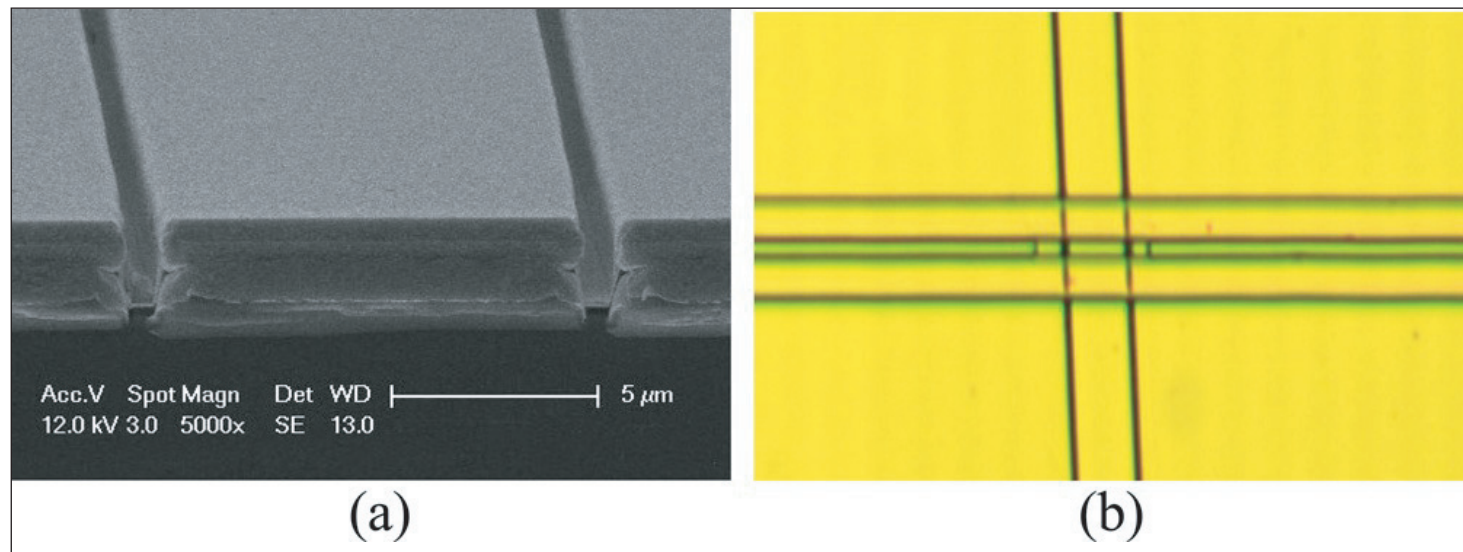


Figure 1. (a) Cross-sectional and (b) top views of trenches in fabricated device.

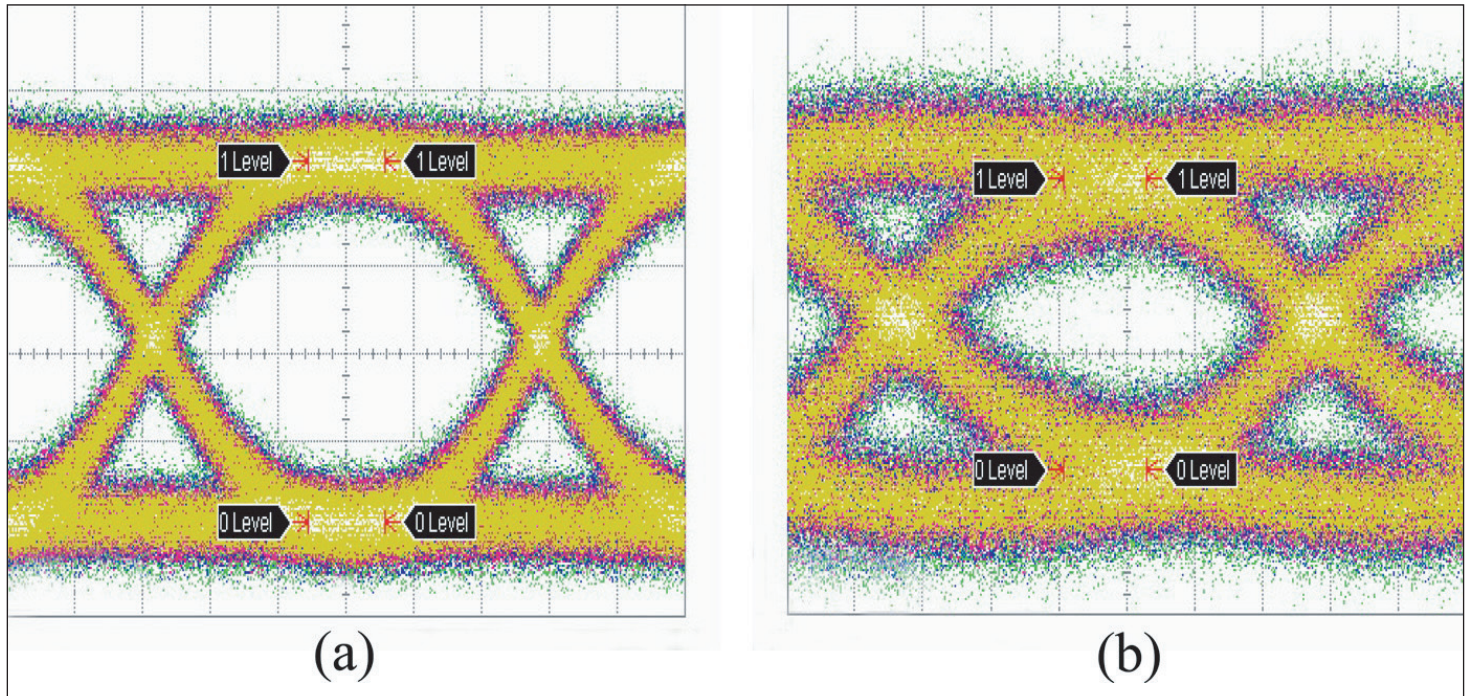


Figure 2. Measured eye-diagrams after 50km standard single-mode fiber transmission at modulation speeds of (a) 2.5Gbps and (b) 6.25Gbps.

than the replacement of the mask pattern in the standard photolithography process.”

The 12–13 μ m region around the trenches was not metalized so that the band-pass filter region was passive. This was to avoid the laser wavelength and side-mode suppression ratio being affected by conditions such as the bias current.

In testing, the devices were directly modulated at 2.5 and 6.25Gbps with a 231 pseudo-binary sequence. The modulated laser light was sent down 50km of standard single-mode fiber (Figure 2). With a 10Gbps signal, the researchers claim that the reception demonstrated “clear eye opening” even after 10km travel.

The researchers report that aging tests at 100°C and 100mA current have reached 3000 hours, showing no appreciable degradation.

The yield for devices with side-mode suppression ratio greater than 20dB exceeded 55%. For 30dB SMSR, the yield was better than 30%. Single-mode lasers based on distributed feedback usually have yields less than 30% for 30dB SMSR.

The researchers comment: “When the reliability issue related to Al oxidization is eliminated by advanced processing technologies, or by using Al-free (InGaAsP/InP) SL-MQW laser diodes, the trenches can then be etched further through the active region, and our simulations show that the yield can be increased further to more than 70%.”

The threshold current was around 12mA and the slope efficiency was 0.2mW/A from a single facet. ■

<http://dx.doi.org/10.1063/1.4930027>

Author: Mike Cooke

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Tunnel junction for vertical-cavity surface-emitting laser

New structure reduces threshold current by 56% and increases differential efficiency by 324% compared with indium tin oxide intracavity contact.

University of California Santa Barbara (UCSB) has developed an n-type gallium nitride (n-GaN) tunnel junction (TJ) intracavity contact to reduce threshold current and increase differential efficiency in its m-plane III-nitride vertical-cavity surface-emitting laser (VCSEL) design [J. T. Leonard et al, Appl. Phys. Lett., vol107, p091105, 2015].

VCSELs can be fabricated in two-dimensional arrays and can emit highly directional high-power radiation. Potential applications for III-nitride VCSELs include atomic clocks, gyroscopes, magnetometers, and visible light communication.

The VCSEL structure produced by metal-organic chemical vapor deposition (MOCVD) on m-plane free-standing GaN substrates was similar to previous UCSB work, although the number of quantum wells was reduced from ten to seven [www.semiconductor-today.com/news_items/2015/jul/ucsb_290715.shtml]. The device was mounted on a copper block with titanium/gold coating.

The ~141nm n-GaN TJ intracavity contact was produced by ammonia molecular beam epitaxy (MBE). At present MOCVD TJs have high resistance. The advantage of MBE is lower hydrogen levels during growth, compared with MOCVD. Hydrogen passivates MOCVD p-GaN layers reducing carrier concentrations.

Before growth of the TJ, the p-GaN of the MOCVD epi-

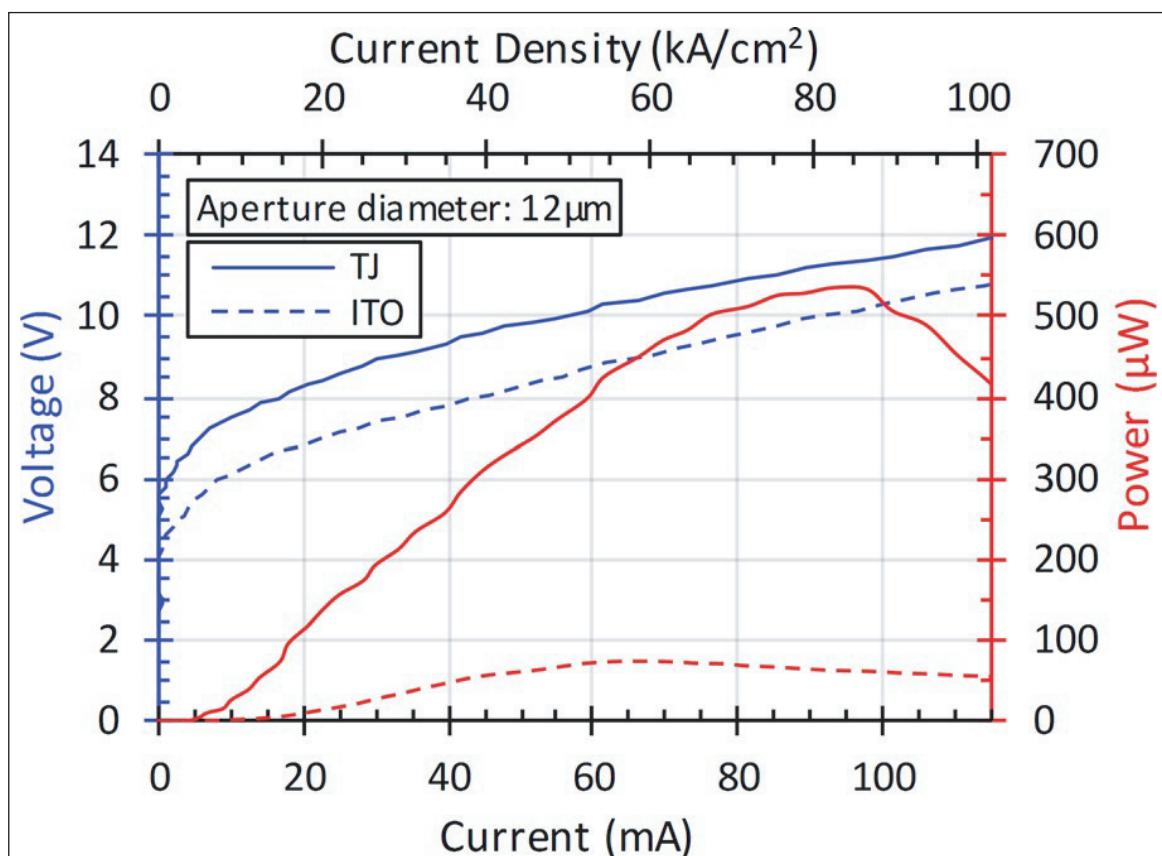


Figure 1. Voltage, light output power versus current characteristics of TJ VCSEL and ITO VCSEL measured under pulsed operation (0.3% duty cycle, 100ns pulse width).

taxial structure was activated, followed by mesa etch and aluminium ion implant to create the aperture. The junction itself consisted of four alternate layers of heavily doped and normally doped n-GaN with thicknesses of 39.6nm except for one of the normally doped layers being 22.1nm. The structure was designed to reduce free-carrier absorption by aligning the heavily doped layers with nodes of the radiation field.

A comparison device used an indium tin oxide (ITO) transparent contact with an $\frac{1}{4}$ th-wave tantalum pentoxide (Ta_2O_5) spacer. The purpose of the spacer was to position the node of the radiation field in the ITO to reduce absorption.

The distributed Bragg reflectors (DBRs) on the n- and p-sides consisted of layers of tantalum pentoxide and silicon dioxide.

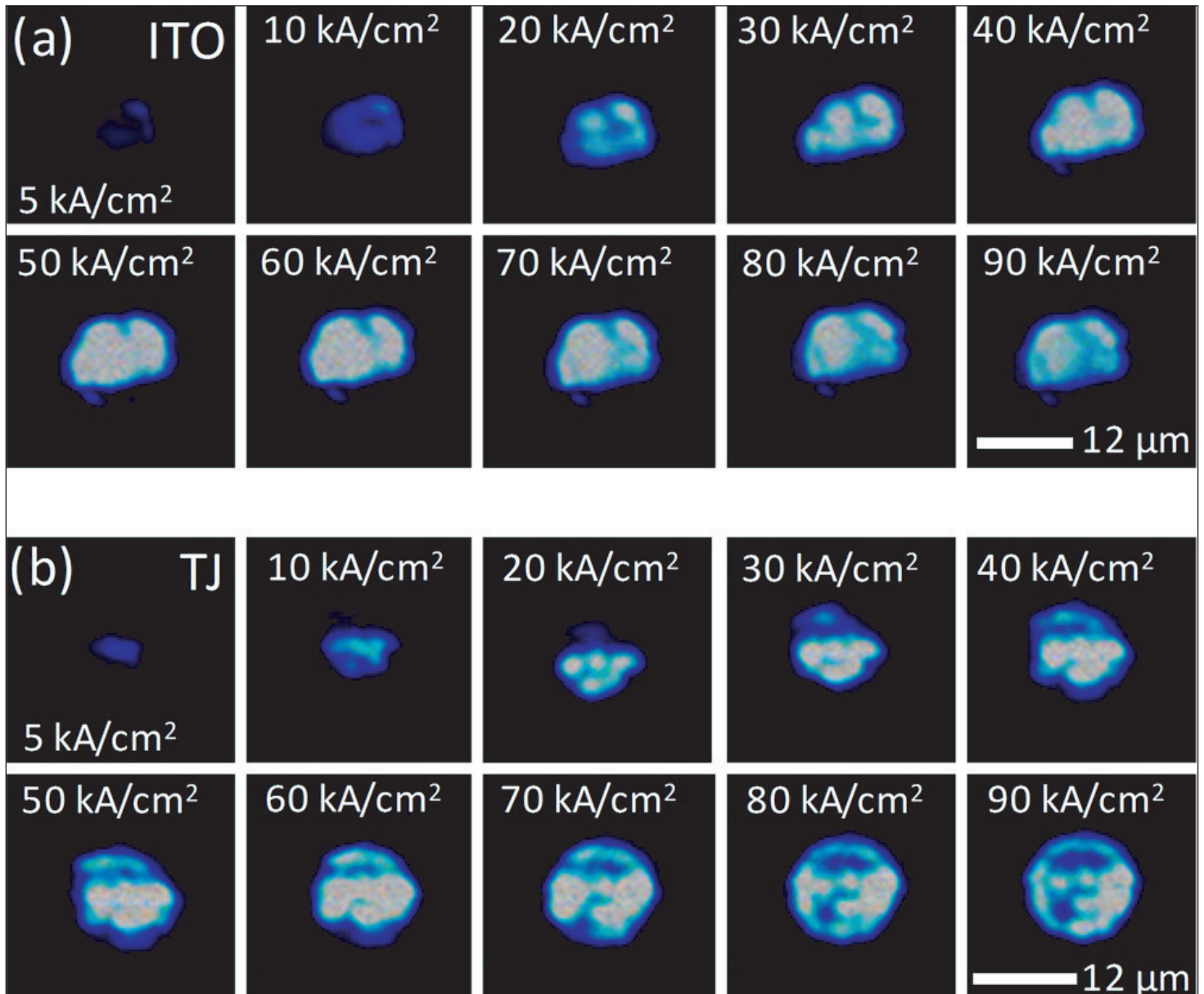


Figure 2. Optical microscope images taken under low gain to prevent detector saturation: (a) shows ITO VCSEL, while (b) shows TJ VCSEL operating at various current densities. Both cases exhibit filamentary lasing in aperture. Non-circular emission pattern in ITO case is result of partial over-etching during top-down photo-electro-chemical etch.

