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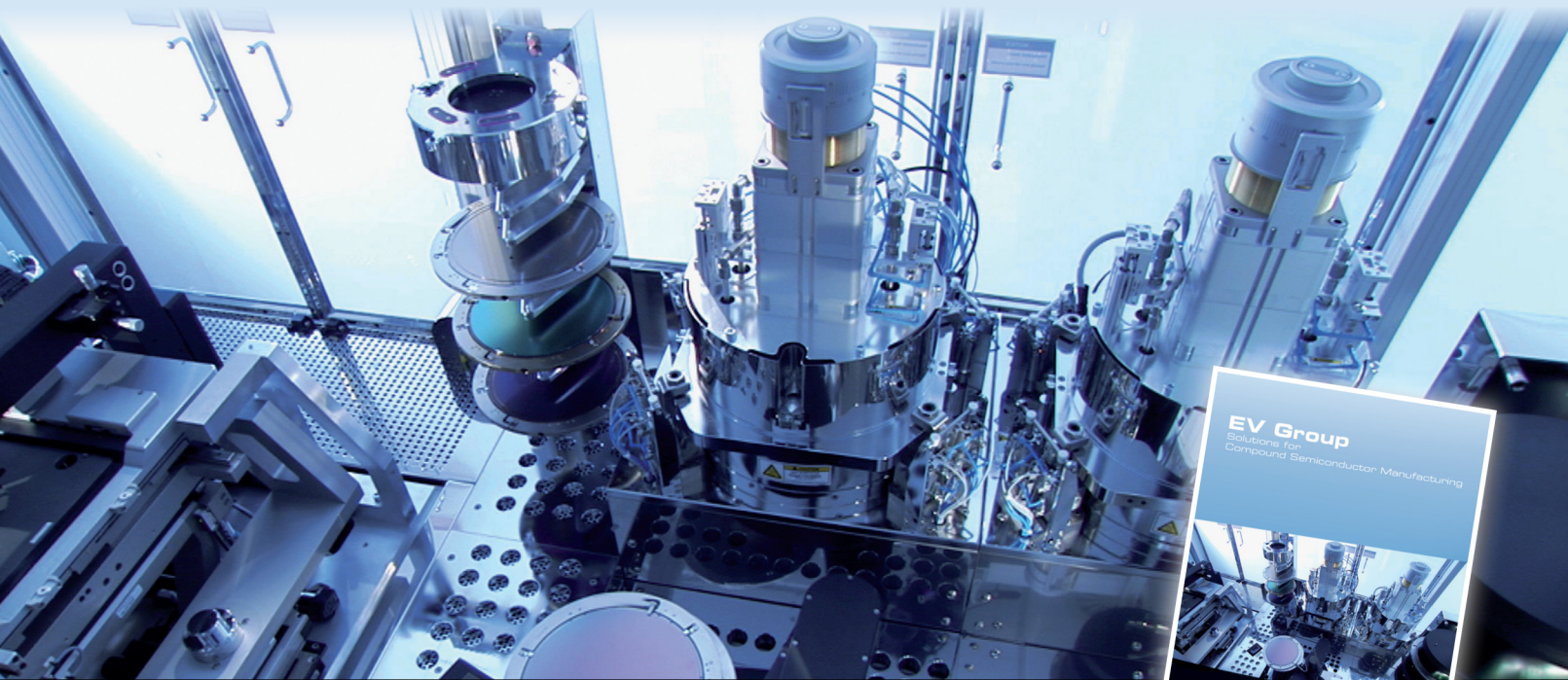

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semiconductorTODAY

COMPOUNDS & ADVANCED SILICON

Vol. 10 • Issue 10 • December 2015/January 2016 www.semiconductor-today.com

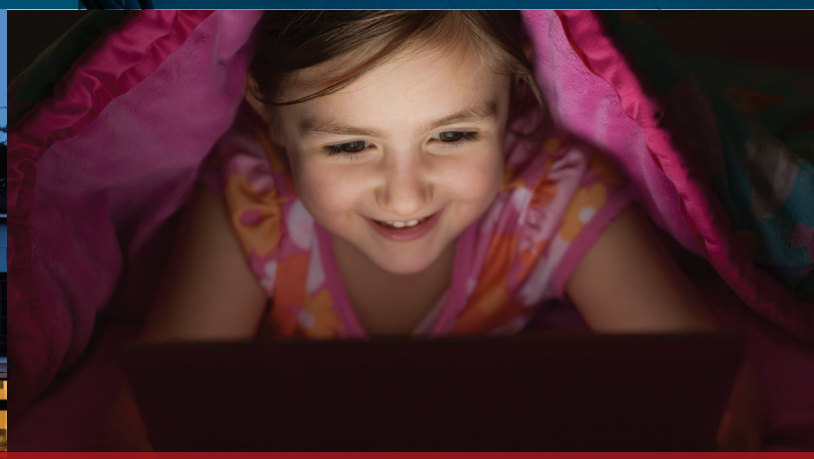
First terahertz VECSEL laser

IEDM conference report

II-VI Inc agrees to buy Anadigics & EpiWorks

GaAs IC market grows 25% • VCSEL market growing at 22% CAGR
Qorvo expands • SETi acquires Nitek • SemiLEDs to go fabless

Lower Cost LEDs



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Veeco's New TurboDisc EPIK700 GaN MOCVD System

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COMPOUNDS & ADVANCED SILICON

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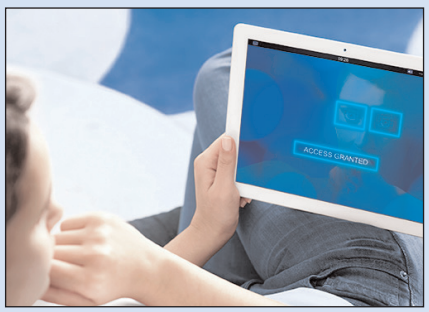
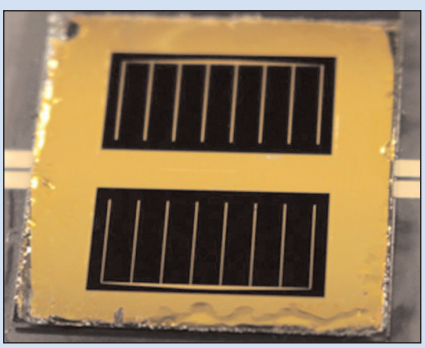
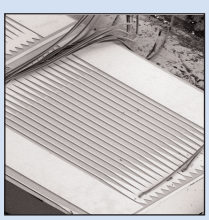
p48 Lee Biing-jye, chairman of Taiwanese LED chip supplier Epistar Corp, has received the 2015 Pan Wen Yuan Award, in the technology sector.



p52 Osram Opto's new infrared SFH 4786S LED provides the basis for low-profile systems for biometric identification by iris recognition.



p68 NREL/CSEM's GaInP/Si tandem cell, which has set a record one-sun dual-junction efficiency record of 29.8%.



Cover: Researchers at University of California, Los Angeles have identified a new way to make a semiconductor laser operating at terahertz frequencies. Unlike a simple mirror, the metasurface amplifies terahertz waves as well as reflecting them. Applications include aerospace and law enforcement. **p56**

editorial

VCSELs driving II-VI expansion

Similarly to the turn of the year two years ago when RF Micro Devices and TriQuint Semiconductor unveiled their agreement to merge, this New Year has seen further consolidation, in the form of the takeover of Anadigics. However, whereas the RFMD–TriQuint merger then took most of 2014 to finalize (forming Qorvo), Anadigics' acquisition was initiated by an offer from GaAs Labs of $0.35 per share ($32m in total) being accepted in November.

GaAs Labs previously (in 2009) acquired M/A-COM Technology Solutions — which subsequently bought gallium arsenide (GaAs)-based device maker Mimix Broadband in 2010 — followed (in 2014) by gallium nitride (GaN) device maker Nitronex (subsequently also merged into MACOM).

However, GaAs Labs' offer was followed by repeated unsolicited higher bids that led to GaAs Labs' withdrawal and rival II-VI Inc agreeing in mid-January to acquire Anadigics for $0.66 per share, worth $61m in total (and to pay a deal termination fee owed by Anadigics to GaAs Labs) — see page 11. A higher $0.75-per-share offer from a further Chinese bidder was deemed to be unfavorable due to the likely delay from needing clearance from the Committee on Foreign Investment in the United States (CFIUS). Anadigics reckons the II-VI tender offer could be concluded in 45–60 days (mid-March).

Compared with the formation of the $2–3bn-turnover Qorvo, quarterly revenue for Anadigics (founded in 1985) has dwindled from over $80m in 2008 and $37m in Q3/2013 to just $12m, with net cash falling to $7.9m. However, apart from being a manufacturer of RFICs using 6" GaAs wafers as well as GaN technology, Anadigics has developed the industry's first vertical-cavity surface-emitting laser (VCSEL) manufacturing line using 6" GaAs substrates. In August, Anadigics announced a foundry manufacturing service agreement involving the transfer of proprietary planar optoelectronic technology from POET Technologies, which has developed processes for the monolithic fabrication of integrated III-V-based electronic and optical devices on a single wafer. Then, in mid-January, POET announced a multi-year development and production supply agreement for epiwafer foundry EpiWorks to manufacture wafers for its monolithic optoelectronics process platform using metal-organic chemical vapor deposition (see page 59).

Subsequently on 19 January, simultaneous with its acquisition of Anadigics, II-VI also announced that it is acquiring EpiWorks, for $43m in cash (due on closing the deal) plus a $6m earn out (totaling $110m for Anadigics and EpiWorks collectively) — see page 58. EpiWorks comments that: "Teaming with II-VI allows us to go beyond the typical epiwafer foundry model by offering not just scale but a level of sophistication, flexibility and capability needed in our industry as it is scaling and evolving... those who can innovate and scale will certainly build a sustained advantage".

In late 2013, II-VI previously acquired from San Jose-based Oclaro its Zurich-based Oclaro Switzerland laser diode subsidiary for $115m and its Amplifier & Micro-Optics business for $88.6m. II-VI this month said it was supplementing its 980nm pump laser sub-assembly capacity in Zurich with a new plant in the Philippines and boosting module assembly capacity at its plant in Shenzhen, China (see page 60).

II-VI's expansion into the VCSEL sector is being driven by forecasts that the market ($611.3m in 2014) will rise at a compound annual growth rate of nearly 22% to $2105.3m in 2020, driven by rising demand in data centers and consumer electronics (see page 6).