The threshold current of the TJ VCSEL was much reduced – 3.5kA/cm^2 (4mA), compared with 8kA/cm^2 (9mA) for the ITO structure (Figure 1).

The researchers report: “Both devices were designed to lase at 405nm; however, a Ta_2O_5 spacer was accidentally deposited on the n-side of the devices, which shifted the cavity resonance wavelength to 410nm and 417nm for the ITO and TJ VCSEL, respectively. It is of note that this may have also led to a misalignment of the peak gain and the cavity resonance wavelengths, which can lead to an increase in the threshold current density.”

The differential efficiency increased to 0.262% from 0.062% for the TJ and ITO VCSELs, respectively. The researchers suspected filamentary lasing, since these values are much lower than simulations predicted.

Indeed, this was confirmed by microscopic inspection of the near field (Figure 2). With filamentation, large areas of the material do not contribute to lasing, reducing efficiency.

The researchers comment: “We suggest that filamentary lasing may be predominantly related to variations in contact resistance and non-uniform current spreading, both of which may then create local variations in the refractive index and free-carrier absorption.”

One drawback in the use of a TJ contact was an increase in the forward voltage by about 1.5V over that of the ITO device. The researchers believe an improved surface treatment before the MBE re-growth could reduce this forward voltage penalty by 0.5–1.0V. ■

<http://dx.doi.org/10.1063/1.4929944>

Author: Mike Cooke

Alternating current LEDs on silicon substrates

Nanowire tunnel junction connections also enable phosphor-free white light devices, reports McGill University.

Canada's McGill University has claimed the first demonstration of alternating current (AC) III-nitride nanowire light-emitting diodes (LEDs) on silicon enabled by tunnel junctions [S. M. Sadaf et al, Nano Letters published online, 18 September 2015]. The tunnel junction connections also allow stacking of

active regions of different wavelength to give white light emission without phosphors.

The researchers comment: "In general, stacking multiple quantum wells/dots in planar structures is not a suitable route to realize low-current, high-voltage operation since it also significantly increases the

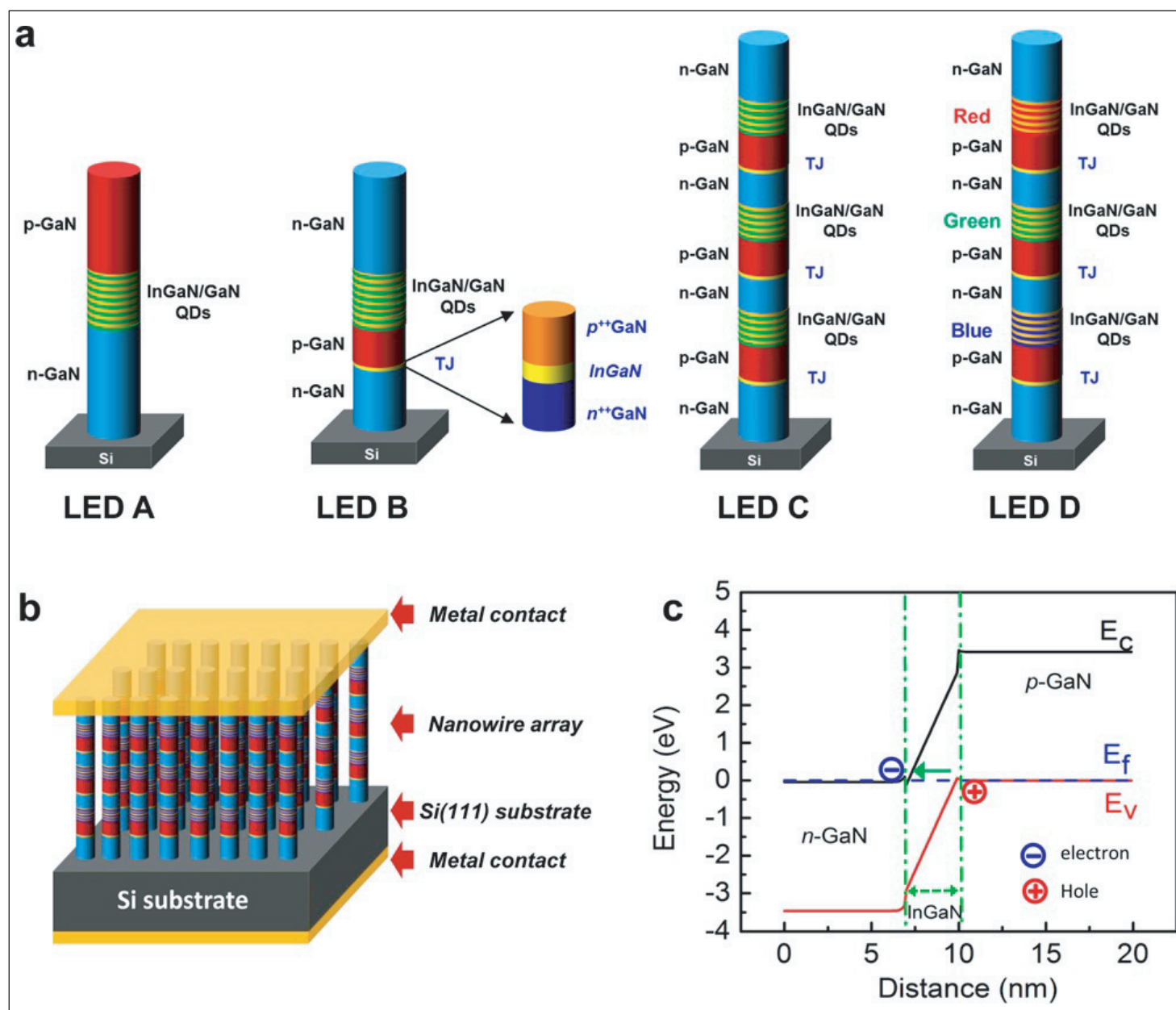


Figure 1. (a) Schematic of dot-in-a-wire LEDs, showing structures of LEDs A, B, C and D. (b) Schematic of fabricated large-area nanowire LEDs. (c) Simulated energy band diagram of GaN/InGaN/GaN tunnel junction showing carrier regeneration and injection process under reverse bias.

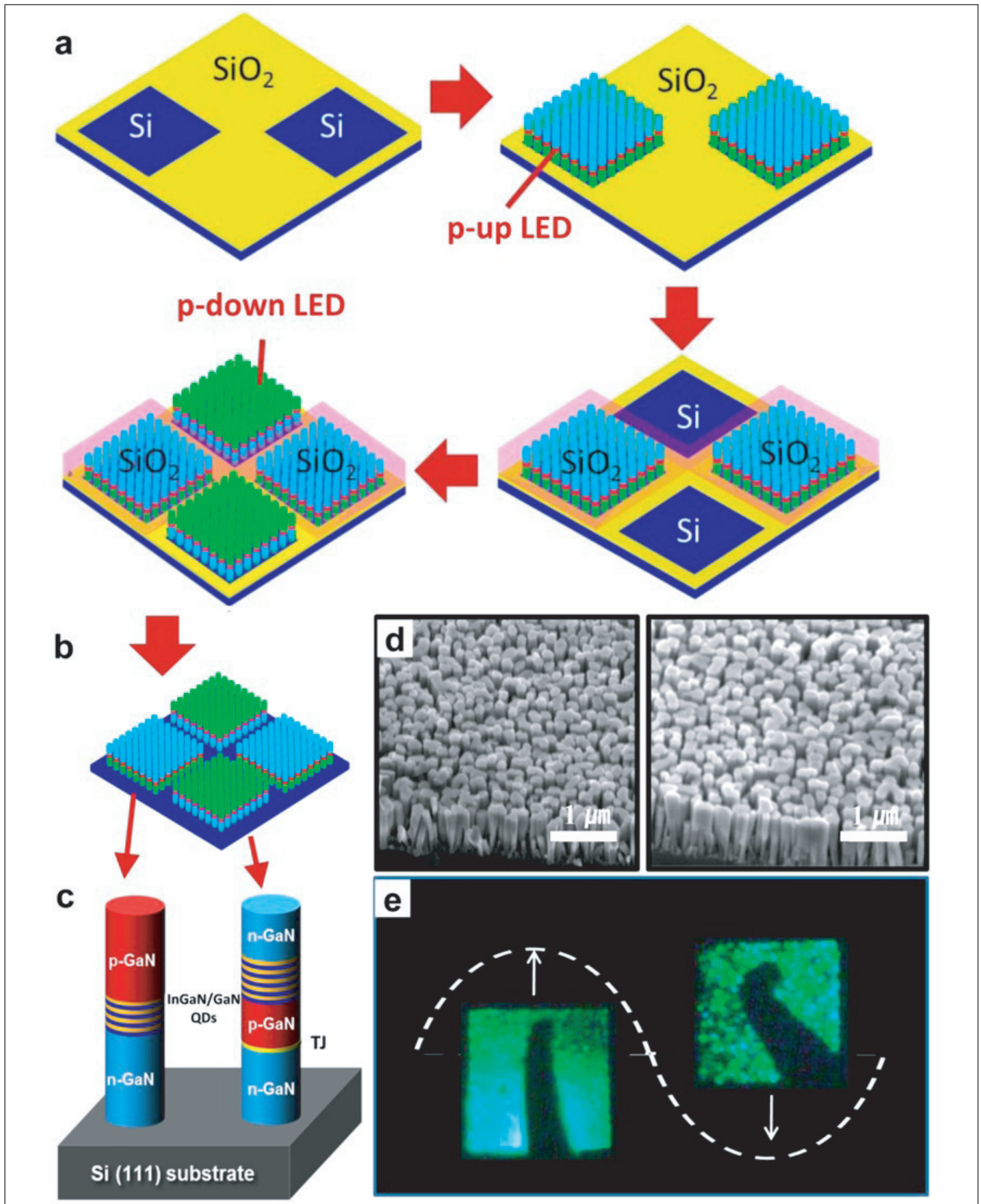


Figure 2. (a) Two-step selective-area growth of p-GaN up and p-GaN down AC nanowire LEDs on silicon substrate. (b, c) Device schematics. (d) Scanning electron micrographs (45° tilted) of as-grown p-GaN up and p-GaN down nanowire LED structures. (e) Optical image of green-light-emitting nanowire LED arrays on silicon under AC biasing conditions.

densities of defects and dislocations. Such issues can be fundamentally addressed in tunnel junction nanowire LED structures, as demonstrated in this work.”

The N-polar nanowires (Figure 1) were grown on n-type (111) silicon using radio frequency plasma-assisted molecular beam epitaxy (PAMBE). The active regions consisted of indium gallium nitride (InGaN) self-organized quantum dots (QDs) in GaN. The self-organization was strain-induced. The dot height was ~3nm. The QD layers were capped with 3nm of GaN.

The growth conditions were nitrogen-rich. Before III-nitride growth, native oxide on the substrate was desorbed by heating to 770°C. Silicon-doped n-GaN regions were grown at 750°C. The InGaN QDs were created at ~650°C to increase indium incorporation.

The tunnel junctions were also grown at 650°C. These consisted of 12nm of silicon-doped n-GaN, 3nm $\text{In}_{0.3}\text{Ga}_{0.7}\text{N}$, and 20nm of magnesium-doped p-GaN. The researchers optimized the indium concentrations and layer thickness to achieve maximum tunneling.

“The use of tunnel junction increases the concentration of holes in the p-GaN, thereby minimizing the restriction of low hole injection efficiency in wide-bandgap nitride materials,” the researchers explain.

Devices with a single active region (SAR) contained 10 layers of QDs. Multiple active region (3x, MAR) contained 5 layers of QD per active region. The MAR devices could include red, green and blue emitting regions to give phosphor-free white light.

LEDs were fabricated by covering the wires with spin-coated polyimide resist, which was etched back by oxygen plasma to expose the tops of the wires. The p- and n-metal contacts consisted of nickel/gold and titanium/gold, respectively. The respective contacts were made to the top of the nanowires and silicon substrate back-side. The metal contacts for the devices were annealed at 500°C for 1 minute in nitrogen.

The LEDs also included 150nm of indium tin oxide (ITO) as a transparent conducting electrode for current spreading. The indium tin oxide was annealed at 300°C for 1 hour in vacuum.

The turn-on voltages for the single-color LEDs A–C were in order 5.5V, 4.9V and 16V. The relatively high turn-on voltages were attributed to height variations of the nanowires and the formation of silicon nitride insulation at the nanowire–silicon interface.

Further optimization of growth and fabrication to make the nanowire height more uniform will lead to more even light emission. Also, higher-frequency operation reduces flicker. At a frequency of 60Hz, these devices are almost flicker free and are suited for practical applications

The researchers comment: “Compared to LED A, LED B shows reduced turn-on voltage, due to the efficient hole injection with the incorporation of tunnel junction and lower contact resistance for n-GaN.”

LED B with tunnel junction also showed increased light intensity compared with the reference LED A without tunnel junction. The researchers attribute this to carrier regeneration in the tunnel junction giving multiple opportunities for radiative recombination. The electroluminescence peak was in the green region.

The peak external quantum efficiency occurred at around 50mA for all devices. The researchers comment: “The intriguing part of the result is that, for LED C, the current corresponding to the maximum efficiency point is almost identical to LED A and LED B, suggesting that MAR tunnel junction LED C can be operated at a higher output power while maintaining the same level of efficiency loss of the conventional LEDs.”

Thus, efficiency droop occurred at higher input power for the MAR device. At 350mA injection current the output power was a few milliwatts. The researchers suggest that adding a wide-bandgap aluminium gallium nitride (AlGaIn) shell to the nanowires could enhance the output power drastically. Such shells are thought to minimize non-radiative surface recombination and increase carrier injection into the active regions.

Temperature-dependent measurements between 80K and 300K (room temperature) on LED C with three active regions showed no significant change in current versus voltage behavior.

LED D with three different wavelength active regions emitted three different colors centered at wavelengths of 445nm, 570nm and 625nm. The color temperature was ~3000K with Commission Internationale de l'éclairage (CIE) chromaticity (x, y) coordinates of (0.47, 0.49) nearly constant over the range 20–250mA.

The researchers also claim the first AC LEDs with p-GaN up and p-GaN down nanowires on the same silicon substrate (Figure 2). This was achieved through selective-area growth with silicon dioxide masking that was removed with a buffered oxide etch. The device thus emitted green light from different areas with positive and negative polarity.

The performance was tested with AC frequencies between 20Hz and 60Hz and peak-to-peak voltage of 10V.

The researchers believe further optimization of growth and fabrication to make the nanowire height more uniform will lead to more even light emission. Also, higher-frequency operation reduces flicker. The researchers comment: “At a frequency of 60Hz, these devices are almost flicker free and are suited for practical applications.” ■

<http://pubs.acs.org/doi/abs/10.1021/acs.nanolett.5b02515>

Author: Mike Cooke



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Polarized white LED without phosphor conversion

Potential applications include lower-power-consumption back-lighting for liquid-crystal displays.