Mark Telford, Editor

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Editor
Mark Telford
Tel: +44 (0)1869 811 577
Cell: +44 (0)7944 455 602
Fax:+44 (0)1242 291 482
E-mail: mark@semiconductor-today.com

Commercial Director/Assistant Editor
Darren Cummings
Tel: +44 (0)121 288 0779
Cell:+44 (0)7990 623 395
Fax:+44 (0)1242 291 482
E-mail: darren@semiconductor-today.com

Advertisement Sales
Darren Cummings
Tel: +44 (0)121 288 0779
Cell:+44 (0)7990 623 395
Fax:+44 (0)1242 291 482
E-mail: darren@semiconductor-today.com

Original design Paul Johnson
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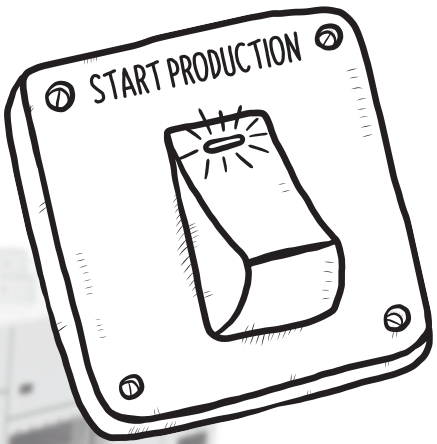

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VCSEL market to grow at 21.99% CAGR to $2.1bn in 2020

North America to be largest market, while APAC grows fastest at 23.8%

The market for vertical-cavity surface-emitting lasers (VCSELs) was $611.3m in 2014 and is projected to grow at a compound annual growth rate (CAGR) of 21.99% from 2015 to $2105.3m in 2020, according to the report 'VCSEL Market — Forecast to 2020'' from Markets and Markets.

VCSELs are widely used in optical fiber data communication, sensing, infrared illumination, pumping and industrial heating. Their major role in all these applications comprises reducing operating cost and power consumption as well as providing high performance. The main end-users of the technology are data centers and sectors such as consumer electronics, industrial, automotive, and healthcare.

Over the past two decades, about 1 billion VCSELs have been shipped, most of which were 850nm-emitting lasers based on gallium arsenide (GaAs). Major players covered by the report include Avago Technologies, Finisar Corp, II-VI Inc, IQE plc, JDS Uniphase Corp, and Princeton Optronics Inc. The majority of shipments have been utilized in data communications and sensing. This growth can be attributed to the rising demand for VCSELs in data centers and consumer electronics products.

VCSELs are expected to be in demand in data centers in the next 5–6 years because of their low power consumption and high-speed data transmission capabilities over short ranges. Moreover, emerging applications such as 3D imaging and gesture recognition are expected to generate new opportunities in the consumer electronics sector as well. However, despite the many advantages offered by VCSELs, their limited range of data transmission restricts their deployment to a select few applications, notes the report.

Emerging applications such as 3D imaging and gesture recognition are expected to generate new opportunities in the consumer electronics sector

VCSELs are expected to see the fastest growth in infrared illumination, pumping and industrial heating applications. Geographically, North America should be the largest market, whereas the Asia-Pacific (APAC) region is estimated to exhibit the fastest growth, at a CAGR of 23.8% during 2015–2020.

www.researchandmarkets.com/publication/mslc8z2/vcsel_market_by_application

Infrared LED market to grow at CAGR of over 9% during 2015–2020

The global infrared LED market is projected to grow at a compound annual growth rate (CAGR) of more than 9% during 2015–2020, according to the report 'Global Infrared LED Market By Application (Imaging, Lighting, Surveillance, Automotive and Others), By Region (Asia-Pacific, Americas, Europe, and Middle East and Africa) and Competition Forecast and Opportunities, 2010–2020' by TechSci Research.

Demand for infrared LEDs has been increasing over the last few years, due to their rising penetration into applications including the automotive, defense and consumer electronics sectors. Major applications include imaging, surveillance, automotive, and lighting. Specifically, major factors propelling growth include the rising use of infrared LEDs in smartphones for iris recognition, and increasing use of these LEDs in CCTV and surveillance systems.

Demand for infrared LEDs has been increasing over the last few years, due to their rising penetration into applications including the automotive, defense and consumer electronics sectors

Infrared LEDs are also being used increasing in handheld devices for identity verification and mobile payment technologies. Also, rising security concerns in both developing countries and developed countries is driving demand for surveillance devices and biometrics systems that are being deployed across various sectors such as education, defense, healthcare, and residential.

Asia-Pacific is the largest regional market for infrared LEDs in the world, due to the increasing penetration of infrared LEDs in smartphones, automotive, surveillance systems and other segments, notes the report.

Major companies involved in manufacturing infrared LEDs for various end-user applications include Epistar Corp, Nichia Corp, Everlight Electronics and High Power Lighting, adds the market research firm.

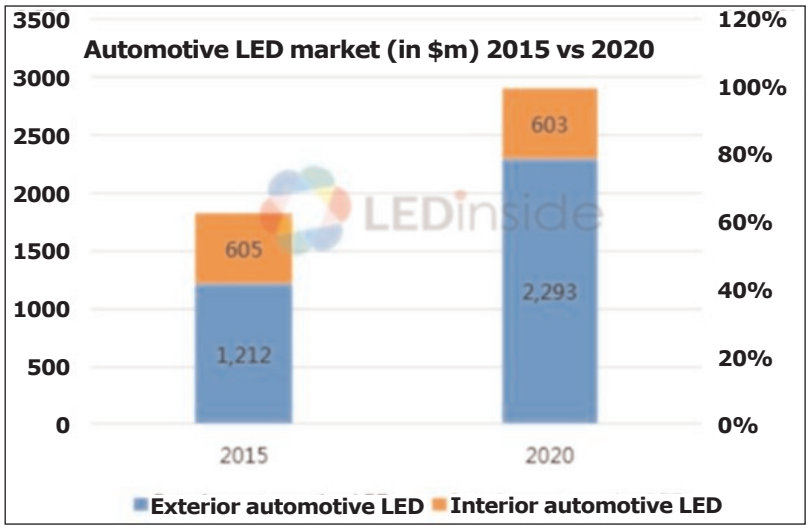
www.techsciresearch.com/report/

Exterior automotive LED market to grow at 8% CAGR from $1.21bn in 2015 to $2.29bn in 2020

LED makers are branching into niche application markets as competition in their industry expands, comments LEDinside in its latest 'Gold Member Report – 2016 LED Market Demand and Supply Analysis'. Currently, entering the automotive LED market is regarded as a blue-ocean strategy because the market has relatively few contestants and allows for higher pricing, it adds.

In particular, the market for exterior automotive LEDs is projected to rise at a compound annual growth rate (CAGR) of 8% from $1.21bn in 2015 to $2.29bn in 2020. Also, the market value of standard-power LEDs is gradually declining in contrast to the rapidly rising market value of high-power LEDs. In the future, automotive LED application will take off in the high-power LED market.

Exterior automotive lighting includes directional signals, fog lights, headlights (high/low beam) and position lights. The volume of high-power LEDs used for this application has been growing each year, says LEDinside research manager Duff Lu. The annual volume increases have also beaten the annual declines in high-power LED prices, helping to drive the expected CAGR of over 8% in market value of exterior automotive LEDs during 2015–2020. Lu adds that the penetration of LED products in the exterior automotive market is currently less than 15%, so the growth potential is huge. High/low-beam LEDs in particular will see the highest growth in market value, with a CAGR of 11% during 2015–2020.



Based on LEDinside's estimates, the total LED volume used in exterior automotive applications will grow from 2.79 billion units in 2015 to 3.67 billion in 2020. Specifically, the number used in headlights and position lights will grow at a CAGR of 15%, although high/low-beam LEDs will have the highest CAGR of 23%.

Interior automotive LED market value to fall as applications of standard LEDs contract

As for interior automotive LEDs, most products on the market still use standard-power LEDs. With the average sales prices (ASPs) of standard-power LEDs in a tailspin, the global market value of interior automotive LEDs is expected to suffer negative growth in the next five years. LEDinside estimates that the market reached $605m in 2015 but will drop to $603m by 2020.

The only exception to this down-trend is LEDs for automotive instrument clusters. The market for this application continues to grow against headwinds as the traditional mechanical instruments on the cluster are being replaced by LED instrument panels. The average size of these panels is also expanding, so more LEDs are needed. LEDinside hence projects a CAGR of 3% for this market in 2015–2020.

www.trendforce.com

LEDs over half of horticultural luminaire sales in 2017

In some regions, light-emitting diode (LEDs) are expected to comprise more than half of new horticultural luminaire sales as early as 2017, according to the report 'LED Lighting for Horticultural Applications' from market analyst firm Navigant Research.

Although horticultural LED products have been commercially available for a decade, their adoption is now beginning to pick up as the technology and its quality advances. Today, LEDs are significantly more efficient, and the additional benefit of supplying the correct wavelengths of light to improve crop yield has made them the lighting technology of choice in a growing number of facilities.

"LED technology is able to greatly improve the profitability of indoor farming, which is leading to a boom in the growth of such facilities," says senior research analyst Jesse Foote. "By increasing crop yields and allowing more efficient use of energy and space, LEDs are leading to a boom in new indoor food production facilities."

According to the report, the low heat output of LED lighting allows growers to place lights closer to plants without singeing leaves and without needing additional heating, ventilating and air conditioning (HVAC) equipment, allowing a much greater density of plants within vertical indoor facilities. At the same time, the fine-tuned application of specific wavelengths of light from LEDs can increase crop yield by up to 30%, depending on the plant species.

www.navigantresearch.com

GaAs IC market grows 25% in 2015

Growth driven by smartphones and Internet of Things

Strong wireless demand resulted in growth of more than 25% in the gallium arsenide (GaAs) IC market in 2015, according to a new report from The Information Network.

Every cell phone contains power amplifiers (PA), enabling the handset to transmit voice and data back to the base-station tower. As the most critical radio frequency component in the phone, PAs are currently dominated by circuits made with GaAs.

2G handsets contain one PA while 3G handsets often contain up to five PAs, and GaAs comprises nearly 100% of the market. Typically, the power amplifier is based on GaAs heterojunction bipolar transistor (HBT) technology to amplify RF signals in the phone. Today's RF front-ends are moving towards multi-mode, multi-band power amplifiers (MMPAs). Regarding 4G, according to the report, Apple's 6S smartphone contains six power amplifiers: Avago's ACPM-7600 and ACPM-8010, Qualcomm's QFE2320 and QFE2340, and Skyworks' SKY85303 and SKY85707.

GaAs power amplifiers will continue to lose market share to silicon-based CMOS, but will remain the dominant RF technology

In its report 'The GaAs IC Market', The Information Network notes that GaAs power amplifiers will continue to lose market share to silicon-based CMOS (complementary metal oxide semiconductor), but will remain the dominant RF technology in the foreseeable future. In particular, pricing for PAs has risen from $0.30 per 2G handset to $1.25 per 3G handset and $3.25 for global long-term evolution (LTE) technology, adds the report.

www.theinformationnet.com

RF component market to reach $17.54bn by 2022

Silicon germanium and gallium arsenide to boost growth

The global market for radio frequency (RF) components (including filters, duplexer, power amplifiers, antenna switches, and modulators & demodulators) is expected to reach $17.54bn by 2022, according to a study by Grand View Research Inc.

Growing adoption of consumer electronics including smartphones, tablets, notebooks, set-top boxes and smart televisions is forecasted to fuel industry growth over the next few years. Rising consumer disposable income, particularly in developing countries like India and Brazil — paired with overall improvement in the global economy — may elevate demand significantly, the report reckons. Technological advancements in wireless communications and development in the materials used for manufacturing RF components, such as silicon germanium (SiGe) and gallium arsenide (GaAs), are also expected to drive industry growth.

Increasing popularity and adoption of high-speed networks, such as 3G and 4G, have significantly impacted demand for RF components, notes the report. Technological advancement enhancing antenna efficiency, by replacing traditional filters with advanced tunable filter, may escalate demand over the next seven years. The industry is also poised for growth due to increasing demand across the automotive industry. Increasing effort on the development of advanced and innovative wireless infrastructure may also propel product demand, the report adds.

The power amplifier (PA) segment accounted for over 30% of the overall RF component market in 2014. This is expected to increase over the next few years, due to the increasing prevalence of mixed-mode 3G/4G handsets coupled with a growing emphasis on LTE concept.

Antenna switches are estimated to exhibit rapid growth over the coming years, which may be attributed primarily to increasing experimentation with switch architectures, particularly in higher-end handsets. A growing number of 3G/4G handsets are anticipated to broadly contribute to this rapid growth.

The consumer electronics segment accounted for more than 60% of global revenue in 2014. This is expected to increase over the coming years, due to rising disposable income among consumers, resulting in increasing adoption of consumer electronic products. Increasing consumer spending for smartphone, tablets and other portable electronic devices may spur demand, the report says.

North America accounted for over 30% of global revenue in 2014. Increasing demand for better mobility solutions is estimated to drive regional market growth. The Asia Pacific RF components market is forecasted to see dramatic growth over the coming years, due to the increasing adoption of improved connectivity solutions in the region.

The report lists key players in the RF component industry as Avago Technologies Ltd, Aixtron SE, NXP Semiconductors, RFaxis, STMicroelectronics, Texas Instruments, Renesas Electronics Corp, Fujitsu Ltd and Freescale Semiconductor Inc.

www.grandviewresearch.com/industry-analysis/radio-frequency-rf-components-market

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Qorvo to invest $25m and hire 100 staff in next 3 years to expand Greensboro operations

Local government grants to aid product development in new R&D center

Qorvo Inc of Greensboro, NC and Hillsboro, OR, USA (which provides core technologies and RF solutions for mobile, infrastructure and aerospace/defense applications) is to invest $25m in North Carolina by opening a new facility in Guilford County and hiring 100 staff over the next three years (adding to Qorvo's existing workforce of more than 1400 in Greensboro plus 1000 in Hillsboro), according to an announcement by North Carolina governor Pat McCrory, commerce secretary John E. Skvarla III, and the Economic Development Partnership of North Carolina (EDPNC).

Qorvo was formed in January by the merger of RF component makers TriQuint Semiconductor Inc of Hillsboro and RF Micro Devices Inc, which was founded in Greensboro in 1991, and has a design center in High Point, NC (also in Guilford County). RFMD and TriQuint had combined revenues of $2.1bn in 2014.

"Qorvo's choice of Greensboro for this expansion showcases the exceptional technology talent companies find in our state," says Skvarla. "It makes good business sense that we recognize our existing industries, especially those with deep entrepreneurial roots right here in North Carolina."

As part of its $25m expansion, Qorvo is planning to invest $19.5m in a 150,000ft^2 R&D center adjacent to its corporate offices in Greensboro plus $5.5m in equipment. Qorvo's expanded operations should help to accelerate product development. The extra staff will include new engineering jobs with average annual salaries of about $80,000 per year. Guilford County's overall annual wage is $43,581.

"We appreciate the outstanding support provided by the State of North Carolina as Qorvo builds on its technology and product leadership to serve our many global customers," comments Qorvo's president & CEO Bob Bruggeworth. "North Carolina offers an excellent economic climate for growth and innovation as we continue to expand here and in our other locations."

Qorvo's expansion in North Carolina was made possible in part by a performance-based grant of up to $500,000 from the One North Carolina Fund, which provides financial assistance to support local governments in creating jobs and attracting economic investment. Companies receive no money upfront and must meet job creation and capital investment targets to qualify for grant funds. All One NC grants require a local government match. In September the Guilford County Board of Commissioners approved providing up to $333,570 in performance-based incentives to Qorvo, and the Greensboro City Council approved up to $544,279 in performance-based incentives.

As well as North Carolina Commerce and EDPNC, other key partners in the project include the City of Greensboro, Greensboro Partnership, High Point Economic Development Corporation, Guilford County, Guilford County Workforce Development Board, Guilford Tech Community College, NC A&T University, UNC Greensboro, Duke Energy and Piedmont Natural Gas. Greensboro Partnership says Qorvo will recruit talent from local colleges and schools, including N.C. A&T State University, UNC Greensboro and Guilford Technical Community College.

www.edpnc.com

Qorvo lowers quarterly revenue guidance from $720-730m to $620m due to weak demand for Mobile Products

March quarter to be flat sequentially

Qorvo Inc of Greensboro, NC and Hillsboro, OR, USA, which provides core technologies and RF solutions for mobile, infrastructure and aerospace/defense applications, has lowered its guidance for revenue and earnings for its fiscal third-quarter 2016 (to end-December) compared with the guidance given on 5 November.

Rather than its original guidance of $720–730m (up about 2.5% on last quarter's $708.3m), Qorvo now expects revenue of about $620m (down 12.5%), due to weaker-than-forecasted demand in the Mobile Products segment.

Operating expenses are expected to decline sequentially from last quarter's $156.8m, reflecting a significant reduction in variable compensation expense.

During the quarter, Qorvo repurchased about 4.6 million shares of common stock at a total cost of $250m. Qorvo has $750m remaining in its share repurchase program (which was approved in November 2015, and expires on 4 November 2016), and its cash balance at the end of the quarter was over $1bn.

For the March 2016 quarter, Qorvo expects revenue to be roughly flat sequentially. For calendar 2016, it expects above-market revenue growth, based on customer forecasts and existing customer design wins at the firm's largest customers.

Qorvo expects to release fiscal third-quarter 2016 results on 4 February.

www.qorvo.com

Anadigics sells for $0.66 per share to II-VI Inc; II-VI to pay GaAs Labs termination fee

$0.75 Chinese offer thwarted by potential delays from CFIUS clearance

Broadband wireless and wireline communications component maker Anadigics Inc of Warren, NJ, USA says that, on 15 January, it agreed for engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA to acquire it (pursuant to an all-cash tender offer and second-step merger) for $0.66 per share net in cash (an increase of $0.31 per share over the 11 November deal for affiliates of GaAs Labs LLC to acquire it for $0.35 per share). On 12 January, Anadigics announced that the $0.66 per-share offer from II-VI ('Party A') had been determined by its board of directors to constitute a 'superior offer'. GaAs Labs subsequently declined to submit a further amended acquisition proposal.

On 14 January, another Excluded Party (Party B) delivered a further revised proposed merger agreement to acquire Anadigics for $0.75 per share. However, despite the increased offer price, Anadigics' board reckoned that the proposal failed to incorporate certain key terms and conditions demanded for the protection of Anadigics and its stockholders. Because Party B is a Chinese company, the closing of its proposed acquisition could be subject to delay caused by, among other things, the review and clearance process to be undertaken by the Committee on Foreign Investment in the United States (CFIUS). Based on consultation with its management and legal advisors, the board estimated that it could take 100 days or so from the date of execution of a merger agreement for the parties to confer with CFIUS, to assemble and prepare the materials required to make the CFIUS filing, to make the actual CFIUS filing, and for CFIUS to complete what could then be a 75-day review period. To protect Anadigics' business and financial condition in the event that the closing of the proposed transaction with Party B were delayed as a result of the CFIUS review process, the board demanded that Party B (a) pay it a cash reverse termination fee, and (b) provide a loan on terms acceptable to Anadigics and its bank.

In the judgment of Anadigics' board, in light of the firm's current business and financial condition (including the challenges caused by the uncertainty surrounding the bidding process in which it has been engaged since November), Party B's 14 January revised proposal did not provide adequate protection against the potentially irreparable harm to Anadigics' business and financial condition that could result if the proposed transaction did not close in a timely manner, including losing the opportunity to obtain $0.66 per-share through the II-VI merger agreement (due to expire on 15 January).

Anadigics' board believes that (subject to satisfaction of the terms of the proposed II-VI tender offer) II-VI could close its merger transaction with Anadigics in 45–60 days.

On 15 January, in accordance with the II-VI merger agreement, the termination fee owed by Anadigics under the GaAs Labs merger agreement was paid to GaAs Labs by II-VI.

www.anadigics.com

Qorvo launches 802.11ac Wi-Fi front-end modules supporting MIMO and 4K UHD capability

Qorvo Inc has expanded its portfolio of Wi-Fi products to include new front-end modules (FEMs) designed for wireless broadband home gateways and set-top-boxes.

Offering what is claimed to be the industry's best power consumption, linearity, and throughput, the RFFM4552 and RFFM4558 5GHz 802.11ac FEMs support multi-user multi-input/multi-output (MU-MIMO) with up to 8x8 antenna configurations, allowing gateways to deliver multiple wireless streams simultaneously to different devices, including new 4K ultra-high-definition (UHD) televisions and DVD players. Also, the 1024 QAM modulation capabilities enable what are claimed to be the highest data rates possible in Wi-Fi solutions.

"Qorvo's new high-performance FEMs enable service providers and OEMs to differentiate their Wi-Fi routers, broadband gateways and set-top-boxes with improved overall system performance and industry-leading power consumption," claims James Klein, president of Qorvo's Infrastructure and Defense Products. "By offering the best efficiency and thermal performance, our front-end modules help Wi-Fi device manufacturers support the high data rates and throughput needed for today's increasingly connected home," he adds.

The front-end modules deliver system-level compliance in the band-edge to meet FCC regulations and significant performance requirements related to radiated harmonics. The RFFM4552 is available in a 3mm x 3mm QFN package and the RFFM4558 is available in a 2.5mm x 2.5mm package, and both FEMs are sampling now.

www.qorvo.com

Skyworks expands suite of SkyLiTE front-ends to support SoC platforms & IoT with embedded cellular connections

Skyworks has expanded its family of SkyLiTE front-end solutions powering LTE devices. Originally targeted for mobile platforms in emerging markets (when the firm began volume production of its initial SkyLiTE front-end solutions for LTE in January 2015), the newest solutions are also being adopted across Internet of Things (IoT) applications that utilize embedded cellular connections such as the connected car and wearables.

The SkyLiTE product family incorporates the amplification, switching, Wi-Fi filtering and coupler functionality required to support all major FDD/TDD bands and has been architected to support hardware and software compatibility demands for all major system-on-a-chip platforms. With the addition of external duplexers, the product suite provides OEMs with a scalable and reconfigurable front-end system for broad markets and applications worldwide.

"As the world becomes more connected, OEMs require partners who can deliver system-level solutions across traditional as well as new and previously unimagined applications," says VP of marketing Carlos Bori. "With our SkyLiTE portfolio, Skyworks is once again delivering the innovation required by customers seeking the highest levels of integration, performance and flexibility spanning the smartphone, automotive, industrial and wearable markets."

According to a GfK Projector Model Report last September, LTE will represent about 49% of total handsets by 2016, up from 22% in 2014. Further, according to a recent GSMA Intelligence Report, the M2M (machine-to-machine) market has seen rapid growth globally over recent years as operators and governments recognize the potential of IoT and as the number of active deployments starts to accelerate. As of December 2014, there were 243 million cellular M2M connections globally. This is expected to grow at a compounded annual growth rate (CAGR) of 26% over 2014–2020 to almost 1 billion connections. In the automotive sector, Business Intelligence forecasts that there will be 100 million new cars shipped with built-in connectivity by 2020, up from just 20 million today.