University of California, Santa Barbara (UCSB) researchers have developed polarized white light-emitting diodes (LEDs) that do not use phosphors [S. J. Kowsz et al, Appl. Phys. Lett., vol107, p101104, 2015].

Such devices could lead to less power consumption in liquid-crystal displays (LCDs), which depend on polarized light for their operation. Presently, unpolarized light from white LED back-lighting is put through a polarizing sheet to give the polarized light for phase shifting by the liquid crystal. The polarization cuts the light power by at least half. Even if the light was only partially polarized, the loss from transmission through a polarizer could be reduced.

White LEDs are commercially produced using c-plane (0001) III-nitride epitaxial growth, giving unpolarized devices. Growth of the crystal structure in other orientations gives light emission that is partially polarized.

Although indium gallium nitride (InGaN) should theoretically give light emission across the visible spectrum, present commercial technology is limited to wavelengths shorter than green (495–570nm). White LEDs generally use a narrow blue emission in combination with phosphors that convert some of the blue photons (e.g. 435–455nm) into a broad range centered on yellow wavelengths (e.g. 500–650nm).

Instead of phosphors, the UCSB device uses a multiple quantum well (MQW) to convert some blue

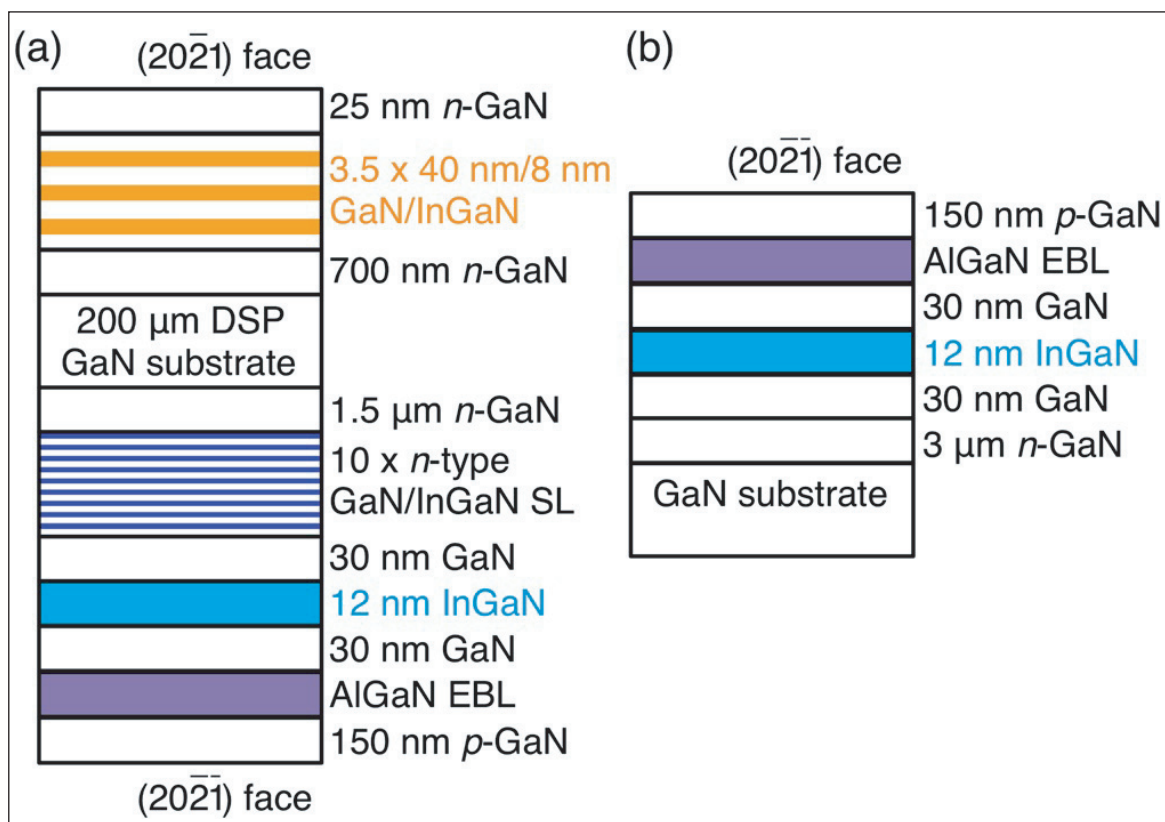


Figure 1. Schematic cross-section of epitaxial structure of (a) double-sided, electrically injected and optically pumped semi-polar device and (b) standard electrically injected semi-polar blue LED.

photons into longer wavelengths by photoluminescence/optical pumping. Such structures have been explored by a number of research groups using c-plane III-nitrides, but these naturally lead to unpolarized light.

The UCSB metal-organic chemical vapor deposition (MOCVD) epitaxial structure (Figure 1) was grown on semi-polar (202̄1)/(202̄1) free-standing GaN from Mitsubishi Chemical Corp. The 7.5mmx7.5mm substrate was polished on each side. The 12nm single quantum well InGaN LED was grown first on the (202̄1) side. The conversion structure with three quantum wells was grown on the (202̄1) side.

The MQW structure on the (202̄1) side was grown at low temperature to enable high indium content incorporation. The final GaN cap layers were grown at the same temperature to avoid decomposition of the

underlying InGaN. If such MQWs were grown in an LED structure, the final p-contact layers would need to be grown at higher temperature to give sufficient p-type conductivity to inject holes, resulting in quality degradation of the InGaN wells.

The contact for the p-GaN consisted of palladium/silver/nickel/gold. The n-contact was a soldered indium dot. The n-type GaN/InGaN superlattice (SL) was designed to assist lateral conduction from the n-contact.

The device produced a narrow peak from the LED section with peak wavelength at 440nm (Figure 2). The conversion section produced a broader spectrum with a maximum at 560nm. The conversion peak is narrower than usually produced with phosphor conversion, but the researchers believe that the MQW structure could include wells with longer wavelength emission to achieve a comparable spectrum.

The color balance across the device was not uniform with emission near the contact (A) being more blue than that further away. The 1931 Commission Internationale de l'Eclairage (CIE) x, y chromaticity co-ordinates were, in order A-E, (0.16, 0.03), (0.24, 0.21), (0.28, 0.29), (0.30, 0.33), and (0.33, 0.39). The C position gave emission close to Planck black-body color content for 9859K.

The researchers report: "Ongoing work is focused on increasing the intensity of the long-wavelength emission from the optically pumped QWs relative to the blue emission from the LED in order to achieve uniform white light emission. The color uniformity can be improved by increasing the yellow light emission from the optically pumped QWs and/or reducing the amount of blue light that is extracted."

For light collected at point C, the researchers found a

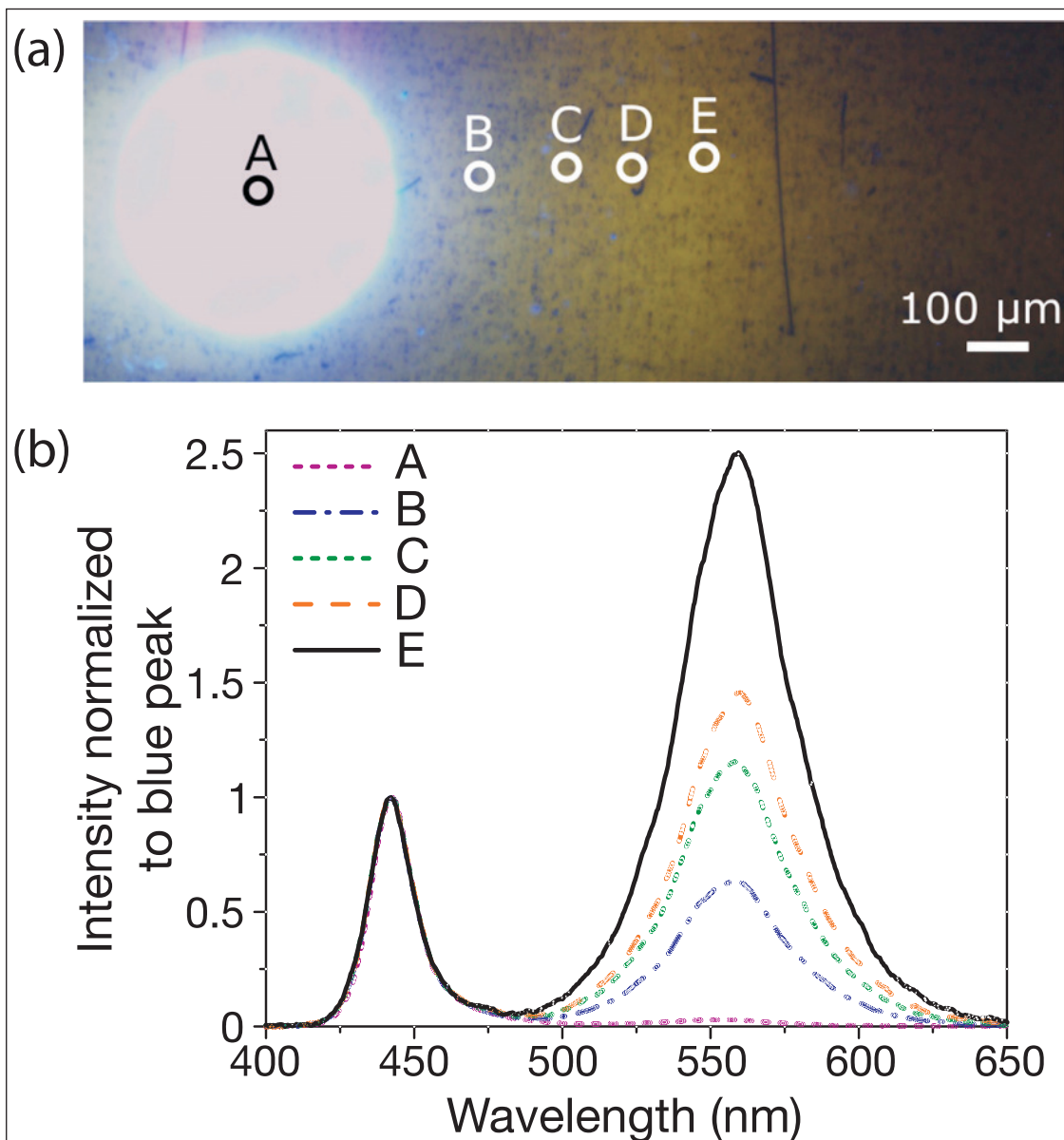


Figure 2. (a) Optical micrograph of electrically injected device based on epitaxial structure in Figure 1 (a), indicating measurement locations. (b) Electroluminescence spectra at different locations normalized to corresponding blue emission peak.

polarization ratio of 0.4, comparing light polarized along $[1\bar{2}10]$ and $[\bar{1}014]$. Spectral analysis found that the polarization ratio of the blue radiation was 0.6. The ratio for the optically pumped layers was 0.33.

Previous research has found higher optical polarization in devices grown on $(20\bar{2}1)$ substrates, compared with $(20\bar{2}1)$. The $(20\bar{2}1)$ polarization also increases with indium content, while the polarization of $(20\bar{2}1)$ wells remains relatively constant. The reason for such behavior is unknown.

Improving the extraction efficiency may not be straightforward, since the common technique of surface roughening would tend to reduce polarization. The researchers suggest that photonic crystals could be a way to tackle this problem. ■

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Author: Mike Cooke

Strategies to avoid efficiency drooping in white light-emitting diodes

Mike Cooke reports on attempts to find ways around current and thermal impacts on indium gallium nitride device performance.

Indium gallium nitride (InGaN) light-emitting diodes (LEDs) are at the core of recent solid-state white illumination efforts, targeting high efficiency and long lifetime. High upfront costs and poor color rendering inhibit consumer take up, hampering national and international drives to higher-efficiency lighting.

Costs are increased by effects such as droop, where the output efficiency is reduced as the current and temperature increase beyond some optimum. Avoiding current droop requires a larger number of LEDs to be assembled into a package so the current through single devices is near optimum. Thermal management techniques are required to tackle temperature droop.

Here we look at recent proposals and possible routes to improve efficiency (and color) by applying novel structures.

Blue/cyan wells

Xi'an Jiaotong University and Shaanxi Supernova Lighting Technology Co Ltd in China have reported reduced droop and improved color rendering in white light-emitting diodes that use a multiple quantum well (MQW) structure with 440nm blue and 460nm cyan wells [Yukun Zhao et al, J. Appl. Phys., vol118, p145702, 2015].

The combination of blue and cyan, along with a suitable phosphor, improved the color rendering index (CRI) to 77.0, compared with 66.4 for a pure blue device. The cyan/blue device was therefore much closer to the 80 CRI US Energy Star specification for indoor white light.

The deeper cyan wells are also thought to ameliorate problems associated with low hole carrier concentrations across an MQW structure caused by low mobility compared with electron carriers. Precision measurements of light emission from InGaN MQWs under current

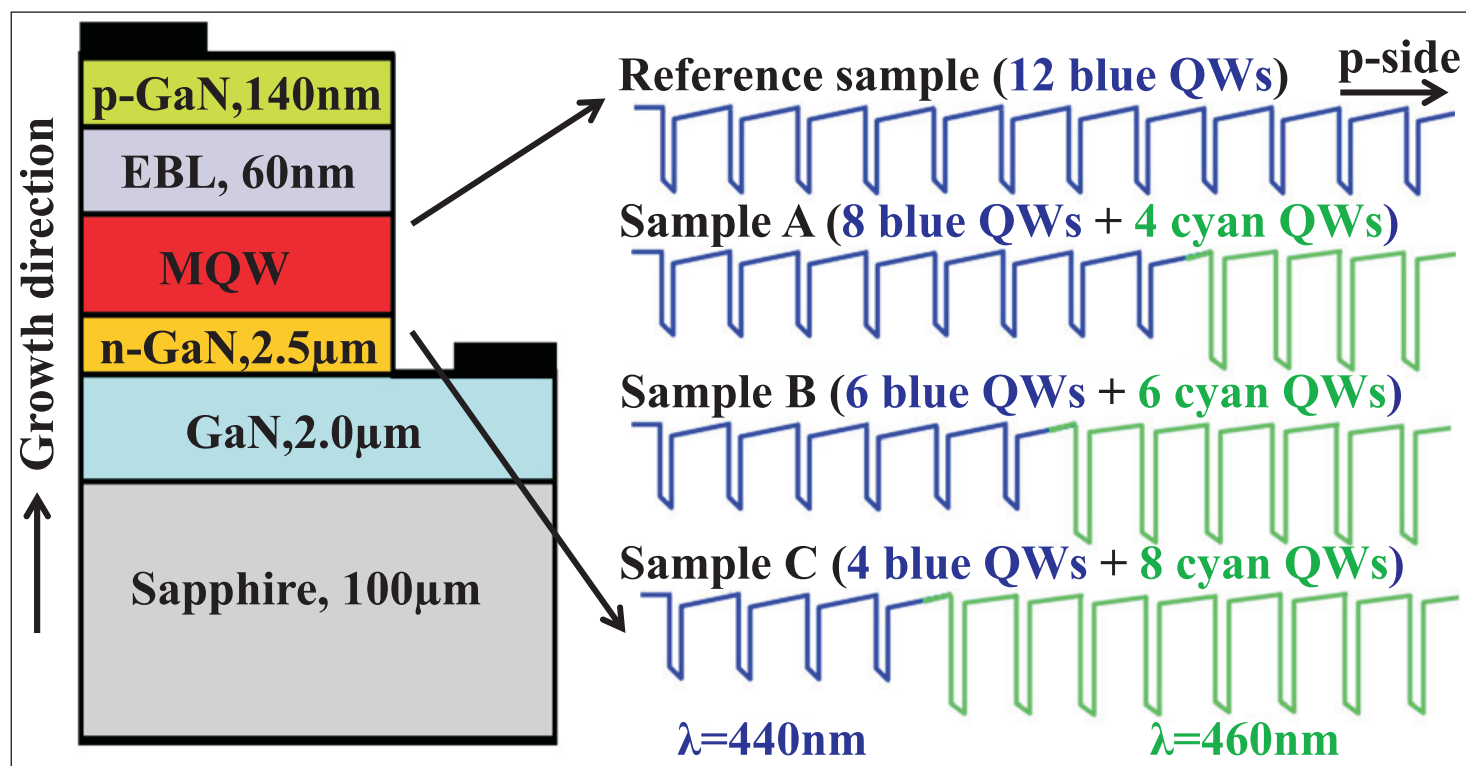


Figure 1. Schematics for LEDs with conventional uniform and dual-wavelength MQW structures.

injection often show that significant levels of radiation come from just the wells next to the p-contact layers.