Targeting these fast-growing segments, Skyworks says its expanded family of SkyLiTE solutions (joining the SKY77643-11, SKY77824-11, SKY77910-11 and SKY77916-11) comprises the following products:

- The SKY77643-21 is a multimode multiband power amplifier (MMPA) module that supports 3G/4G handsets and operates efficiently in WCDMA, TD-SCDMA and LTE modes. It is fully programmable through a Mobile Industry Processor Interface (MIPI). The InGaP and silicon die, along with the passive components, are mounted on a multi-layer laminate substrate and come in a 4.0mm x 6.8mm x 0.8mm, 42-pad multi-chip module (MCM), surface-mount technology (SMT) package for what is claimed to be a highly manufacturable, low-cost solution.
- The SKY77822-21 is a fully matched, 28-pad surface-mount power amplifier module developed for LTE applications. It includes broadband coverage of FDD LTE Bands 7 and 30, TDD LTE Bands 38/40 and Band 41, all in a compact 4.0mm x 3.65mm package. The device delivers savings in current consumption for data-intensive applications by attaining high efficiencies throughout the power range.
- The SKY77916-21 is a transmit/receive front-end module (FEM) that offers the complete transmit VCO-to-antenna and antenna-to-receive SAW filter solution for advanced cellular handsets comprising quad-band GSM, GPRS, EDGE multi-slot operation, and TD-SCDMA and TDD LTE transmission. The FEM fully enables broadband 3G/4G RF switch-through, outward switching of the power amplifier RF inputs, 14 transmit/receive antenna switch ports, and an integrated directional coupler.
- The SKY77641 is an MMPA module that supports 3G/4G handsets and operates efficiently in WCDMA, TD-SCDMA and LTE modes. Fully programmable through a MIPI, it consists of a WCDMA/LTE block for low, high and mid-bands, and a multi-function control block with RF input/output ports internally matched to 50 to reduce the number of external components.

www.skyworksinc.com

Skyworks launches BDS/GPS/GNSS low-noise amplifiers

Skyworks has launched two new low-noise amplifiers for global navigation satellite systems (GNSS).

Each device integrates all output matching components, and hence requires only a single external input matching component. The LNAs use surface-mount technology in the form of quad flat no-lead (QFN) packaging, allowing for highly manufacturable and low-cost solutions. The SKY65605-21 comes in a 0.7mm x 1.1mm x 0.55mm package and the SKY65611-11 in a 1.1mm x 0.9mm x 0.45mm package.

The devices provide what is claimed to be high linearity, excellent gain, a high 1dB input compression point (IP1dB), and a superior noise figure. The SKY65605-21 and SKY65611-21 are both designed for BeiDou/GPS/GLONASS/Galileo receiver applications and are optimized to operate at 1559–1606MHz. Suitable applications include smartphones, personal navigation devices, wearables, machine-to-machine systems, base stations, asset tracking instruments and professional radios.

Skyworks launches 75Ω LNAs and high-performance switches enabling higher data rates in connected home

Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) has unveiled its suite of 75Ω low-noise amplifiers (LNAs) and high-performance switches supporting higher data rates across broadband networking platforms in the connected home.

As more devices become connected within the home, consumers are demanding reliable, high-speed, wide-area network (WAN) connections to carry data, voice, video and multimedia content simultaneously, notes Skyworks. The firm's newest solutions support DOCSIS 3.1 standards, which enable speeds of 1Gbps on existing hybrid fiber coaxial (HFC) networks and up to 10Gbps on next-generation systems. According to a recent news article, as of March 2015, the top ten states in the USA with the highest networks speeds averaged internet speeds of just over 40Mbps.

"With consumers demanding ever increasing data rates for audio and video streaming, web browsing and other wireless networking applications within the home, there is a need for high-performance analog solutions supporting broadband platforms that can significantly add capacity and lay the groundwork for future increases in download speeds," says John O'Neill, VP of broad markets. "Skyworks' newest products meet these demanding requirements and further demonstrate our ability to deliver innovative, system-level solutions," he adds. "By partnering with OEMs, Skyworks is able to offer consumers some of the world's fastest networking speeds and Wi-Fi connections within the connected home and across the Internet of Things."

According to a May 2015 Visual Networking Index Forecast by Cisco, broadband speeds will more than double by 2019. By 2019, global fixed broadband speeds will reach 42.5Mbps, up from 20.3Mbps in 2014. Skyworks says that its suite of solutions is enabling devices that support these higher data-rate speeds. Specifically, the firm's new broadband networking solutions include the following products:

- The SKY65450-92LF is a monolithic microwave integrated circuit (MMIC) front-end, low-noise amplifier with bypass mode designed especially for set-top box and home gateway applications. Optimized to operate between 40MHz and 1GHz, the device is claimed to provide high linearity, excellent gain, and best-in-class composite triple beat and composite second order. It is fabricated using silicon germanium (SiGe) BiCMOS technology and manufactured in a 6-pin, SC-70 surface-mount technology (SMT) package.
- The SKY65452-92LF is a MMIC front-end LNA designed for set-top box and home gateway applications. Optimized to operate between 40MHz and 1GHz, the device is claimed to provide high linearity, excellent gain, and best in class composite triple beat and composite second order. It is fabricated using SiGe BiCMOS and manufactured in a 6-pin, SC-70 SMT package.
- The SKY13547-490LF is a single-pole, double-throw (SPDT) 75Ω switch. Its high linearity and low insertion loss meet the most stringent requirements of DOCSIS 3.1 applications. The switch is a 'reflective short' on the isolated port and is provided in a compact 2mm x 2mm, 12-pin QFN package.
- The SKY13548-385LF is a SPDT 75Ω switch intended for mode switching in either pre-select filter or post-select filter in set-top boxes and cable modem applications. Using advanced switching technologies and manufactured in a compact 1mm x 1mm, 6-pin QFN package, the SKY13548-385LF is said to maintain low insertion loss and high isolation for all switching paths.

Skyworks Solutions highlighted its Internet of Things product portfolio at the 2016 International Consumer Electronics Show (CES) in Las Vegas (6–9 January).

www.skyworksinc.com

Skyworks launches BDS/GPS/GLONASS/Galileo low-noise amplifier front-end modules with integrated filters

Skyworks Solutions has launched two new low-noise amplifier (LNA) front-end modules (FEMs) with integrated filters for global navigation satellite systems (GNSS).

The devices provide what is claimed to be high linearity, excellent gain, a high 1dB input compression point (IP1dB), and a superior noise figure (NF). The pre-filters provide the low in-band insertion loss and integrated notch filtering for what is claimed to be excellent rejection of desired frequency bands.

Each device is supplied in small-footprint, surface-mount technology multichip module (MCM) packaging (1.1mm x 1.5mm x 0.7mm for the SKY65713-11 and 1.7mm x 2.3mm x 0.7mm for the SKY65715-81).

The SKY65713-11 and SKY65715-81 LNA FEMs both support products integrating GNSS (global navigation satellite system) functionality such as smartphones, personal navigation devices, wearables, machine-to-machine (M2M) systems, base stations, asset tracking instruments, professional radios and Internet of Things (IoT) applications.

RFaxis unveils new family of CMOS RF front-end ICs for Internet of Things

Fabless semiconductor firm RFaxis Inc of Irvine, CA, USA, which designs RF semiconductors and embedded antenna solutions for wireless connectivity and cellular mobility, has launched a new family of ultra-miniature 2.4GHz RF front-end IC (RFeIC) products for the high-growth Internet of Things (IoT)/M2M (machine-to-machine) market. The RFX25xx-series of products further expands RFaxis' portfolio of RF front-end ICs for the 2.4GHz frequency band that are widely adopted by wireless communication systems for IoT.

The RFX25xx-series is a family of 2.4GHz RFeICs in an ultra-miniature 2.5mm x 2.5mm QFN package (a smaller size option to the existing RFX24xx-series of products). These product families are intended for use in the 2.4GHz spectrum for 802.15.4 ZigBee/Thread, RF4CE, 6LoPAN, ANT and proprietary ISM modulations, while also supporting linear modulations such as Bluetooth Low Energy (BLE), 802.15.4g Smart Utility Network (SUN), and low-power Wi-Fi. They cover a wide array of IoT applications for smart home, smart office, smart building, smart utility, and low-power wide-area networking (LP-WAN), both on the sensor node side and the gateway side.

The RFX25xx-series consists of the RFX2501, RFX2502, RFX2503, RFX2510, RFX2511 and RFX2513. The RFX2501 comes integrated with a high-efficiency power amplifier (PA), low-noise amplifier (LNA), and Transmit/Receive switching circuitry. Similarly, the RFX2502 comes integrated with a high-efficiency, higher saturated and linear power output PA, LNA, Transmit/Receive switch, and directional power detector circuitries.

The RFX2503 comes integrated with a high-efficiency PA, LNA with added bypass mode, Transmit/Receive switch, and directional power detector circuitries.

The RFX2510 is similar and comes integrated with a high-efficiency PA, Transmit/Receive switch with bypass mode, and directional power detector circuitries. It is suitable for wireless IoT systems with transceivers that already have low noise figure, with the added benefit of very minimal current consumption during Receive mode.

For antenna diversity applications, the RFX2511 features a high-efficiency PA, LNA with bypass mode, Transmit/Receive switch, double-pole, double-throw (DPDT) antenna switch for diversity, and directional power detector circuitries. Its derivative product is the RFX2513, which comes with a high-efficiency PA, Transmit/Receive switch with bypass mode, DPDT antenna switch for diversity, and directional power detector circuitries.

As wireless connectivity for IoT and M2M continues to evolve, the need for high-performance, yet simple and cost-effective RF front-end solutions becomes more critical than ever, says RFaxis. The total IoT/M2M wireless connectivity market for fixed, short-range radios as well as LP-WAN is estimated to be 20 billion connected devices by 2025 (according to Machina Research)

The product family comes with different sets of features that allow users to upgrade their wireless IoT systems with extended range, increased tolerance to antenna impedance variations, improved link reliability through antenna diversity, and improved coexistence performance with adjacent radios through LNA bypass. All come with associated matching networks, RF decoupling and harmonic filters, in a single-die, single-chip, and bulk CMOS device in miniature 3mm x 3mm QFN packages. All are also available in bare die form for ultra-compact designs such as system-in-package (SIP) modules. All are rated up to 125°C ambient temperature required by most applications such as smart lighting.

As wireless connectivity for IoT and M2M continues to evolve, the need for high-performance, yet simple and cost-effective RF front-end solutions becomes more critical than ever, says RFaxis. The total IoT/M2M wireless connectivity market for fixed, short-range radios as well as LP-WAN is estimated to be 20 billion connected devices by 2025 (according to Machina Research in May 2015).

"RFaxis is committed to offer a wide breadth of products to the IoT market to enable ultra-compact, high-performance and cost-competitive designs," says RFaxis' chief technical officer Oleksandr Gorbachov. "This latest release of the RFX25xx family addresses our customers' demand for the fast-growing IoT and M2M segments," he adds. "As devices for the smart home, smart office, smart utility and use cases continue to develop and expand, RFaxis is well-positioned to offer a variety of products through this added family of innovative, single-die, single-chip RF front-end ICs in pure CMOS."