In the Xi'an Jiaotong/Shaanxi Supernova LEDs, the cyan wells are believed to form a reservoir for holes that can be injected into the blue wells lower down in the device structure

(Figure 1). The epitaxial samples were prepared through metal-organic chemical vapor deposition (MOCVD) on sapphire. The active region contained 12x 3nm wells and 12nm GaN barriers. The electron-blocking layer (EBL) consisted of aluminium gallium nitride (AlGaN).

Various combinations of cyan ($\text{In}_{0.18}\text{Ga}_{0.82}\text{N}$) and blue ($\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$) were produced. The higher indium content of the cyan wells was achieved by reducing the growth temperature to encourage greater indium incorporation.

LED chips were fabricated with an indium tin oxide (ITO) current-spreading layer and dimensions of $250\mu\text{m} \times 580\mu\text{m}$. For white light, the chips were encapsulated in oxynitride phosphor (ZYP570N, www.beijingyuji.com/EN-led-Oxynitride-Yellow-Phosphor/239.html).

Simulations suggested that the configuration of 6 cyan and 6 blue wells (Sample B) should have the best combination of increased electron and hole concentrations across the MQW assembly. Further, the reservoir effect of the cyan wells enables stronger injection of holes into the blue region of the MQW.

Sample B also had a higher EBL electron barrier, inhibiting overspill of electrons into the p-GaN contact. At the same time, the EBL had a lower barrier to hole injection.

Table 1. Experimental results of IQE and droop ratios at $80\text{A}/\text{cm}^2$.

Peak intensity ratio	IQE ($80\text{A}/\text{cm}^2$)	IQE (max)	Q ($80\text{A}/\text{cm}^2$)
Reference sample	37.8%	76.0%	50.3%
Sample A	42.2%	75.2%	43.9%
Sample B	48.3%	79.8%	39.5%
Sample C	38.0%	85.5%	55.6%

Although LED sample C had the highest peak internal quantum efficiency (IQE), the highest efficiency at $80\text{A}/\text{cm}^2$ current density was achieved by LED B (Table 1), corresponding to the lowest droop ratio (Q). The poor performance of sample C LEDs at high current was probably due to increased threading dislocation densities, as suggested by x-ray analysis.

Sample B also produced the best CRI in encapsulated devices (Table 2, Figure 2). The correlated color temperature (CCT) was also close to pure white (5500K). The better color performance of sample B devices is attributed to greater intensity of the longer 460nm wavelength giving a CRI enhancement.

III-nitride laser

Weng Chow and Mary Crawford of Sandia National Laboratories in the USA have been theoretically analyzing potential advantages and pitfalls in using lasers rather than LEDs as sources for white-light systems [W. W. Chow and M. H. Crawford, *Appl. Phys. Lett.*, vol107, p141107, 2015].

Table 2. Color rendering and temperature at $80\text{A}/\text{cm}^2$.

Sample	Reference	A	B	C
CIE (x, y)	0.3289,0.3395	0.3239,0.3482	0.3269,0.3498	0.3273,0.3726
CCT (K)	5660	5868	5737	5698
CRI	66.4	75.6	77.0	74.7

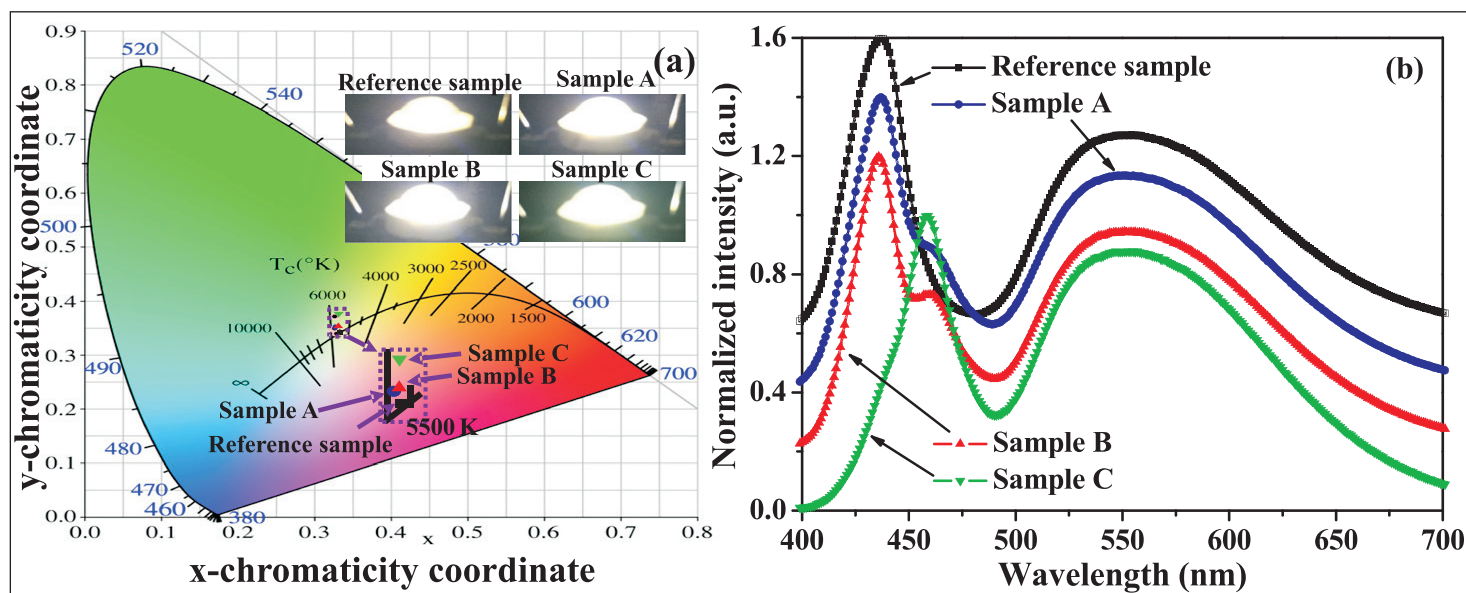


Figure 2. (a) CIE 1931 chromaticity diagram and (b) normalized experimental electroluminescence spectra of four encapsulated LED samples with phosphors at $80\text{A}/\text{cm}^2$. Insets: four LED samples radiating on probe platform.

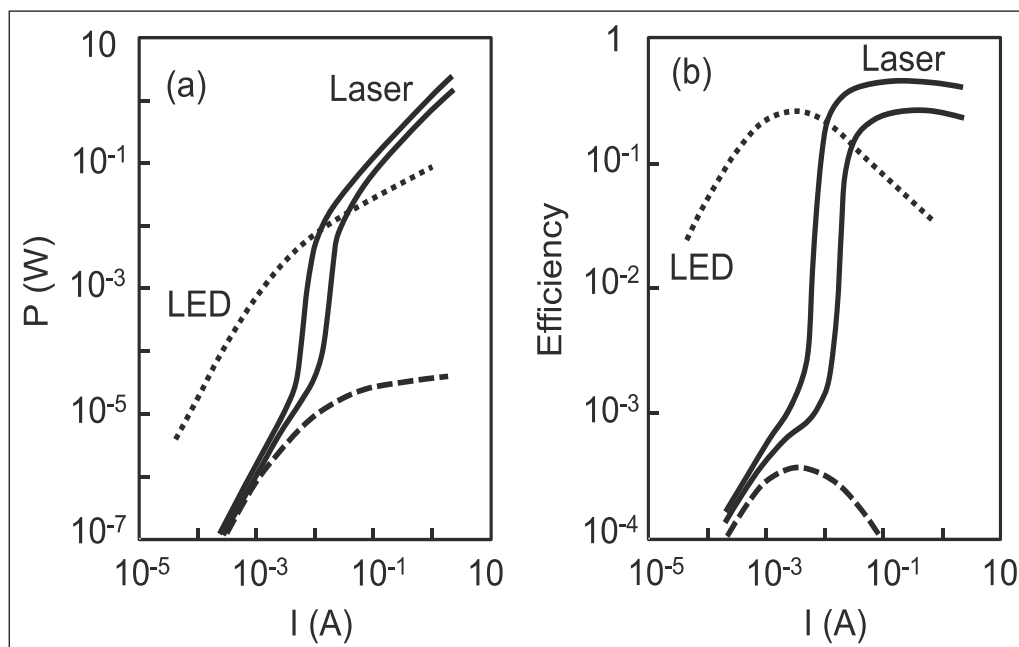


Figure 3. (a) Simulated output power and (b) efficiency versus injection current for LED (dotted curve) and array of 9 VCSELS. Solid curves show cases where lasing threshold is reachable because of sufficiently low cavity loss (1/ps and 2/ps). The dashed curve is for high cavity loss of 4/ps, where lasing is not possible. Spontaneous emission factor is 0.01.

► The current droop effect is associated with high carrier populations in the active light-emitting regions of such devices.

Recently, it has been suggested that InGaN laser diodes could avoid the efficiency problem above threshold where the carrier population is clamped to a relatively low level [see, e.g., *Semiconductor Today*, p76, July–August 2015; Mike Cooke, *Semiconductor Today*, p70, November 2013].

Chow and Crawford comment: “The extent to which efficiency droop can be solved by lasers depends on a complicated interplay involving non-radiative losses, stimulated emission, spontaneous emission, and intracavity absorption. An accurate quantitative evaluation should be performed before committing substantial resources towards laser-based lighting development.”

First, the researchers compared models for an LED with a vertical-cavity surface-emitting laser (VCSEL), using a fully quantized approach for the behavior of electrons, holes and photons. The active region consisted of a 2nm single quantum well of $\text{In}_{0.37}\text{Ga}_{0.63}\text{N}$ in GaN barriers. The area of the LED was $100\mu\text{m} \times 100\mu\text{m}$. The VCSEL was a 3x3 array with cells of area $5.6\mu\text{m} \times 5.6\mu\text{m}$ — a 3% fill factor compared with the LED area. The VCSELS used distributed Bragg reflectors (DBRs) as confinement. The VCSEL array properties were designed to give 1W power at 1A current.

The simulations show that, with low absorption cavities, one can expect improved power and efficiency above threshold over LED performance (Figure 3). However, the low efficiency below threshold could

“limit the use of lasers in general lighting applications, e.g. where dimmable lights are advantageous for energy savings,” according to Chow and Crawford.

The researchers therefore suggest that nanolasers could be an alternative without the low efficiency at low current. Such devices use nano-scale resonant structures to channel spontaneous emission into lasing modes, giving more light below threshold. In 2012, there were reports of such devices operating at room temperature with optical pumping.

Chow and Crawford’s nanolaser simulation was for a 12x12 array with $560\text{nm} \times 560\text{nm}$ cells — a 0.5% fill factor compared with the VCSEL array. The nanolaser structure was based on a VCSEL with photonic lattice on the surface. The laser mode was from a

defect site in the photonic lattice. Again, the aim was for 1W power at 1A current. The model gives similar performance to the LED below threshold and to the laser above threshold (Figure 4).

Thermoelectric pumping enhancement

Massachusetts Institute of Technology (MIT) and University of California Santa Barbara (UCSB) in the USA have been investigating the possibility of taking advantage of high temperature and thermoelectric pumping to improve the light output power (LOP) from InGaN LEDs, avoiding the need for external cooling [Jin Xue et al, *Appl. Phys. Lett.*, vol107, p121109, 2015].

The researchers write: “The LED is shown to work in a mode similar to a thermodynamic heat engine operating with charged carriers pumped into the active region by a combination of electrical work and Peltier heat (phonons) drawn from the lattice.”

The team says that their results suggest the possibility of removing bulky heat-sinks in commercial high-power LEDs, bringing a considerable reduction in cost.

The LED is shown to work in a mode similar to a thermodynamic heat engine operating with charged carriers pumped into the active region by a combination of electrical work and Peltier heat

While current-induced droop has received wide attention from scientists and engineers, the temperature-induced effect has not been comprehensively studied, says the MIT/UCSB team.

The MIT/UCSB researchers developed a device with an optimal operating region at 615K that increased the LOP four-fold over room temperature (295K) with virtually no reduction in wall-plug efficiency (WPE).

The researchers comment: "This low-bias optimal regime of high LOP and high WPE at elevated temperature does not universally exist for common GaN-based LEDs. The demonstration of the sample studied is attributed to the low current droop and low thermal droop for the EQE in this device."

The low thermal droop was achieved by using low-defect-density substrates, reducing the amount of Shockley-Read-Hall

non-radiative recombination. The low-bias operation avoided Auger recombination effects and current droop.

The researchers produced 450nm-emitting material on semi-polar $[20\bar{2}1]$ free-standing GaN substrate (Figure 5). The design targeted high power output and low current-induced droop. Encapsulated devices with zinc oxide vertical-stand packaging and back-side roughening to increase light extraction achieved an external quantum efficiency of 50.1% and 140mW light output power at 100A/cm² current density.

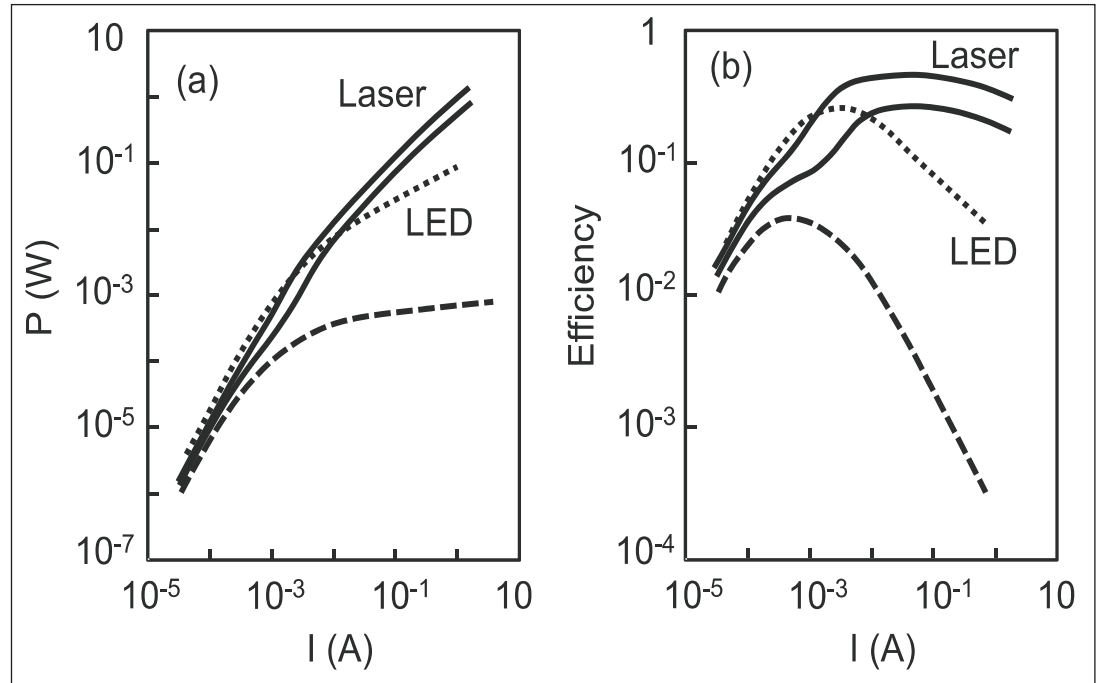


Figure 4. (a) Output power and (b) efficiency versus injection current for LED (dotted curve) and array of 144 nanolasers with spontaneous emission factor 1. Solid curves show cases where lasing threshold is reachable because of sufficiently low cavity loss (1/ps and 2/ps). The dashed curve is for 4/ps cavity loss.