RFaxis is showcasing its new family of ultra miniature RFeIC solutions for IoT at the 2016 Mobile World Congress (MWC) in Barcelona, Spain (22–25 February) as well as at Embedded World 2016 in Nuremberg, Germany (23–25 February).

www.rfaxis.com

RFaxis expands portfolio of CMOS RF front-end ICs for Internet of Things applications

Fabless semiconductor firm RFaxis Inc of Irvine, CA, USA, which designs RF semiconductors and embedded antenna solutions for wireless connectivity and cellular mobility, has added new products to its expanding portfolio of RF front-end integrated circuit (RFeIC) solutions for the global Internet of Things (IoT)/M2M (machine-to-machine) market. The new products further expand RFaxis' family of RF front-end ICs for the sub-GHz and 2.4GHz frequency bands commonly used for range extension in many classes of wireless communication systems for IoT.

The latest additions to the firm's IoT portfolio are the RFX2403, RFX2413 and RFX1030 RFeICs. The RFX2403 comes integrated with a high-efficiency power amplifier (PA), low-noise amplifier (LNA) with bypass, and Transmit/Receive (T/R) switching circuitry for 802.15.4 ZigBee/Thread, proprietary ISM radios in the 2.4GHz spectrum, while also supporting linear modulations such as Bluetooth Low Energy (BLE). It is pin-to-pin compatible to the widely used RFX2401C with added bypass mode and directional-coupler-based output power detector circuitry, allowing users to upgrade their wireless systems with features such as extended range, lower power consumption for long battery life, increased tolerance to antenna impedance variations, and improved coexistence performance with adjacent radios.

Similarly, the RFX2413 comes integrated with a high-efficiency PA and antenna diversity switch, and a power detector circuitry, also for the 2.4GHz band. With a low bypass insertion loss, the RFX2413 is suitable for wireless IoT systems with transceivers that already have low noise figure, with the added benefit of barely any current draw during Receive mode.

The RFX1030 comes integrated with a 1W high-power, high-efficiency PA, LNA, and Transmit/Receive switching circuitry, and a directional power detector circuitry intended for the sub-GHz 802.15.14 and proprietary ISM radio topologies such as LoRa, SigFox and Weightless, and Narrowband Cellular IoT (NB-CIoT).

All three new products come with associated matching networks, RF decoupling and harmonic filters, in single-die, single-chip, bulk CMOS device in miniature 3mm x 3mm QFN packages. All are rated up to 125°C ambient temperature, required by most applications especially for smart LED lighting, smart home, smart office, and smart building. Samples will be made available during first-quarter 2016.

RFaxis says that, as wireless connectivity for IoT and M2M continues to evolve from smart energy to the smart home, smart office, smart building, smart city and recently also to low-power wide-area networking (LP-WAN), the need for simple high-performance yet cost-effective RF front-end solutions is becoming more critical than ever. The total IoT/M2M wireless connectivity market for fixed, short-range radios as well as LP-WAN is estimated to be 20 billion connected devices by 2025 (according to Machina Research in May 2015).

"Our latest product release for IoT addresses our customers' demand for increased performance and reliability of 2.4GHz and sub-GHz wireless networks," says RFaxis' chief technical officer Oleksandr Gorbachov. "As deployments for IoT services become a key driver for growth in the wireless connectivity space, the RF front-end for such radios needs to keep up with the demand for cost and performance," he adds. "RFaxis is well positioned to support this emerging market with its family of innovative, single-die, single-chip CMOS RF front-end products."

www.rfaxis.com

Skyworks receives Mexico's National Export Award

Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) has received Mexico's 2015 National Export Award (PNE).

The PNE is one of four national awards given by Mexico's federal government recognizing companies, educational institutions and organizations whose efforts have contributed to strengthening Mexico's competitiveness in international markets. Skyworks was recognized for being a role model of innovation and efficiency in delivering high-value products to global markets.

This is the third consecutive annual award for Skyworks from Mexico's federal government. Skyworks received the National Quality Award in 2013 and the National Technology and Innovation Award in 2014.

Skyworks' Mexicali facility plays a key role in the assembly, test and packaging of its analog and RF solutions.

Skyworks has been manufacturing integrated circuit modules in Mexicali since 1969, investing in technology, facilities and equipment. The firm is one of the largest employers in Mexicali, with about 3600 staff. It participates in governmental programs that promote research and development in Mexico and over the years has worked with governmental agencies, universities and R&D centers to increase competencies, create new capabilities, grow business opportunities and nurture supplier development in Mexicali.

www.skyworksinc.com

Qualcomm and TDK forming joint venture to provide RF front-ends for mobile devices

Qualcomm Inc of San Diego, CA, USA and electronics component maker TDK Corp of Tokyo, Japan have agreed to form the joint venture RF360 Holdings Singapore Pte Ltd to enable delivery of RF front-end (RFFE) modules and RF filters into fully integrated systems for mobile devices and fast-growing business segments such as Internet of Things (IoT), drones, robotics and automotive applications.

The joint venture will draw upon TDK's capabilities in micro-acoustic RF filtering, packaging and module integration technologies and Qualcomm's expertise in advanced wireless technologies — via the RF front-end products of its affiliate Qualcomm Technologies Inc (QTI), which operates Qualcomm's semiconductor business Qualcomm CDMA Technologies (QCT) — to serve customers with RF solutions into fully integrated systems.

Qualcomm and TDK will also expand their collaboration around key technology fields, including sensors and wireless charging.

Subject to the receipt of regulatory approvals etc, the agreement is expected to close by early 2017.

"TDK is a leading electronic components manufacturer with cutting-edge expertise in RF filters and modules, and we are looking forward to deepening our collaboration and together accelerating innovation and better serving the ecosystem for next-generation mobile communications," says Qualcomm's CEO Steve Mollenkopf. "The joint venture's RF filters will bolster Qualcomm RF360 front-end solutions to enable Qualcomm Technologies Inc (QTI) to deliver a truly complete solution to the ecosystem. This will enable us to expand our growth opportunity by allowing us to accelerate our strategy to provide OEMs across our business segments with fully integrated systems that will enable them to deliver at scale and on an accelerated timeframe," he adds.

"Customers will benefit from our unique and comprehensive portfolio, which will further strengthen TDK's position in key growth business segments," says TDK's president & CEO Takehiro Kamigama. "It was a major objective to ensure that our customers can continue to expect a seamless supply of discrete filters and duplexers, as well as modules."

Mobile communications is placing growing demands on all players, notes Qualcomm. Current and future smartphones must support dozens of frequency bands for 2G, 3G and 4G LTE, while offering connectivity for wireless LAN, satellite navigation, Bluetooth, and more. In addition, convergence of 4G mobile communications and the IoT means that manufacturers of wireless solutions for mobile IoT devices must achieve new levels of miniaturization, integration and performance, especially for the RF front-end in these devices. Further, 5G will expand this complexity even more. Module solutions will be essential to supporting this increasing complexity in the RFFE.

Qualcomm says that, together with RF360, QTI will design products from the modem/transceiver to the antenna in a fully integrated system.

RF360 will have a comprehensive set of filters and filter technologies, including surface acoustic wave (SAW), temperature-compensated surface acoustic wave (TC-SAW) and bulk acoustic wave (BAW) to support the wide range of frequency bands being deployed in networks across the globe. Moreover, RF360 will enable the delivery of RFFE modules that will include front-end components designed and developed by QTI. These components include CMOS, SOI and GaAs power amplifiers, a broad portfolio of switches enhanced via a recent acquisition, antenna tuning and envelope tracking.

RF front-ends will represent an $18bn opportunity by 2020, reckons market research firm Mobile Experts in December, with filters acting as a key driver. According to US-based Mobile Experts and market research firm Navian in Japan, the filter assets that will reside in RF360 Holdings are currently among the top 3 in the industry. TDK is currently shipping in excess of 25 million filter functions per day and growing, and holds design wins at all major handset OEMs, including leading premium-tier smartphones. TDK, and subsequently RF360 Holdings, is committed to investing in capacity increases to meet the growing industry demand. The business that will be transferred constitutes part of the TDK SAW Business Group activities, and the current annual revenue run rate is nearing $1bn of sales (involving about 4200 staff). RF360 will be a Singapore corporation (with headquarters functions in Munich, Germany) with R&D, manufacturing and/or sales locations in the USA, Europe and Asia.

RF360 will initially be owned 51% by Qualcomm Global Trading Pte Ltd (QGT) and 49% by TDK subsidiary EPCOS AG. Filter and module design and manufacturing assets, plus related patents, will be carved out from TDK and its subsidiaries and be largely acquired by RF360, with certain assets being acquired directly by Qualcomm affiliates. QGT has an option to acquire (and EPCOS has an option to sell) the remaining interest in the joint venture 30 months after the closing date.

Giving effect to the payments to be made at the closing, additional future payments to TDK based on sales by the joint venture of RF filter functions, as well as Qualcomm and TDK's joint collaboration efforts (and assuming QGT's exercise of its option to acquire EPCOS' interest in the joint venture), the total transaction value should be about $3bn. Qualcomm expects the deal to be accretive to non-GAAP earnings per share in the 12 months following the transaction close.

www.qualcomm.com

China's San'an selects Mentor Graphics' Calibre platform for verification of GaAs wireless ICs in pilot production

Electronic hardware and software design solutions provider Mentor Graphics Corp of Wilsonville, OR, USA says that Xiamen San'an Integrated Circuit Co Ltd (San'an IC) of Xiamen Torch High-tech Industrial Development Zone, China has selected its Calibre nmDRC and Calibre nmLVS products as its golden signoff physical verification solution for gallium arsenide ICs used in mobile and other wireless applications.

With a total investment of 3bn yuan on a planned area of 281 acres, San'an IC is one of the Fujian Major Industrial Projects 2014–2018 and Xiamen Key Projects 2015 (and an emerging industry of strategic importance with government support). San'an IC is building new production lines for gallium arsenide (GaAs) and gallium nitride (GaN) wafer epitaxy, as well as for the fabrication of GaAs high-speed chips and GaN high-power chips, targeting microelectronic devices for wireless communications. Pilot production was scheduled to begin by the end of this year. San'an IC reckons that it will, upon volume production, become the first fab in China to combine large-scale R&D and manufacturing capabilities for compound semiconductor chips.

As part of its foundry offering, San'an IC will provide the Calibre design rule decks to its customers to help ensure that their designs are error-free and meet all foundry requirements before submitting them to San'an IC for manufacturing.

Mentor Graphics says that designs are becoming much more complex at all IC nodes as designers address new requirements such as low power, more operational modes, more protocols, redundancy and security. As a result, designers need more sophisticated tools that can handle complex requirements and still maintain fast turnaround.

"With radio frequency (RF) and sensor applications expanding rapidly, we need a single verification flow that can handle multiple technologies and process nodes," comments Honda Huang, Design Support & Marketing Office director at San'an IC. "The Calibre platform gives us that flexibility — it works seamlessly with our RF design tools, and supports effective communication with our clients. The Calibre nmDRC and nmLVS products allow us to easily implement complex rules for RF design with very efficient commands and features like equation-based DRC that significantly reduce our coding effort," he adds.

"San'an IC's adoption of Calibre for advanced GaAs ICs used in RF applications is part of a growing worldwide trend to use the most advanced Calibre technologies for larger-feature-size applications," says Shu-Wen Chang, director of Calibre Foundry Programs at Mentor Graphics.

www.sanan-ic.com
www.mentor.com

Gilat announces Ku- and Ka-band phased-array antenna program after signing development agreement with aerospace systems integrator

Gilat Satellite Networks Ltd of Petah Tikva, Israel (which provides products and services for satellite-based broadband communications) has signed a development agreement with a major aerospace systems integrator to further develop both its Ku-band electronically steered-array/phased-array antenna (ESA/PAA) and Ka-band technologies.

Gilat has been developing its own monolithic microwave integrated circuit (MMIC) technology for phased-array antennas since 2009. The firm recently deployed fully operational air and ground antenna arrays and demonstrated their capabilities, including the transmission of real-time video.

The latest MMIC release includes silicon-germanium (SiGe) chipsets for both Ku- and Ka- frequency bands, allowing for ultra-low-profile ESA antennas that are now commercially available. Gilat has received initial orders for its ESA antenna in Ku-band and will continue the development of dedicated products for commercial air and ground applications.

"The growing demand for broadband in-flight connectivity over satellite has not yet been met with a high quality and affordable phased-array antenna. This is what Gilat will bring to the market," says Moshe (Chico) Tamir, corporate VP & head of Gilat's Strategic Initiatives Division. "Our unique technology, when combined with widely used mass-production techniques, results in affordable ESA antennas with highly reliable tracking capabilities, built-in amplification and no moving parts," he adds. "The scalable design of almost any array size allows for the mounting of our ultra-low-profile antennas, on wide- and narrow-body commercial aircraft, regional and business jets, and high-speed trains. The antenna can even be embedded into a vehicle's roof top. Our ESA/PAA technology can also provide affordable satellite connectivity solutions for new markets, such as the Internet of Things (IOT), machine-to-machine (M2M) and the connected car."

www.gilat.com

MACOM acquires Aeroflex's diode business from Cobham

Diodes & transistors to complement MACOM's RF & microwave diodes

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 acquired Aeroflex's diode business from UK-based Cobham plc for $38m (funded with available cash). The business had about $37m in revenue in 2014.

Cobham (which designs and makes equipment, specialized systems and components for the aerospace, defense, energy and electronics industries) acquired Aeroflex Inc of Plainview, NY, USA in May 2014, and retains the Test & Measurement division (now Cobham Wireless).

The Aeroflex diode business will complement MACOM's product portfolio of RF and microwave diodes with the addition of JAN (Joint Army Navy)-certified diodes and transistors. The acquisition also should increase the scale and opportunity of MACOM's diode business to drive cost of goods sold (COGS) efficiencies and be accretive to the firm's non-GAAP operating margins and earnings per share (EPS), once facilities are fully integrated.

www.macomtech.com

Anokiwave appoints former Hittite chief financial officer

Anokiwave Inc of San Diego, CA, USA, a provider of highly integrated silicon core chips and III-V front-end integrated circuits for millimeter-wave (mmW) and active electronically scanned array (AESA) markets, has appointed William W. Boecke as chief financial officer, supporting the firm's plans to continue its strategic expansion in 2016 and beyond.

Boecke joined Anokiwave in October and, working with the executive management team, is tasked with ensuring that the firm continues to grow on a strong financial foundation, capitalizing on the growing worldwide demand for next-generation mmW solutions.

"Bill is an accomplished finance executive and semiconductor industry veteran," comments CEO Robert Donahue. "His prior success driving profitable growth and performance improvements will be invaluable as we look to grow the company."

Boecke has over 20 years of experience in the semiconductor industry, serving in various senior financial management positions. Prior to Anokiwave, he was VP & chief financial officer of Hittite Microwave Corp of Chelmsford, MA, USA (acquired by Analog Devices Inc in July 2014). Boecke has a B.S. from St. John's University and an M.B.A. from Boston College. He became a Certified Public Accountant in NY.

www.anokiwave.com

Microsemi completes acquisition of PMC-Sierra

Microsemi Corp of Aliso Viejo, CA, USA (which makes chips for the communications, security, aerospace and industrial markets) says that its subsidiary Lois Acquisition Corp has now merged with and into PMC-Sierra Inc of Sunnyvale, CA, USA (which provides semiconductor and software solutions for storage, optical and mobile networks), completing Microsemi's acquisition of PMC. Under Section 251(h) of the General Corporation Law of the State of Delaware, no vote of PMC's stockholders was required to consummate the merger.

At the effective time of the merger, each outstanding share of PMC common stock (other than shares directly owned by PMC, Microsemi, Lois Acquisition Corp or any other subsidiary of Microsemi and shares held by PMC stockholders that are entitled to and have properly demanded appraisal of such shares under Delaware law) was converted into the right to receive $9.22 in cash plus 0.0771 shares of Microsemi common stock (together with cash in lieu of any fractional shares of Microsemi common stock, without interest and less any applicable withholding taxes, the same price received by PMC stockholders who validly tendered their shares in the related exchange offer). Following the merger, PMC shares will cease to be traded on Nasdaq.

Originally (on 5 October) analog and mixed-signal semiconductor maker Skyworks Solutions Inc of Woburn, MA, USA agreed to acquire PMC for $10.50 per share. But on 19 October, Microsemi made a rival unsolicited offer to acquire PMC for $8.75 in cash plus 0.0736 shares of Microsemi for each share of PMC (amounting to $11.35 per share). After a more rounds of bidding, on 19 November PMC-Sierra declared Microsemi's bid a 'superior proposal'. On 24 November Skyworks said it had decided not to modify its offer, leading to PMC terminating their agreement (entitling Skyworks to an $88.5m termination fee from PMC).

"PMC's innovative semiconductor and software solutions are transforming the networks that connect, move and store big data," comments Microsemi's chairman & CEO James J. Peterson. "As we integrate we will leverage its industry-leading talent base and product portfolio, driving the combined company's next wave of innovation."

www.pmcs.com
www.microsemi.com

Raytheon UK's SiC foundry receives mass-production order for Schottky barrier diodes

Raytheon UK's foundry in Glenrothes, Scotland has received an order from a major fabless semiconductor manufacturer to mass produce silicon carbide (SiC) Schottky barrier diodes that will be used in a wide variety of power conversion applications.

"This order not only demonstrates the increasing demand for silicon carbide semiconductors but is another example of Raytheon UK providing a customer with a fast-track, cost-effective and low-risk route to market," says John Kennedy, head of Raytheon UK's Integrated Power Solutions. "We have the process know-how and we are adept at minimizing the engineering costs," he claims. "As an independent foundry, we have greater scope to find more innovative solutions for our customers."

SiC properties include: a breakdown electric field of 2000kV/cm (compared with silicon's 300kV/cm) — allowing for higher voltages; a bandgap energy of 3.26eV (compared with silicon's 1.12eV) — enabling higher-temperature operation; and thermal conductivity of 4.9W/cm.K (compared with silicon's 1.5W/cm.K).

Hence, when fabricated from SiC, a Schottky barrier diode can handle higher voltages than its silicon-only counterpart, whilst also reducing power losses. Complexities around thermal management systems are simplified too, enabling the creation of smaller, lighter and more energy-efficient and environmentally friendly electronic circuits, systems and end-products, notes Raytheon UK.

As part of the contract to fabricate the Schottky barrier diodes, Raytheon UK will produce more than 1000 wafers in the first year. The customer will package the devices, which will have voltage ratings ranging from 600V to 1.7kV and current ratings from 1 to 50A.

Raytheon UK's Glenrothes foundry is claimed to be the longest-established independent full-scale production-qualified facility in Europe — if not the world — capable of SiC wafer processing. It has, for example, already fabricated Schottky and PiN diodes, as well as JFETs and MOSFETs, for other customers.

www.raytheon.co.uk/semiconductors

Raytheon wins NMI Research Collaboration award

At the recent annual awards of the NMI (National Microelectronics Institute), the industry trade body for electronic systems in the UK & Ireland) in London, Raytheon UK's High Temperature Silicon Carbide (HiTSiC) Semiconductors team received the 2015 NMI Research Collaboration award for pioneering work with academia and, in particular, Newcastle University.

The HiTSiC team comprises seven process engineers from Raytheon and a graduate — based on site in Glenrothes, Scotland, UK — from Newcastle University. Working under a Knowledge Transfer Partnership (KTP) project, the team is striving to enhance the performance of Raytheon's semiconductor fabrication processes. The endeavours have the potential to further realise the benefits of silicon carbide as a semiconductor material (the properties of which include high switching speeds, lower losses, a high breakdown voltage and an ability to operate at high temperatures). When exploited fully, SiC-based semiconductors can contribute significantly to more power-efficient — and by extension more environmentally friendly — high-reliability electronic systems and power distribution networks.

Left to right: Derek Boyd (NMI), John McLean (Science and Technology Facilities Council), and Robert Young, Dave Clark, Alan McQuilton & Aled Murphy (Raytheon UK).

"There is an increasing recognition in all industry sectors that employ electronics of the huge potential of silicon carbide — and it's through collaborative projects with academia that we can better access that potential, as well as putting the UK at the forefront of developments," says John Kennedy, head of Raytheon UK's Integrated Power Solutions.

"I have been leading the development of silicon carbide electronic systems for extreme environments for a number of years," says Dr Alton Horsfall, reader in Semiconductor Technology at Newcastle University and the academic lead on the silicon carbide KTP with Raytheon. "It is fantastic to see the impact of our research being recognised through the interaction with Raytheon and the development of commercial components."

One particular area of research that the team is working on relates to better understanding trap defects in the interface between SiC and silicon dioxide (SiO_2), which critically impacts on MOSFET performance.

"The defects represent a significant obstacle in the mass adoption of SiC technology in a wide range of sectors, such as aerospace, automotive, rail and energy, in which increasingly high-performance devices are required," says Kennedy.

http://nmiawards.uk/

Rohm expands full-SiC power module lineup with 1200V/300A model for high-power inverters and converters in solar power conditioners and industrial equipment

Power semiconductor device maker Rohm Co Ltd of Kyoto, Japan has developed a 1200V/300A full-SiC (silicon carbide) power module — integrating a SiC-SBD (Schottky barrier diode) and SiC-MOSFET (metal-oxide-semiconductor field-effect transistor) into a single package (equivalent in size to a standard IGBT module) — designed for inverters and converters in solar power conditioners and industrial equipment.

The high 300A-rated current makes the BSM300D12P2E001 suitable for high-power applications such as large-capacity power supplies for industrial equipment. Meanwhile, 77% lower switching loss versus conventional insulated-gate bipolar transistor (IGBT) modules enables high-frequency operation, contributing to smaller cooling counter-measures and peripheral components, says Rohm.

In March 2012, Rohm began mass production of what was reckoned to be the first full-SiC power module with an integrated power semiconductor element composed entirely of silicon carbide. In addition, its 120A and 180A/1200V products continue to see increased adoption in the industrial and power sectors. Also, although further increases in current are possible due to energy-saving effects, in order to maximize the high-speed switching capability of SiC products an entirely new package design is needed that can minimize the effects of surge voltage during switching, which can become particularly problematic at higher currents, adds the firm.