Temperature-dependent experiments were carried out without encapsulation or packaging, reducing EQE and WPE. The LED die was placed on the flat surface of a hemispherical sapphire lens with anti-reflective coating. The lens-chip assembly was put in an opening in a copper arm that was used for heating. The light output from the lens was collected by a parabolic reflector and guided into a calibrated silicon photodetector.

The device was tested in pulse-mode, presumably to avoid self-heating affecting the temperature-dependent measurements (Table 3). The LED showed a small EQE

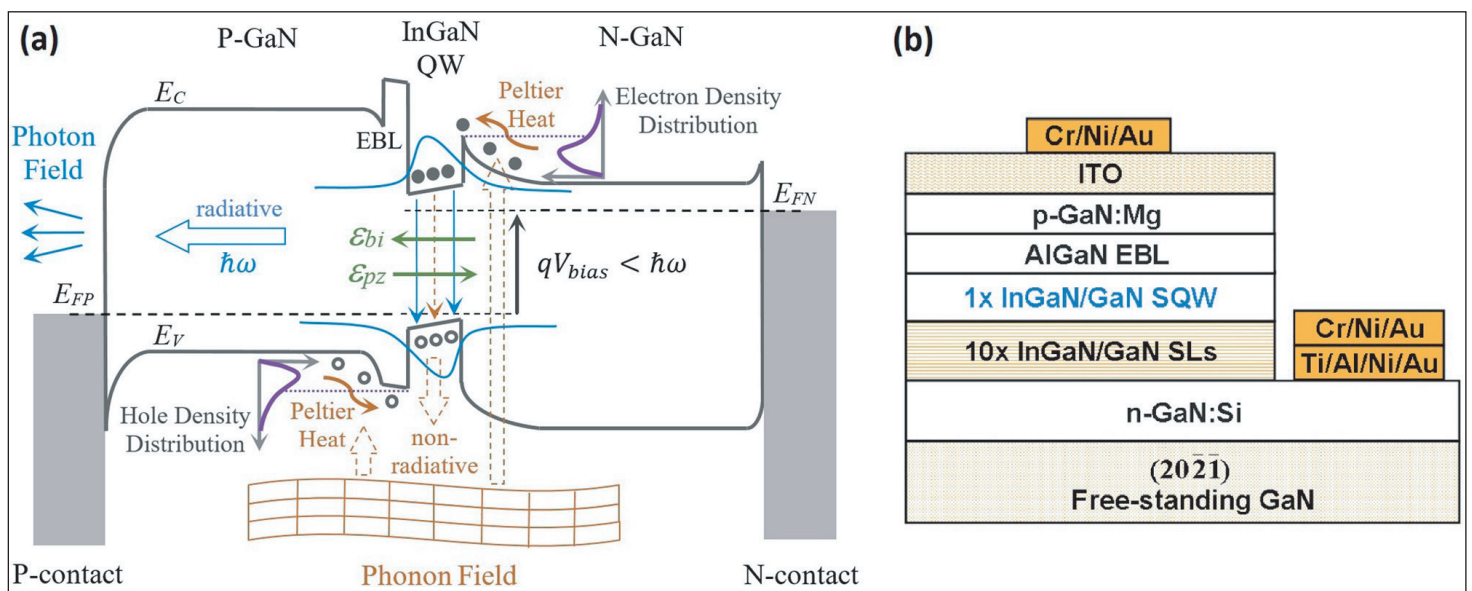


Figure 5. (a) Band diagram of InGaN single-quantum-well (SQW) LED, and thermoelectric pumping mechanism. (b) Epitaxial structure of device.

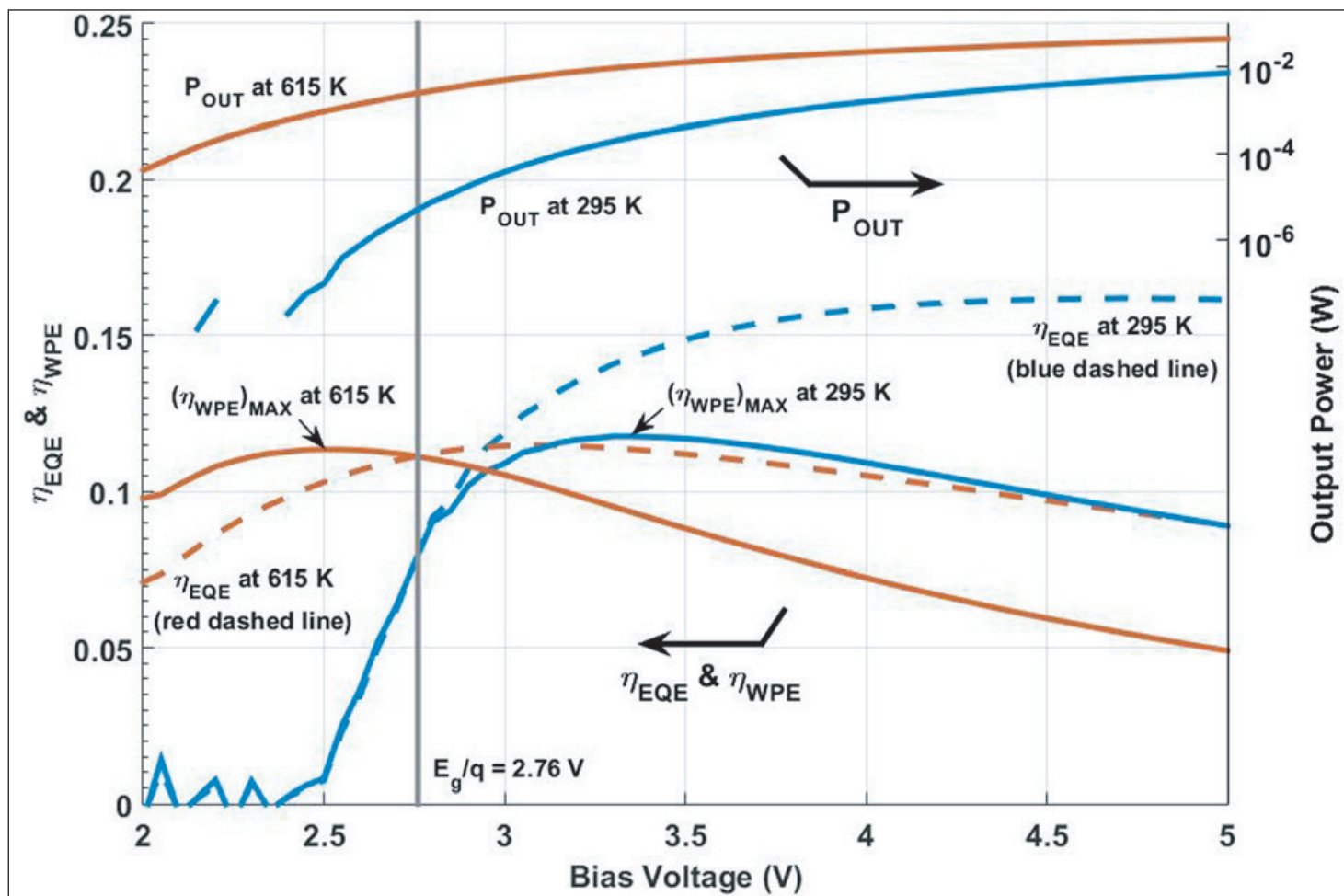


Figure 6. EQE (dashed lines) and WPE (solid lines) versus LED bias voltage at two extreme temperatures cases. Blue lines correspond to 295K (room temperature) and red lines correspond to 615K high temperature. Bias voltage of 2.76V corresponds to 450nm-wavelength photon.

Table 3. Conditions of peak WPE at different temperatures.

T	V	J	P _{OUT} at max WPE	η_{EQE}	$\eta_{\text{WP MAX}}$	Q _{Peltier}
295K	3.35V	0.61A/cm ²	2.40W/cm ²	14.31%	11.77%	3.46x10 ⁻¹ W/cm ²
375K	3.10V	1.00A/cm ²	3.61W/cm ²	13.07%	11.61%	3.12x10 ⁻¹ W/cm ²
455K	2.95V	2.11A/cm ²	7.01W/cm ²	12.06%	11.26%	3.43x10 ⁻¹ W/cm ²
535K	2.75V	2.94A/cm ²	9.06W/cm ²	11.19%	11.21%	-9.83x10 ⁻² W/cm ²
615K	2.50V	3.26A/cm ²	9.24W/cm ²	10.30%	11.35%	-9.02x10 ⁻¹ W/cm ²

droop at higher currents ($\sim 10\text{A}/\text{cm}^2$). The WPE was more peaked at a particular current that increased with temperature. While the EQE peak reduced at higher temperature, the WPE was more constant. The researchers comment: "In fact, since the collection efficiency of the experimental setup is optimized at room temperature, thermal expansion of the heating stage relative to the photodetector is likely responsible for the small roll-off in the measured WPE at higher temperatures."

At the same time as the WPE peak shifts to higher currents at higher temperature, the required bias decreases — from 3.35V at 295K to 2.5V at 615K — giving reduced power consumption (Figure 6). The light output power increased by around 4x with the temperature increase for a small WPE drop of 0.42%

measured on equipment calibrated at 295K and not corrected for thermal expansion effects. The WPE exceeded the EQE above 535K, indicating the effects of thermo-

electric pumping. The researchers comment: "The injection current density in the case of 615K (3.26A/cm²) is already close to the value of 5A/cm², which is the operating point of common high-power GaN-based LEDs." The researchers used an empirical equation to derive a characteristic temperature for the thermal droop, which for their devices was 869K, compared with less than 200K for typical GaN LEDs grown on c-plane sapphire. The high characteristic temperature indicates very low thermal droop. ■

<http://dx.doi.org/10.1063/1.4931365>

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

Improving performance of magnesium doping for p-type gallium nitride

Laser activation together with a nickel cap has been shown to lower the voltage drop across a p-i-n diode.

Taiwan's National Tsing Hua University has been studying ways to improve the performance of p-type gallium nitride (p-GaN) in terms of hole density and contact resistance with nickel/gold [Bo-Sheng Zheng et al, *J. Appl. Phys.*, vol118, p085706, 2015].

Low hole density is a particular problem with p-GaN due to the high activation energy of magnesium acceptors.

A further problem is parasitic incorporation of hydrogen that further kills hole densities.

Annealing is often used to drive out hydrogen and improve performance. High temperatures can damage the device structure, particularly the indium gallium nitride (InGaN) layers used in light-emitting diodes.

The researchers assessed the relative merits of rapid thermal and laser annealing, along with the use of a nickel cap to enhance desorption of hydrogen. Nickel caps could also improve the surface integrity in laser annealing, where scanning normally produces surface damage.

p-contact	Heavily Mg-doped GaN [$1.5 \times 10^{20}/\text{cm}^3$]	15nm
p-contact	Mg-doped GaN [$3 \times 10^{19}/\text{cm}^3$]	0.5 μm
Intrinsic	Undoped GaN	3 μm
n-contact	Si-doped GaN	1.5 μm
Buffer	AlN	25nm
Substrate	c-plane sapphire	

Figure 1. Epitaxial structure.

GaN was grown on 2" c-sapphire with a p-i-n structure (Figure 1) by metal-organic chemical vapor deposition (MOCVD). The hole density in the magnesium-doped region, according to Hall measurements, was $1.8 \times 10^{17}/\text{cm}^3$. The electron density in undoped GaN was in the range $1-3 \times 10^{16}/\text{cm}^3$.

Four magnesium-doping activation schemes were studied that involved different combinations of rapid thermal annealing (RTA) or neodymium-doped yttrium aluminium garnet (Nd:YAG) laser annealing, with or without nickel cap (Table 1). The samples were cleaned before application of the nickel caps. After

Table 1. Electrical characteristics of samples subjected to different heat treatments.

	RTA	Laser (50kHz, 600mJ/cm ²)	Hole density	Specific contact resistance	Remarks
As-grown	n/a	n/a	$1.8 \times 10^{17}/\text{cm}^3$	$\sim 1 \times 10^{-2} \Omega\text{-cm}^2$	n/a
Sample A	Without Ni 900°C, 2 min.	n/a	$5.1 \times 10^{17}/\text{cm}^3$	$2.8 \times 10^{-3} \Omega\text{-cm}^2$	n/a
Sample B	n/a	Without Ni	$3.2 \times 10^{17}/\text{cm}^3$	$2.3 \times 10^{-3} \Omega\text{-cm}^2$	Surface deformation
Sample C	Ni cap (50nm) 500°C, 10 min.	n/a	$4.4 \times 10^{17}/\text{cm}^3$ (Ni/Au contacts)	$3.5 \times 10^{-2} \Omega\text{-cm}^2$	Formation of Ga-O-Ni compound
Sample D	n/a	Ni cap (200nm)	$3.8 \times 10^{17}/\text{cm}^3$	$1.6 \times 10^{-4} \Omega\text{-cm}^2$	n/a

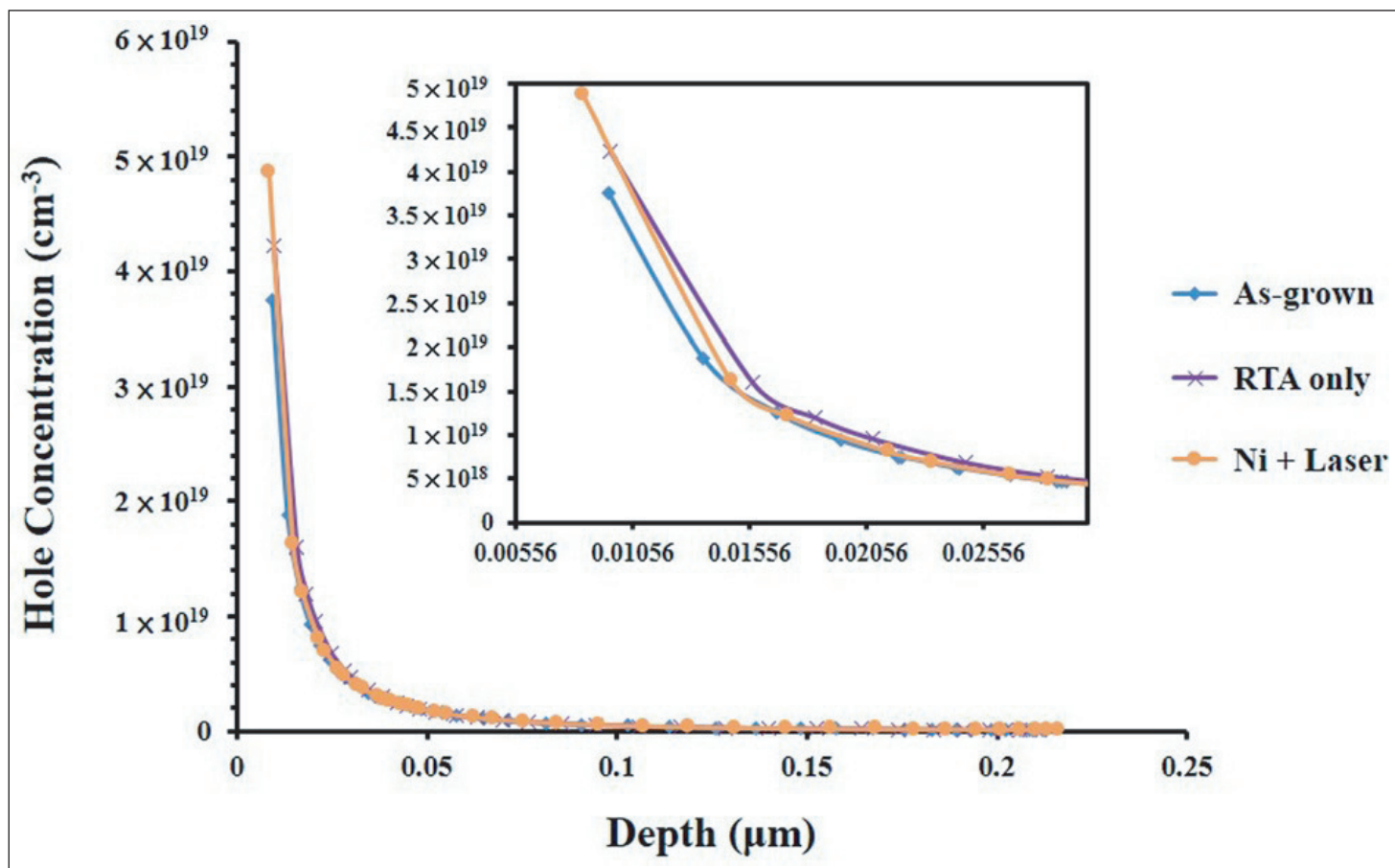


Figure 2. Profiles of hole concentration versus depth for p-GaN subject to RTA without nickel caps and laser annealing with nickel caps.

annealing, the nickel caps were removed with aqua regia or hydrochloric acid.

For testing, annealed nickel/gold ohmic contact metals were applied. Diodes were fabricated with mesa etching. The Hall measurements for the hole density were carried out in the van der Pauw configuration with indium ball electrodes. The specific contact resistance was measured by the circular transmission-line method.

All the annealing processes increase hole density by a factor of 2–3x. The RTA process gives higher hole density than the laser activation. The researchers write: “We attribute the increase in hole density to a better activation of Mg, most

Low hole density is a particular problem with p-GaN due to the high activation energy of magnesium acceptors. A further problem is parasitic incorporation of hydrogen that further kills hole densities. The researchers assessed the relative merits of rapid thermal and laser annealing, along with the use of a nickel cap to enhance desorption of hydrogen. Nickel caps could also improve the surface integrity in laser annealing

likely due to the break-off of hydrogen from Mg at high annealing temperatures. The parasitic hydrogen attached to Mg is incorporated during the epitaxial crystal growth of GaN.”

The contact resistance of the RTA sample C with nickel cap was worse than the as-grown sample. The other treated samples performed better, but there was not a straightforward inverse relation between hole density and contact resistance. The team comments: “This seemingly puzzling contradiction in numbers suggests that the hole concentration depth profiles in heat-treated samples may not be uniform. Instead, there might be a gradient in the profiles tapering from the surface toward bulk. It is possible that a steeper gradient may yield a higher surface concentration but actually a smaller overall sheet carrier density.”

The problem with the sample C contact resistance was attributed to a gallium–oxygen–nickel compound, which is thought to interrupt carrier transport. By contrast, laser annealing with nickel cap (sample D) was found to be free of such parasitic compounds, according to transmission electron microscopy (TEM) that shows a smooth rather than rough surface.

The hole density relation with depth was probed with capacitance–voltage measurements (see Figure 2). The results exhibited enhanced density near the surface.

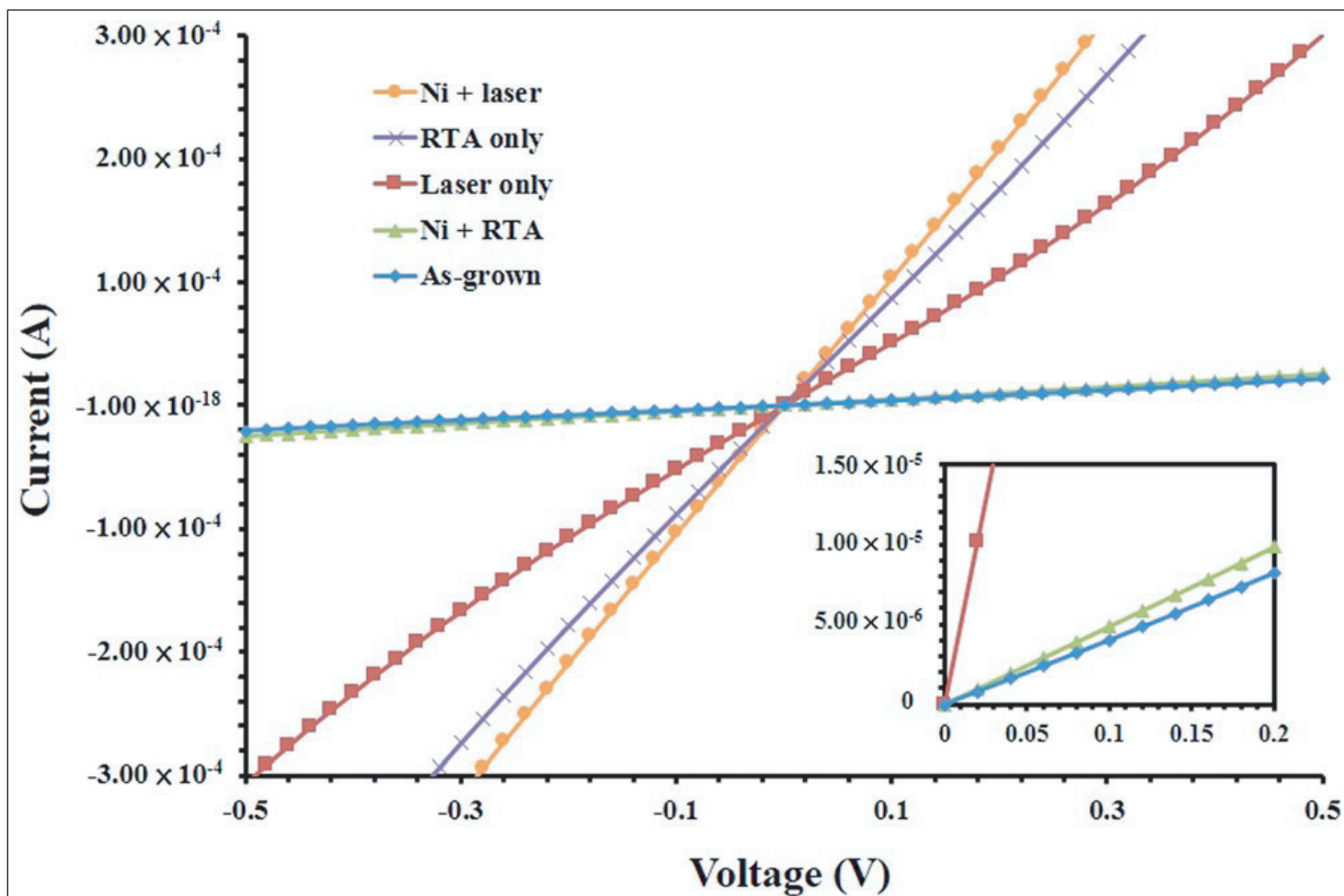


Figure 3. Forward current-voltage characteristics at room temperature of p-i-n diodes.

Current-voltage curves for nickel/gold contacts on p-GaN and for the p-i-n mesa diodes (Figure 3) showed improved current flow for annealed samples. The pin A diode with highest current was for laser annealing with nickel cap. The B diode was for RTA annealing, and C for as-grown. The voltage drop for

100A/cm² current was 3.70V, 3.94V and more than 4.0V for diodes A-C in order. The ideality factors were between 2.6 and 2.8. The breakdown of all devices occurred around 600V. ■

<http://dx.doi.org/10.1063/1.4929522>

Author: Mike Cooke

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Quaternary III-nitride barrier boosts two-dimensional electron gas

Higher power densities, increased efficiency over range of frequencies, high performance over wide bandwidths and higher thermal conductivity promise telecom, healthcare, space and military 30GHz+ applications.

Researchers based in France claim the best two-dimensional electron gas (2DEG) properties ever reported for III-nitride (III-N) semiconductor structures [Farid Medjdoub et al, Appl. Phys. Express, vol8, p101001, 2015].

The team from Institute of Electronic, Micro-electronic and Nanotechnology (IEMN) and Thales Research and Technology sees potential telecom, healthcare, space and military 30GHz+ applications based on higher power densities, increased efficiency over a range of frequencies, high performance over wide bandwidths, and higher thermal conductivity.

Such 2DEGs are used as conduction channels in high-electron-mobility transistors (HEMTs) and other devices. The 2DEG forms near the interface between gallium nitride (GaN) and a barrier structure. Normally the barrier consists of a wider-bandgap material such as aluminium gallium nitride (AlGaN) — a ternary III-nitride material.

IEMN has previously developed indium aluminium nitride (InAlN) as an alternative that can be lattice matched with GaN. However, this ternary material is difficult to grow with sufficient uniformity. Problems

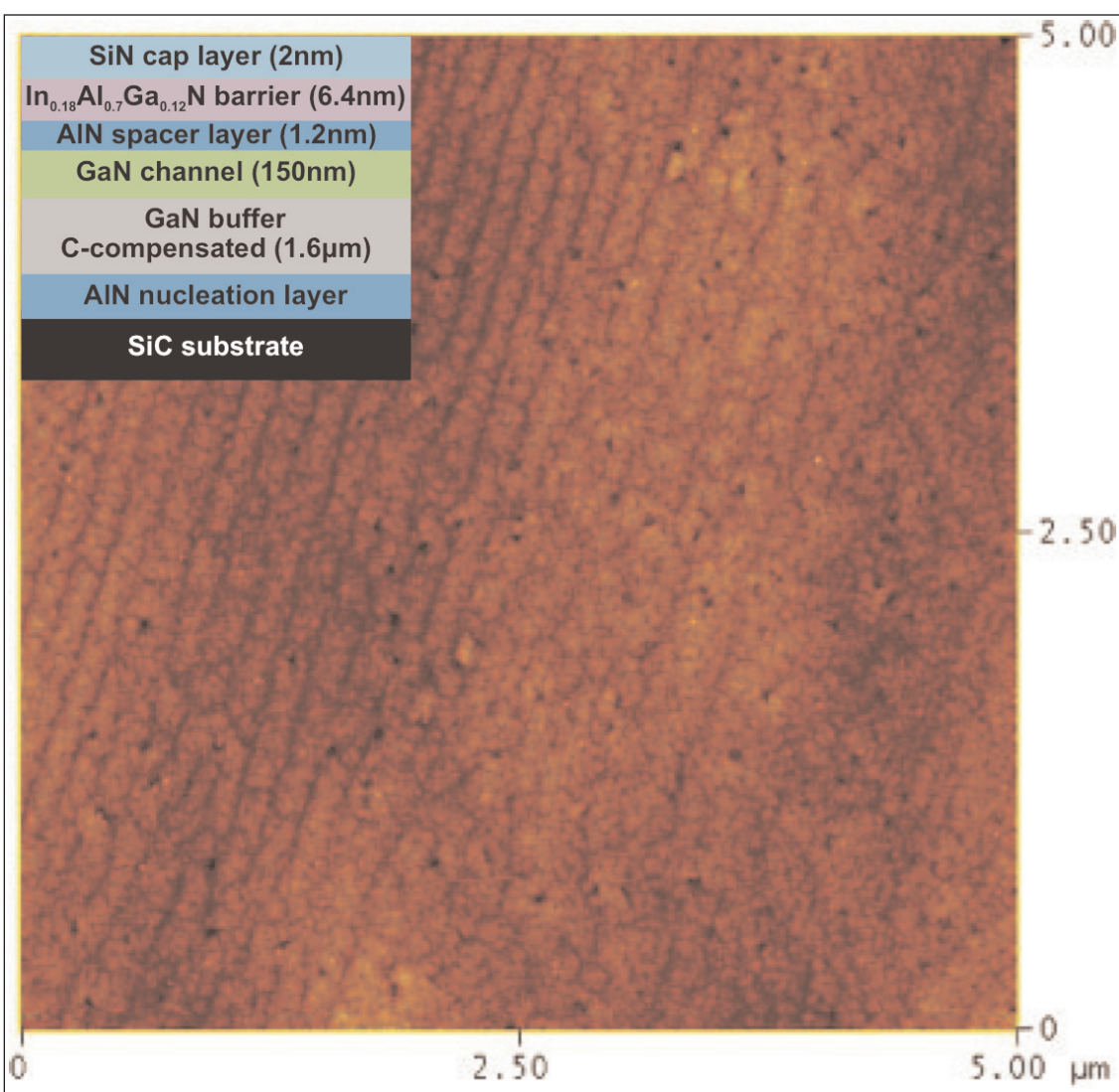


Figure 1. 5µm x 5µm AFM image of $\text{Si}_x\text{N}_y/\text{InAlGaN}/\text{AlN}/\text{GaN}$ HEMT heterostructure. Inset shows cross section of fabricated device.

arising from non-uniformity include alloy scattering, interface roughness, and carrier interactions with optical and acoustic phonons.

The IEMN/Thales team has combined the advantages of AlGaN and InAlN by using a quaternary InAlGaN barrier, allowing for lattice matching.

The InAlGaN/AlN/GaN structure (Figure 1) for creating

a 2DEG was grown using low-pressure metal-organic chemical vapor deposition (LP-MOCVD) on 4" semi-insulating silicon carbide (SiC). The InAlGaN had 18% indium content and 12% gallium content, giving material lattice matched to GaN. The silicon nitride (SiN) cap was produced in-situ, using ammonia and silane precursors.

The researchers describe the resulting material surface as 'mirror-like' with roughness of 0.27nm root-mean-square, according to atomic force microscopy (AFM). A low defect density and atomic steps were found.

Mobility, carrier density and sheet resistance were assessed using Hall measurements on van der Pauw structures and mercury-probe capacitance-voltage measurements at room temperature and 77K (Table 1). Benchmarked against the work of others (Figure 2), the team describes its work as 'state-of-the-art'.

The researchers comment further: "A real breakthrough in terms of electrical and structural properties of the SiN/InAlGaN/AlN/GaN heterojunction has been obtained, as compared with the InAlN/AlN/GaN heterojunction (typical values of μ_{300K} are about $1300\text{cm}^2\text{V}^{-1}\text{s}^{-1}$ for $1.3\times 10^{13}\text{cm}^{-2}$)."

The team looks forward to optimizations of the thickness and growth conditions of the AlN spacer as a means to achieving higher mobility. The SiN layer is seen as contributing to the high 2DEG performance through preventing strain relaxation and early passivation of surface charges.

The researchers add: "The electron mobility improvement in this ultrathin barrier heterostructure is attributed to the optimization of the material quality showing low interface roughness owing to the introduction of Ga into the barrier layer, the use of an in-situ-grown Si_xN_y cap layer, and the introduction of an optimized AlN spacer layer."