In response, the BSM300D12P2E001 features an optimized chip layout and module construction that significantly reduces internal inductance, suppressing surge voltage while enabling support for higher-current operation up to 300A.

Going forward, Rohm says that it will continue to strengthen its lineup by developing products compatible with larger currents by incorporating SiC devices utilizing high-voltage modules and trench configurations.

www.rohm.com

GaN Systems announces 10x production increase at TSMC

Three-year collaboration with world's biggest foundry unveiled

GaN Systems Inc of Ottawa, Ontario, Canada, a fabless developer of gallium nitride (GaN)-based power switching semiconductors for power conversion and control applications, says that Taiwan Semiconductor Manufacturing Co (TMSC, the world's biggest silicon wafer foundry) has expanded volume manufacturing of products based on GaN System's proprietary Island Technology by 10x in response to surging global demand from consumer and enterprise customers. GaN Systems claims to have the industry's broadest and most comprehensive portfolio of GaN power transistors with both 100V and 650V GaN FETs shipping in volume.

Transistors based on Island Technology and using TSMC's GaN fab process are claimed to have the best figure of merit in the industry, outstripping the capabilities of the highest-performance silicon power semiconductors, the latest SiC (silicon carbide) devices and competing GaN products. The combination of TSMC's GaN process and GaN Systems' Island Technology design is further enhanced by GaNPX packaging, which delivers high current handling, low inductance and what is claimed to be exceptional thermal performance. GaN Systems' power switching transistors provide what is claimed to be best-in-class 100V and 650V devices, driving product innovation ranging from thinner TVs to extended-range electric vehicles.

"Our collaboration with GaN Systems has brought the promise of gallium nitride from concept through reliability testing and on to volume production," notes TSMC's VP business management Sajiv Dalal.

"Smart mobile devices, slim TVs, games consoles, automotive systems and other mass-volume items have been designed with GaN transistors as the enabling power technology, so it is imperative that devices are available in correspondingly large quantities," says GaN Systems' president Girvan Patterson. "Using our patented Island Technology, we have designed and made available for widespread adoption GaN power solutions that greatly exceed the performance standards exhibited by silicon devices. That is why, after three years of working together, we are so excited to formally announce our collaboration with TSMC, the world's leading third-party semiconductor manufacturing company," he adds.

Delivering large volumes of highly reliable GaN transistors in near-chip-scale packaging is the culmination of work that GaN Systems began in 2008. The firm was founded with the aim of creating a low-cost, highly reliable GaN-on-silicon product based on Island Technology, a method of creating small islands where electro-migration is mitigated, die size is minimized, and very high current devices are realized with high yield, says the firm. Using Island Technology with TSMC's GaN-on-Si manufacturing techniques enabled GaN Systems to deliver normally-off transistors to market in mid-2014. The firm claims that this has allowed global power system manufacturers in the energy storage, enterprise and consumer sectors to design, develop, test and bring to market more powerful, lighter and far smaller new products. "To meet customers' increasing demand for high GaN volumes in 2016, TSMC's commitment to volume production flow comes at the perfect time," notes GaN Systems.

www.tsmc.com
www.gansystems.com

Global Semiconductor Alliance's 'Start-Up to Watch' award

At the annual awards celebration of the Global Semiconductor Alliance (GSA) in December, GaN Systems was presented with the 2015 'Start-Up to Watch' award (for firms demonstrating the potential to positively change its markets or the semiconductor industry in general through innovative technology). The award comes from the over 400 GSA members spanning 35 countries (accounting for over 75% of semiconductor industry revenue).

To qualify for the award the recipient must also: be a semiconductor firm (either fabless or an integrated device manufacturer); be privately held; and have cumulative product revenue below $20m. The process includes down-selection to four finalists, followed by in-person company presentations to the GSA Private Awards Committee, which consists of senior semiconductor and foundry executives, venture capitalists and select serial entrepreneurs from the semiconductor industry.

"The world is using more electronics and more energy at an ever increasing rate. Without increasing the efficiency of power electronics and reducing their size, the trend is unsustainable," notes GaN Systems' CEO Jim Witham. "Our products help to alleviate the world's exponentially growing appetite for more compact, efficient and cost-effective power management solutions. GaN Systems' innovations allow our products to far exceed the performance limitations of silicon, enabling previously unachievable levels of power conversion performance for consumer, data-center, industrial and transportation applications. Today, hundreds of customers worldwide have developed products with GaN Systems," he adds.

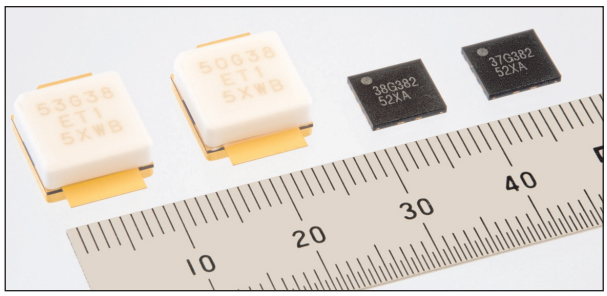
"It is humbling to receive this award from an organization made up of hundreds of esteemed global industry leaders," comments GaN Systems' president Girvan Patterson.

Mitsubishi Electric expanding lineup of 3.5GHz GaN HEMTs for 4G base transceiver stations

Tokyo-based Mitsubishi Electric Corp is expanding its lineup of gallium nitride high-electron-mobility transistors (GaN HEMTs) for use in base transceiver stations (BTS) operating in the 3.5GHz band of fourth generation (4G) mobile communication systems.

As a result of the deployment of long-term evolution (LTE) and LTE-Advanced mobile networks, demand is rising for BTS that can offer increased data volume, smaller size and lower power consumption. In response, Mitsubishi Electric has developed the four new GaN HEMTs for use in macro BTS and the large numbers of micro cells that mobile network operators are employing to increase the data capacity of their advanced 4G networks built with LTE and LTE-Advanced technologies.

Mitsubishi Electric's expanded product line-up includes a flangeless ceramic package (in 180W and 90W models) for macro-cell BTS and a plastic-molded package (in 7W and 5W models) for micro-cell BTS. Operating from a drain voltage of 50V and at a frequency of 3.4–3.8GHz, the four new GaN HEMTs offer output power and efficiency levels that are claimed to be among the highest currently available.



(From left to right) The new plastic-molded packaged (MGFS53G38ET1 and MGFS50G38ET1) and flangeless ceramic-packaged (MGFS38G38L2 and MGFS37G38L2) GaN HEMTs for 3.5GHz 4G mobile communication macro-cell and small-cell BTS applications.

Regarding drain efficiency (load pull), the 90W (MGFS50G38ET1) and 180W (MGFS53G38ET1) models for macro-cell BTS achieve 74% and 70%, respectively, and the 7W (MGFS38G38L2) and 5W (MGFS37G38L2) models for micro-cell BTS achieve 67%. High efficiency allows the use of a simple cooling system, which contributes to smaller BTS size and lower power consumption.

The flangeless ceramic package also reduces the size of the devices themselves and the power amplifier modules in which they are deployed.

Samples of the four new GaN HEMTs will be released starting on 1 February. Going forward, the firm says it will continue to expand its GaN-HEMT lineup for use at different output powers and frequencies, and in mobile communication systems beyond 4G.

www.MitsubishiElectric.com/

Wolfspeed exhibits X-band radar products at IRSI 2015 in Bangalore

Wolfspeed of Raleigh, NC, USA, a Cree Company that supplies gallium nitride on silicon carbide (GaN-on-SiC) high-electron-mobility transistors (HEMTs) and monolithic microwave integrated circuits (MMICs), exhibited its portfolio of GaN RF devices for L-, S-, C- and X-band radar at the 2015 International Radar Symposium India (IRSI-15) in Bangalore (15–19 December).

Founded in 1983 and revived in 1999 as a biennial series, IRSI featured technical conference presentations and tutorials addressing state-of-the-art technologies, techniques and practices related to: radar systems, receivers, antennas, arrays, controllers, processors, software, devices, components, emitters, transmitters, modeling, and simulation, in addition to radar signal and array processing, tracking and data processing, and image and weather radar. In support, the IRSI exhibition is showcasing subsystem products, models, photographs, modules, and multimedia presentations.

Exhibiting with APC Technologies, Wolfspeed representatives Jim Milligan (director RF), Chris Harris (European business development manager) and Vidya Bakshi (operations manager) presented the firm's portfolio of GaN RF devices for L-, S-, C- and X-band radar. This included the CMPA801B025 X-band GaN MMIC power amplifier (rated for 25W and 8.5–11.0GHz operation) for pulsed radar and broadband CW applications, which features: 37W typical P_{OUT}, 16dB power gain, 35% typical power-added efficiency (PAE), and <0.1dB power droop. The GaN MMIC is also internally matched to 50Ω, and is supplied in both a 10-lead metal/ceramic flanged package and a new, smaller-form-factor pill package for optimal electrical and thermal performance.

"IRSI will provide us with a valuable opportunity to introduce our cutting-edge GaN RF devices, world-class design assistance, proven fabrication processes, and testing and international customer support services to influential members of the local radar industry," comments Milligan.

www.wolfspeed.com/rf/products/l-band-s-band-x-band-c-band-ku-band/cmpa801b025f

EPC recruits director of Applications Engineering

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA, which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications, says that Dr Yuanzhe Zhang has joined its engineering team as director, Applications Engineering.

Zhang earned a doctorate in electrical engineering from the University of Colorado in Boulder, and a bachelor's degree at Zhejiang University in Hangzhou, China. While working on his Ph.D. he published several papers on the use of GaN transistors in very-high-frequency DC-DC converters and envelope tracking power supplies for telecom infrastructure.

Yuanzhe Zhang.

As a member of the EPC applications team, Zhang's focus will be designing envelope tracking systems for 4G, LTE and 5G wireless infrastructure that demonstrate the benefits of using GaN transistors. His research and experience in these applications will be shared with customers to accelerate their designs using high-performance eGaN FETs. His designs will aim to demonstrate GaN transistors' superior performance over MOSFETs and LDMOS.

"This is part of our continuous efforts of focusing on customer partnership in designing eGaN technology-based solutions," says EPC's CEO & co-founder Alex Lidow. "With our increased team resources, we are supporting the innovative developments of each customer using gallium nitride technology," he adds. "We are very pleased to have Dr Yuanzhe Zhang joining us at the time when we are moving full-speed ahead in fast-growing applications such as envelope tracking for telecom infrastructure."

http://epc-co.com/epc/Applications/EnvelopeTracking.aspx

EPC appoints senior VP of global sales & marketing

EPC says that, to support its accelerating growth, Nick Cataldo has joined its leadership team as senior VP of global sales & marketing.

Cataldo has over 35 years of marketing and sales operation experience in the semiconductor industry. His primary responsibilities at EPC are creating and implementing sales & marketing strategies to achieve global sales objectives.

"Nick Cataldo has extensive experience in leading-edge power semiconductors as well as recent experience in new materials that are edging out the incumbent silicon," says CEO & co-founder Alex Lidow.

Cataldo joins EPC from United Silicon Carbide, where he was VP of global sales. Previously, he held senior sales & marketing leadership positions at International Rectifier and Semtech.

"This is the first time in 60 years that there is a technology that is both higher performance and lower cost to manufacture than silicon," comments Cataldo about EPC.