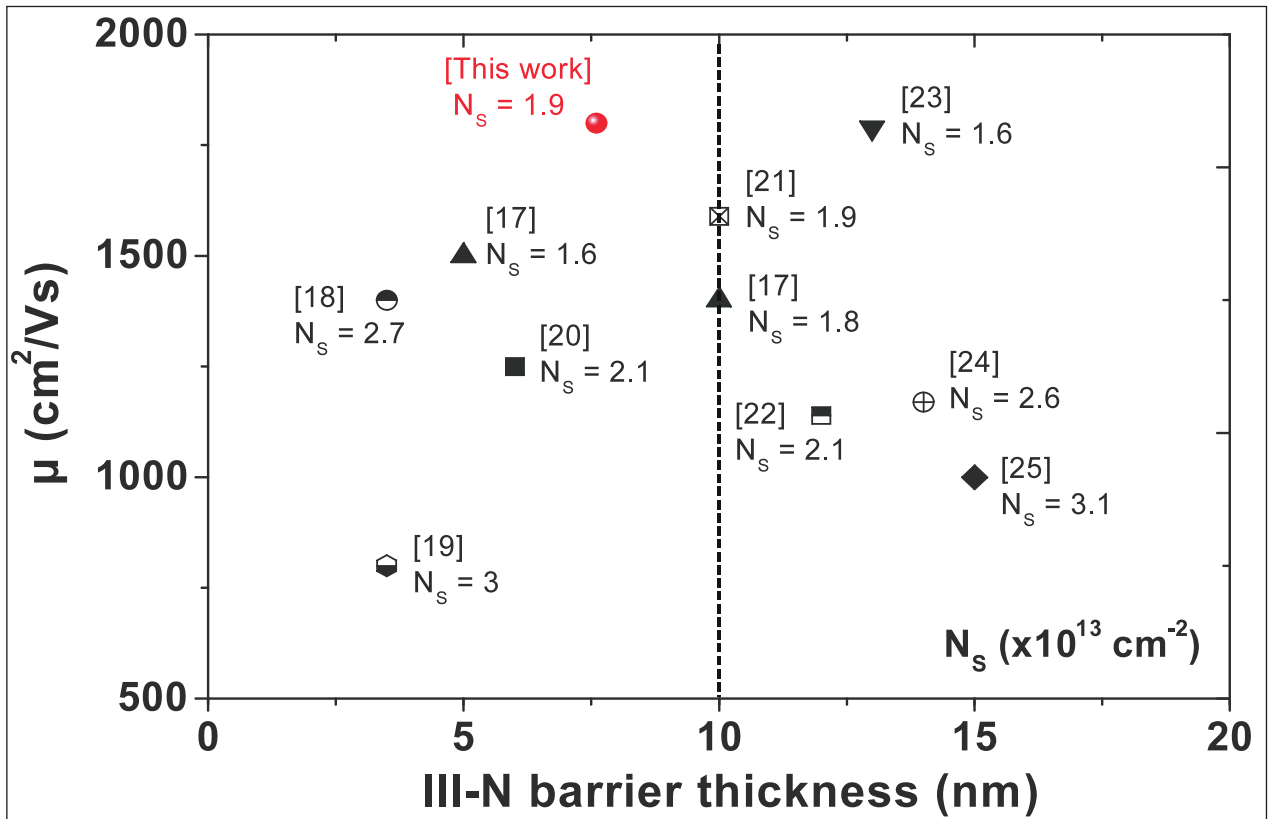


Figure 2. Benchmark of RT electron mobility as a function of barrier thickness (including spacer interlayer) in III-N-based HEMT structures. Carrier density N_s is indicated for each reference.

Table 1. Characteristics of 2DEG at $1.9\times 10^{13}/\text{cm}^2$ sheet carrier density.

	Room temperature	77K
Mobility	$1800\text{cm}^2/\text{V-s}$	$6800\text{cm}^2/\text{V-s}$
Sheet resistance	$191\Omega/\text{square}$	$<50\Omega/\text{square}$

HEMT devices were fabricated with annealed titanium/aluminium/nickel/gold ohmic contacts on the InAlGaN barrier layer and a 250nm nickel/gold Schottky gate. Isolation was achieved using nitrogen implantation. The gate-source and gate-drain spacings were $0.3\mu\text{m}$ and $2\mu\text{m}$, respectively. The device width was $50\mu\text{m}$.

The maximum DC drain current density was $1.5\text{A}/\text{mm}$ at +2V gate potential. The peak transconductance was more than $300\text{mS}/\text{mm}$.

The off-state leakage for -5V gate was well below $1\mu\text{A}/\text{mm}$. The off-state broke down at about 50V drain bias.

Frequency measurements gave current-gain and power-gain extrinsic cut-off frequencies (f_T/f_{max}) of 60GHz and 190GHz, respectively.

The researchers comment: "A further reduction in contact resistances should result in an increase in extrinsic transconductance and, thus, a significant improvement of frequency performance." ■

<http://dx.doi.org/10.7567/APEX.8.101001>

Author: Mike Cooke

Bulk gallium nitride substrate enables 4kV-breakdown vertical p-n diode

Avogy's vertical p-n diodes on bulk GaN also achieve area-differential specific on-resistance of less than $3\text{m}\Omega\text{-cm}^2$.

Avogy Inc of San Jose, CA, USA has used bulk gallium nitride (GaN) substrates to create vertical p-n diodes with a breakdown voltage of more than 4kV and area-differential specific on-resistance of less than $3\text{m}\Omega\text{-cm}^2$ [I.C. Kizilyalli et al, IEEE Electron Device Letters, published online 9 September 2015].

Bulk GaN has lower dislocation densities compared with material grown on alternative substrates such as sapphire, silicon carbide, silicon, or even free-standing GaN (where the growth substrate is removed).

Controlling dislocation densities is vital to access higher breakdown voltage and lower on-resistance.

Increasing breakdown to 4kV brings potential application for ship propulsion, rail, wind, uninterruptable power supplies (UPS), geothermal instrumentation, high-voltage multipliers, military power supplies, and the power grid, according to the researchers.

Avogy has begun with p-n junction devices as a first step towards the realization of more complex vertical junction field-effect transistors (JFET) and junction

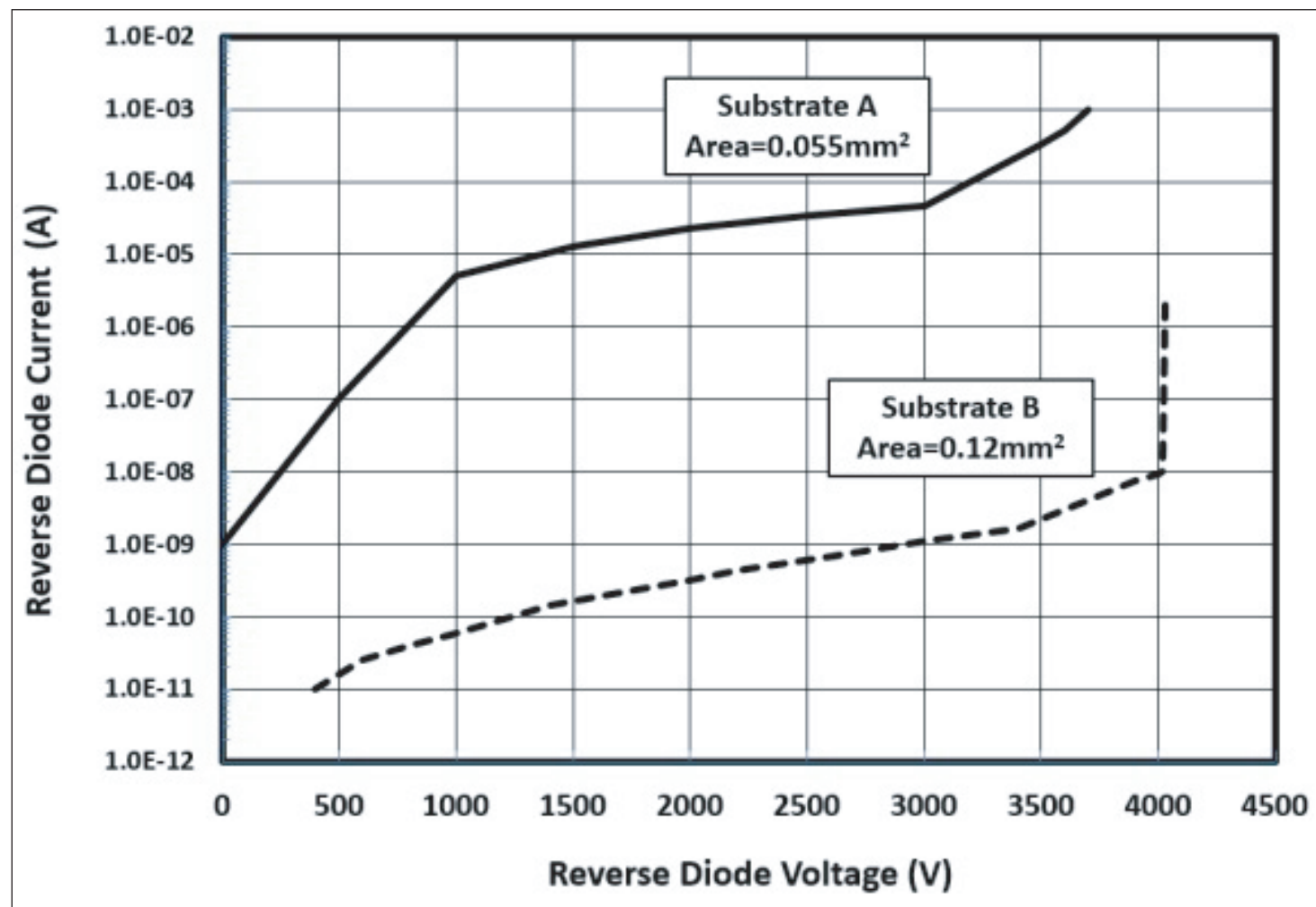


Figure 1. Reverse characteristics at 300K of GaN p-n diodes on optimized substrate B and comparison devices on unoptimized substrate A.

barrier Schottky (JBS) diodes, which have lower turn-on voltages ($<1\text{V}$) and lower conduction losses.

The epitaxial structures were grown on 2-inch bulk GaN substrate with very low threading dislocation density of $10^4/\text{cm}^2$. "This is four orders of magnitude lower than for GaN films grown in the conventional manner on non-native substrates," according to the researchers.

The researchers designed the edge-termination, n-type drift layer and thickness to achieve junction breakdown around 5kV. In particular, the edge-termination spread the anode potential to a distance that exceeded the drift layer thickness by a factor of about 4.5. The edge-termination involved two implant steps.

The net doping density of the $40\mu\text{m}$ drift layer was $2\text{--}5 \times 10^{15}/\text{cm}^3$. "Controlling the doping of GaN to these levels by MOCVD is challenging since it is at or below the level of typical unintentional background impurities, particularly carbon," the researchers comment.

The p-region of the diode consisted of heavily magnesium-doped GaN deposited on the drift layer. The contacts were palladium/platinum.

The researchers have found that nominally c-plane oriented devices with a slight inclination towards the m-plane are optimal for reverse leakage performance and reliability. The inclination is achieved by mis-cutting by several tenths of a degree to encourage step-flow growth, avoiding the formation of screw dislocations.

Spiral growth around screw dislocations leads to unwanted large hexagonal hillocks on the GaN surface in on-axis deposition. White-light interferometry gave a mean roughness of less than 20nm over a $1\text{mm} \times 1\text{mm}$ area for an optimized substrate (B), compared with more than 50nm for a sample with lower mis-cut angle (A).

The researchers report: "The implementation of the improved substrate specification results in a marked improvement in the reverse leakage and the first demonstration of a breakdown voltage exceeding 4kV in GaN vertical p-n diodes [see Figure 1]." Last year,

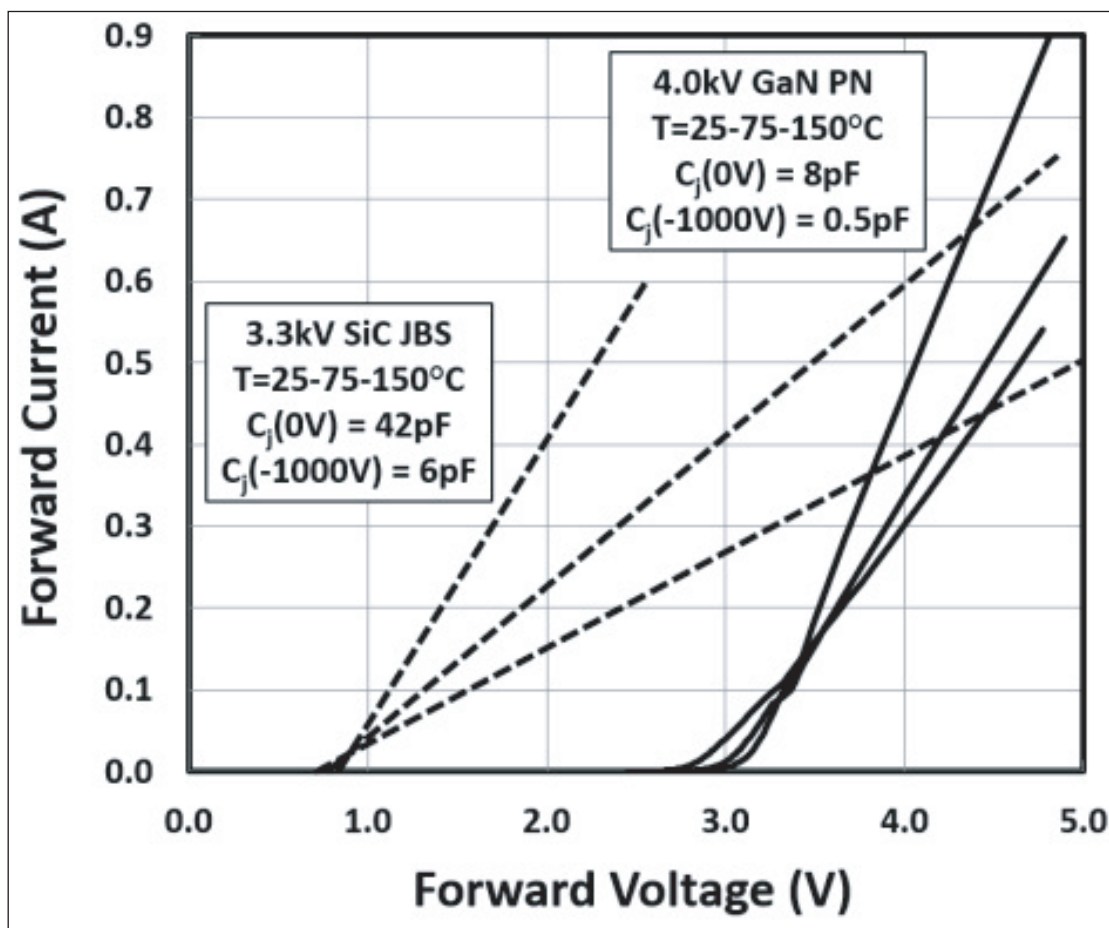


Figure 2. Forward current-voltage characteristics of 4kV GaN p-n diode and 3.3kV SiC JBS diode (dotted line) at 25–75–150°C.

Avogy researchers reported devices with breakdowns up to 3.5kV and leakage about $10\mu\text{A}$ through a 0.055mm^2 effective area.

The team believes that further improvement of the edge-termination should lead to 5kV breakdown. The researchers calculate the field in the drift region to be $2.0\text{--}2.7\text{MV}/\text{cm}$ at breakdown, well short of GaN's critical field of $\sim 5\text{MV}/\text{cm}$. They conclude that the breakdown occurs in the edge-termination.

The turn-on voltage is around 3.0V, consistent with GaN's bandgap of 3.4eV. The effective device area was $250\mu\text{m} \times 500\mu\text{m}$, as defined by the edge-termination implants. The device can handle up to 1A without substrate thinning or packaging.

In 30ms-pulsed quasi-DC operation, the area-differential specific on-resistance was $2.3\text{m}\Omega\text{-cm}^2$ at room temperature. An increase in resistance with temperature was attributed to reduced electron mobility.

The researchers compared the performance with silicon carbide junction barrier Schottky (SiC JBS) diodes (Figure 2). The junction capacitance of the GaN device was much lower, suggesting lower switching losses. ■

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Author: Mike Cooke

Claiming record 4.7kV breakdown for gallium nitride p-n diodes

A triple-drift-layer structure also reduces on-resistance to give the best combined values, reports research team in Japan.

Researchers in Japan have claimed record breakdown voltage combined with low on-resistance for vertical gallium nitride (GaN) p-n diodes fabricated on free-standing GaN substrates [Hiroshi Ohta et al, IEEE Electron Device Letters, published online 22 September 2015]. This was achieved using a triple-drift-layer structure. In particular, the layer next to the p-type GaN was very lightly doped so that the peak field near the p-n junction was suppressed, allowing higher voltages to be sustained. A second moderately doped layer reduced on-resistance.

The research team came from Hosei University, Quantum Spread Co Ltd, and Hitachi Metal subsidiary Sciocs Co Ltd. They used 2-inch free-standing GaN substrate for the devices (Figure 1). These substrates were produced by void-assisted separation, resulting in a threading dislocation density of less than $3 \times 10^6/\text{cm}^2$.

The device material was grown using metal-organic vapor phase epitaxy. The researchers used specially designed diluted silane gas lines to achieve the very low silicon doping for the lightly doped n--GaN layers.

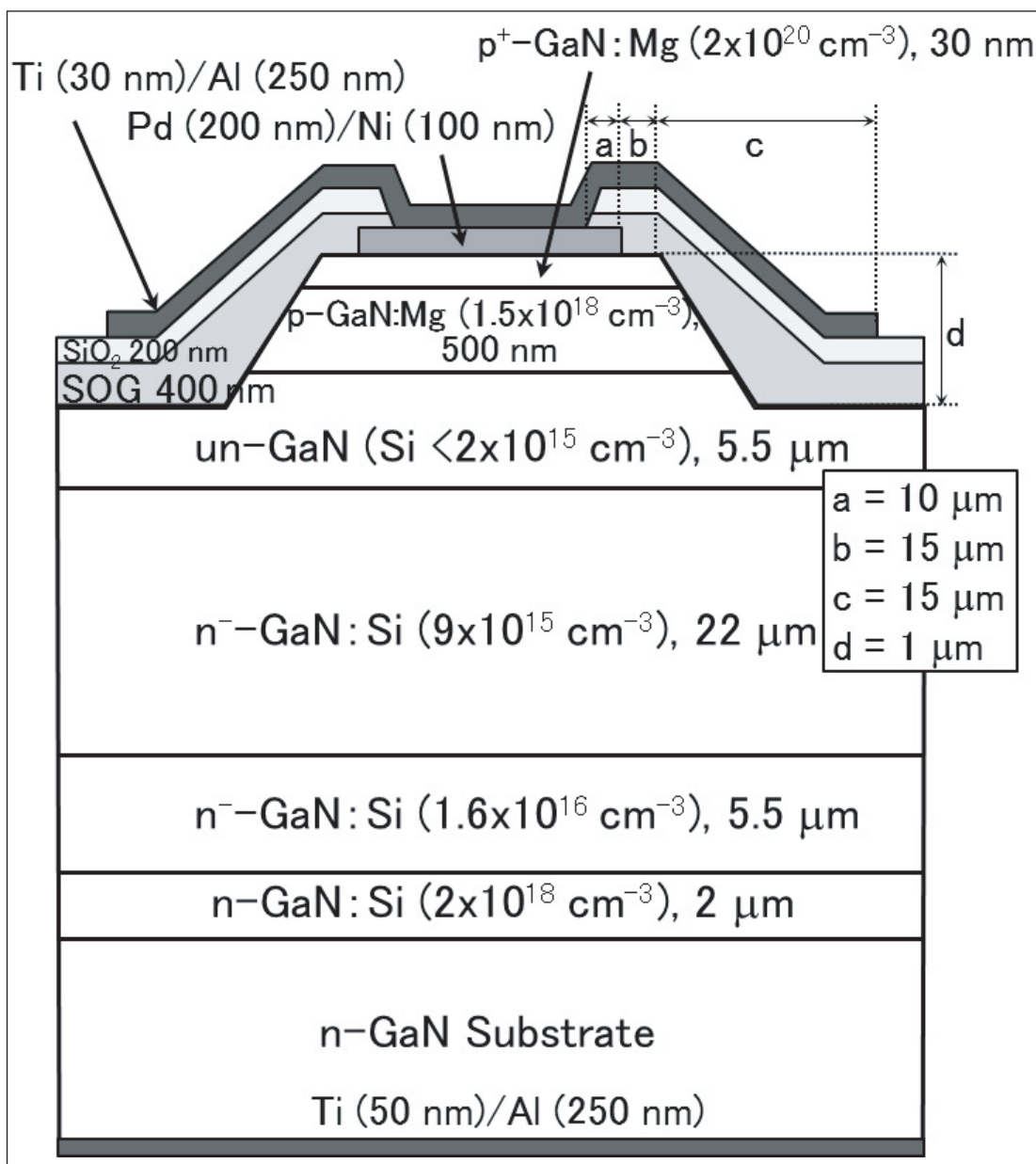


Figure 1. Schematic cross sections of the GaN p-n junction diodes with the triple drift layers and the FP structure.

The researchers comment: "By reducing the doping concentration underneath the p-GaN layer, the peak electric field at the p-n interface can be suppressed

under negatively biased conditions.”

The silicon doping profile was confirmed by secondary-ion mass spectroscopy, but the limit of the measurement was around $9 \times 10^{15}/\text{cm}^3$. The researchers believe that the actual doping concentration in the most lightly silicon-doped n^- -GaN layer could be less than this.

The material was annealed at 850°C for 30 minutes before device fabrication to activate the magnesium doping of the p-GaN layers.

The device included a field-plate (FP) structure on sputtered silicon dioxide/spin-on-glass (SiO_2/SOG) insulator/passivation for the p-type ohmic contact to the p-GaN layer.

A triple-drift-layer device with $100\mu\text{m}$ -diameter circular p-electrode achieved an on-resistance (R_{on}) as low as $1.7\text{m}\Omega\text{-cm}^2$. A comparison device with double drift layer ($2\mu\text{m}$ undoped and $22\mu\text{m}$ $1.1 \times 10^{16}\text{ cm}^3$ silicon doping) had a lower on-resistance of $1.4\text{m}\Omega\text{-cm}^2$. The turn-on voltage was around 3.1V .

The researchers comment: “These low R_{on} ’s were brought by high-quality epitaxial layers grown on the GaN substrates with low dislocation density. The high-quality layers enhances photon-recycling effect which increases conductive holes from deep magnesium acceptors excited by high-density photons generated through electron-hole-pair recombination at the p-n junction.”

Triple-drift-layer devices with electrode diameters of $60\mu\text{m}$ and $200\mu\text{m}$ achieved reverse breakdown voltages as high as 4.7kV , which is 1kV higher than a single-drift-layer diode reported in 2014. Recently, US-based Avogy reported a diode on bulk GaN with breakdown exceeding 4kV [www.semiconductor-today.com/news_items/2015/oct/avogy_011015.shtml]. Ohta et al’s double-drift-layer structure achieved 3.8kV breakdown.

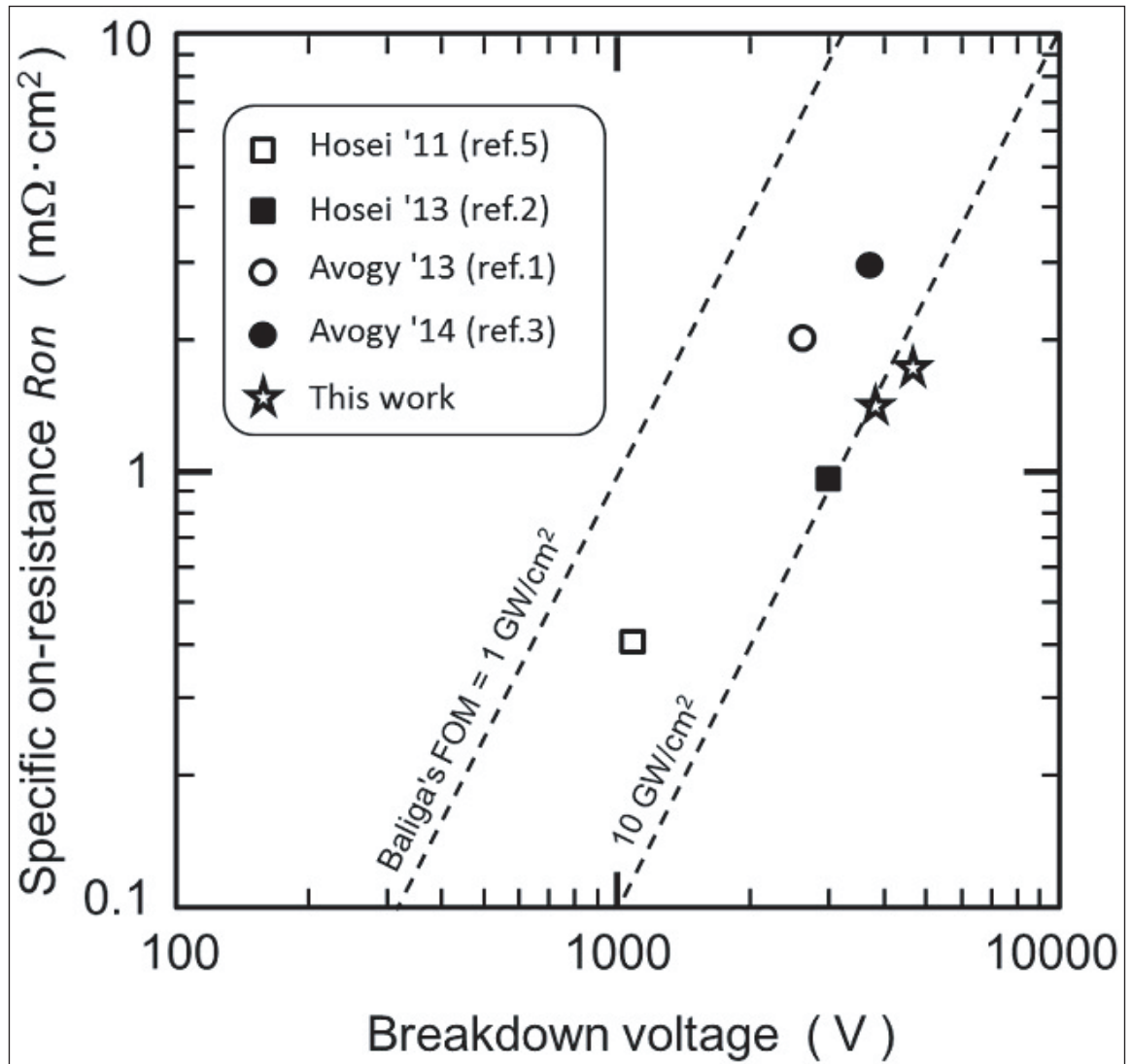


Figure 2. Relationship between the specific on-resistance and breakdown voltage of the GaN p-n junction diodes fabricated by Ohta et al with previously reported results.

The researchers comment that it might be possible to obtain similar or higher breakdown voltage from a single undoped GaN thicker layer, but the R_{on} would increase significantly because of lower electron carrier densities under forward bias. “Hence, the particular drift layer of this study was shown to be effective in raising the total performance of GaN p-n diodes,” they add.

The Baliga figure of merit (FOM) — $(\text{breakdown voltage})^2/R_{\text{on}}$ — was $13\text{GW}/\text{cm}^2$, “the best values ever reported among those achieved by GaN p-n junction diodes on free-standing GaN substrates,” according to the team. GaN devices have previously achieved Baliga FOMs an order of magnitude larger than for silicon carbide Schottky-barrier diodes.

The breakdown for the GaN p-n diodes occurred at the mesa or field-plate edge, suggesting that improvements in insulation and field-plate fabrication could increase breakdown performance. ■

<http://ieeexplore.ieee.org/xpl/abstractAuthors.jsp?reload=true&arnumber=7273835>

Author: Mike Cooke

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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.,
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www.crosslight.com

Semiconductor Technology Research Inc

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www.semitech.us

22 Used equipment**Class One Equipment Inc**

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Fax: +1 770 808 8308

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23 Services**Henry Butcher International**

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UK

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www.henrybutcher.com

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Stuttgart,
Germany

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Fax: +49 711 8804 1950

www.mw-zander.com

24 Consulting**Fishbone Consulting SARL**

8 Rue de la Grange aux Moines,
78460 Choisel,
France

Tel: + 33 (0)1 30 47 29 03
E-mail: jean-luc.ledys@neuf.fr

25 Resources**Al Shultz Advertising Marketing for Advanced Technology Companies**

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www.semi.org

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2015 IEEE International Electron Devices Meeting (IEDM)

Washington Hilton, Washington DC, USA

E-mail: iedm@his.com

www.ieee-iedm.org

16–18 December 2015

SEMICON Japan 2015

Tokyo Big Sight, Tokyo, Japan

E-mail: jcustomer@semi.org

www.semiconjapan.org/en

27–29 January 2016

SEMICON Korea 2016

COEX, Seoul, South Korea

E-mail: semiconkorea@semi.org

www.semiconkorea.org/en

13–18 February 2016

SPIE Photonics West 2016

Moscone Center San Francisco, CA, USA

E-mail: customerservice@spie.org

<http://spie.org/SPIE-PHOTONICS-WEST-conference>

1–3 March 2016

SIL 2016: Strategies in Light, co-located with The LED Show

Santa Clara Convention Center, CA, USA

E-mail: registration@pennwell.com

www.strategiesinlight.com

15–17 March 2016

SEMICON China 2016

Shanghai New International Expo Centre, China

E-mail: semichina@semi.org

www.semiconchina.org

19–24 March 2016

APEC:

2016 IEEE Applied Power Electronics Conference and Exposition

Long Beach Convention Center, CA, USA

E-mail: apec@apec-conf.org

www.apec-conf.org

4–7 April 2016

SPIE Photonics Europe 2016

SQUARE Brussels Meeting Centre, Brussels, Belgium

E-mail: info@spieeurope.org

<http://spie.org/SPIE-PHOTONICS-EUROPE-conference>

13–16 April 2016

LED Taiwan 2016 and Taiwan International Lighting Show

Taiwan World Trade Center, Taipei, Taiwan

E-mail: sluo@semi.org

www.ledtaiwan.org

17–21 April 2016

SPIE Defense + Commercial Sensing 2016 (DCS), incorporating:

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SPIE Defense + Security (Conference on Sensors, Imaging, and Optics)
SPIE Commercial + Scientific Sensing and Imaging (Conference on Advanced Technologies and Applications)

Baltimore Convention Center, Baltimore, MD, USA

E-mail: customerservice@spie.org

<http://spie.org/SPIE-DCS-conference>

<http://spie.org/SPIE-DCS-Defense+Security>

<http://spie.org/SPIE-DCS-Commercial-Sensing>

25–27 April 2016

12th International Conference on Concentrator Photovoltaics (CPV-12)

Freiburg, Germany

E-mail: info@cpv-12.org

www.cpv-12.org

6 May 2016

31st annual Reliability Of Compound Semiconductors (ROCS) Workshop 2016

Hyatt Regency Miami, FL, USA

Abstract deadline: 29 February 2016

E-mail: rocs@jedec.org

www.jedec.org/home/gaas

16–19 May 2016

2016 CS MANTECH (International Conference on Compound Semiconductor Manufacturing Technology)

Hyatt Regency Miami, FL, USA

E-mail: conferencechairman@gaasmantech.org

www.csmantech.org

5–10 June 2016

CLEO 2016 (Conference on Lasers and Electro-Optics)

San Jose Convention Center, CA, USA

E-mail: info@cleoconference.org

www.cleoconference.org

13–17 June 2016

2016 Symposia on VLSI Technology and Circuits

Hilton Hawaiian Village, Honolulu, HI, USA

E-mail: vlsi@vlsisymposium.org

www.vlsisymposium.org

26–30 June 2016

Compound Semiconductor Week 2016 (CSW2016), including:

43rd International Symposium on Compound Semiconductors (ISCS2016);

28th International Conference on Indium Phosphide and Related Materials (IPRM2016)

Toyama International Conference Center, Japan

Abstract deadline: 8 February 2016

www.csw-jpn.org

12–14 July 2016

SEMICON West 2016

Moscone Center, San Francisco, CA, USA

E-mail: semiconwest@xpressreg.net

www.semiconwest.org

28 August – 1 September 2016

SPIE Optics + Photonics 2016

San Diego Convention Center, CA, USA

Abstract deadline: 8 February 2016

E-mail: customerservice@spie.org

<http://spie.org/optics-photonics1>

7–9 September 2016

SEMICON Taiwan 2016

Taipei Nangang Exhibition Center, Taiwan

E-mail: semicontaiwan@semi.org

www.semicontaiwan.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

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

5–7 December 2016

IEEE International Electron Devices Meeting (IEDM 2016)

Hilton San Francisco and Towers, CA, USA

E-mail: iedm@his.com

www.ieee.org/conference/iedm

7–9 December 2016

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