In addition, Steve Colino will assume the title of VP of strategic technical sales, reporting to Cataldo. In his new role, Colino will be able to concentrate on customers who are looking to take maximum advantage of eGaN technology and its IC capability to increase functionality and value to their end-use customers, says the firm. "Steve is the one who put EPC in a position of rapid growth and he is uniquely qualified to drive our technology and business to the next level by working with our most innovative customers," says Lidow.

EPC publishes second edition of Wireless Power Handbook

EPC has announced publication of the second edition of the 'Wireless Power Handbook'. This edition is a practical engineering handbook designed to provide power system design engineers with experiences and points of reference critical to understanding and designing highly efficient wireless power systems using GaN transistors.

As a supplement to EPC's 'GaN Transistors for Efficient Power Conversion', the updated and expanded practical guide provides step-by-step analysis on the use of GaN transistors in wireless power transfer systems. Topics covered include how to effectively compare component devices, such as eGaN FETs and MOSFETs, when used in an amplifier design. This comparison, complete with experimental verification, illustrates the superiority of eGaN FETs over MOSFETs in this high-performance application.

This second edition has been expanded to include the latest work on AirFuel Alliance class 2 and 3 transmitters, adaptive tuning, radiated EMI, multi-mode wireless power systems, and control strategies. Also, wireless power systems are demonstrated using the latest eGaN FETs and integrated circuits that set new efficiency benchmarks as well as reduce overall system costs.

'Wireless Power Handbook: a Supplement to GaN Transistors for Efficient Power Conversion, 2nd Edition' is available for $39.95 and can be purchased from both Digi-Key and Amazon.com.

www.amazon.com/dp/0996649212/ref=cm_sw_su_dp

EPC's CEO & co-founder Alex Lidow receives SEMI Award for North America

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA, which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications, says that at the Industry Strategy Symposium (ISS) banquet of SEMI (industry association Semiconductor Equipment and Materials International) in Half Moon Bay, CA, USA (on 12 January) its CEO & co-founder Dr Alex Lidow was presented with the 2015 SEMI Award for North America (in the area of Process & Technology Integration) for innovation in power device technology, enabling the commercialization of GaN devices with performance and cost advantages over silicon.

The awards also honored Chenming Hu for the BSIM (Berkeley short-channel insulated-gate FET model) families of compact transistor models, and an Intel team for the implementation of bulk CMOS FinFET production.

Established in 1979, the SEMI Award was designed to recognize significant technological contributions to the semiconductor industry and to demonstrate the industry's high esteem for the individuals or teams responsible for those contributions.

EPC's CEO & founder Alex Lidow.

With silicon-based devices approaching their limits in speed and efficiency, Lidow was prompted to develop GaN technologies, but high cost limited commercial success. Lidow led GaN development activity at International Rectifier Corp and continued that work at EPC, which he co-founded in 2007. EPC introduced the first commercial E-mode GaN power transistors in 2009. Challenges from resolving packaging limitations to establishing a low-cost supply chain were overcome, paving the way for the commercialization of GaN power devices.

GaN transistors and integrated circuits, which EPC says it now sells to almost every major electronics company in the world, allow companies to make smaller, faster and more power-efficient products compared with those made from silicon. The use of GaN enables new technologies and the advancement of existing technologies in a variety of areas, including 4G and 5G wireless communications, wireless charging, augmented-reality glasses, autonomous vehicles and wireless medical technology.

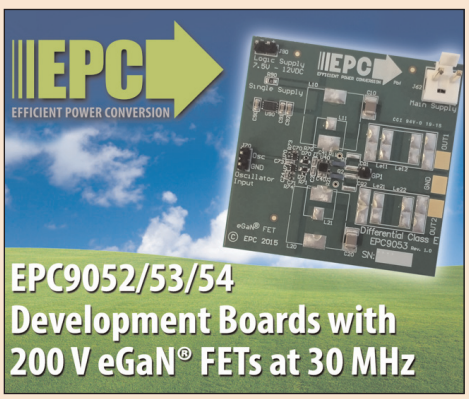
"It has been my driving passion to save energy by developing more efficient semiconductors," says Lidow. "The innovative team at EPC has delivered the industry's first off-the-shelf enhancement-mode gallium nitride transistors and ICs and will continue to partner with our customers to use GaN to change the way we live."

www.semi.org/en/About/Awards/AwardNorthAmerica/P_000658

Development boards for 200V eGaN FETs operating up to 30MHz

EPC has launched high-efficiency GaN-based differential mode development boards that can operate at up to 30MHz, providing an easy-to-use way for power systems designers to evaluate the performance of GaN transistors and get their products into volume production quickly, says the firm.

The development boards are designed for class-E applications, such as wireless charging, but can be used for any application where a low-side switch is utilized. Examples include, but are not limited to, push-pull converters, current-mode class-D amplifiers, common source bi-directional switch, and generic high-voltage narrow-pulse-width applications such as LiDAR.



The development boards feature 200V-rated eGaN FETs. The amplifiers are set to operate in differential mode and can be re-configured to operate in single-ended mode and include the gate driver and logic supply regulator.

All three boards (the EPC9052 for EPC2012C eGaN FETs, the EPC9053 for EPC2019 eGaN FETs, and the EPC9054 for EPC2010C eGaN FETs) have common preference specifications. The operating load conditions (including configuration) determine the optimal design load voltage and resistance.

The EPC9052/9053/9054 are priced at $158.13 each and are available from Digi-Key. Quick Start Guides (containing set-up procedures, circuit diagram, performance curves, bill of material and Gerber files for the boards) are provided on-line.

http://epc-co.com/epc/Products/DemoBoards.aspx
http://digikey.com/Suppliers/us/Efficient-Power-Conversion.page

NXP's RF Power business becomes Ampleon under new owner JAC Capital

R&D and engineering resources to be boosted, targeting RF data and energy transfer

Following its acquisition of the RF Power business line of NXP Semiconductors N.V. of Eindhoven, The Netherlands, new owner China's Jianguang Asset Management Co Ltd (JAC Capital) has formed Ampleon of Nijmegen, The Netherlands.

Ampleon takes responsibility for all RF Power business activity, including sales and support of the complete line-up of silicon-based LDMOS and gallium nitride (GaN) RF power products. Founded on a history of more than 50 years, Ampleon has 1250 staff across 16 engineering, sales and manufacturing facilities worldwide.

"With a unique focus on RF power technology and innovation we are extremely well positioned to meet the growing market need for power-, cost- and space-efficient RF solutions," says CEO Reinier Beltman. "This is not only in our key traditional markets such as wireless infrastructure, broadcast, industrial, scientific & medical (ISM), and aerospace & defense but also in the new RF energy markets such as solid-state cooking and plasma lighting," he adds. "RF energy applications will see us establishing new partnerships and introduce new products as we embrace these exciting developments across the value chain. We will be working closely with customers to help them adopt RF energy technology into their designs."

Focusing on partnering with customers to exploit opportunities in RF data and energy transfer, Ampleon aims to increase its commitment to R&D and grow its engineering resources.

Ampleon is a founding member of the RF Energy Alliance, whose members aim to build a fast-growing ecosystem around the use of solid-state RF energy as a highly efficient and controllable source of heat and power.

www.nxp.com
www.ampleon.com

TMS launches modular line of non-ITAR 0.1–6.0GHz GaN amplifiers with small form factor for harsh airborne requirements

Teledyne Microwave Solutions Inc of Mountain View, CA, USA (TMS, a business unit of Teledyne Technologies Inc) has launched a line of gallium nitride (GaN)-based wideband amplifiers that is claimed to further lower the form factor threshold for the 0.1–6.0GHz frequency range.

The new line consists of five GaN wideband amplifier models (TSA-213241, TSA-213242, TSA-213243, TSA-213244 and TSA-213245) that are claimed to raise the bar for SWaP (size, weight and power) in this category of GaN amplifiers while meeting the stringent airborne requirements of the most demanding commercial and military applications. The dimensions (excluding connectors) are 2.5" long by 2" wide by 0.42" high (just 2.1 cubic inches).

TMS says that it has created a modular, non-ITAR line of amplifiers that it can quickly tailor to the specific needs of customers. With wider bandwidths that enable more design flexibility, the new GaN amplifier line targets the most demanding SWaP needs of airborne markets.

"This GaN line is the latest addition to the portfolio we have developed over decades, including our AVP catalog series," says Dan Cheadle, chief technology officer of Cougar Products for Teledyne Microwave Solutions. "Leveraging the high power output and high efficiency of GaN, these amps offer a durable GaN solution that delivers the highest output power over wide bandwidths in the smallest footprint possible today."

This family of amplifiers was designed and manufactured with attention to thermal requirements to ensure the high reliability required in the most demanding applications. With a calculated mean time between failures (MTBF) of over 40,000 hours @ +85°C, the amplifiers are suitable for airborne applications as well as challenging land-based environments.

Depending on frequency band, the output power ranges between 15W and 40W. Each amplifier includes pre-amp and driver stages to produce a minimum overall gain of 50dB. Internal control circuitry ensures safe startup so supply voltages can be applied in any order. In addition to normal DC connections via a 15-pin Micro D connector, other control/interface features available via the connector include a TX enable/disable TTL command (100ns typical, 200ns maximum); over-temperature automatic shutdown and associated alarm (TTL); and the ability to monitor unit temperature via an analog voltage that is proportional to case temperature.

www.teledynemicrowave.com

EpiGaN's GaN-on-Si epiwafers to be distributed globally by SunEdison

EpiGaN nv of Hasselt, near Antwerp, Belgium, which supplies commercial-grade gallium nitride on silicon (GaN-on-Si) epitaxial wafers for 650V HEMT (high-electron-mobility transistor) power semiconductors, has signed a global representation and distribution agreement granting silicon substrate maker SunEdison Semiconductor exclusive rights to market and sell its 150mm and 200mm GaN-on-Si epiwafers for power switching applications, strengthening EpiGaN's worldwide reach and transitioning EpiGaN into a global GaN epiwafer supplier.

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

EpiGaN develops III/V materials and delivers GaN-on-Si epiwafers to device makers worldwide. Its product portfolio covers power switching applications up to 650V as well as RF power devices for millimeter-wave applications. The firm is currently developing and sampling GaN structures on 200mm Si substrates for power switching devices to enable its customers to position themselves in rapidly growing market segments.

EpiGaN says that a key concept of its technology base is the in-situ SiN cap layer, which is claimed to provide best-in-class passivation properties and superior device reliability. The use of in-situ SiN allows the use of pure AlN layers as barrier material, with the resulting heterostructures having sheet resistance values below 300Ω/sq.

It is reckoned that combining EpiGaN's GaN-on-Si technology with SunEdison Semiconductor's market presence and expertise will create a new one-stop solution for integrated device manufacturers (IDMs) that are active in next-generation GaN power technology on silicon substrates.

"This new agreement with a well established supplier such as SunEdison Semiconductor, with its excellent track record in the power electronics industry, will enable us to provide additional value to our global

customer base through our superior GaN-on-Si products, customer services and technical support," says EpiGaN's co-founder & CEO Dr Marianne Germain.

"EpiGaN's strong technology capability complements our own, and we look forward to further developing this promising market together," comments SunEdison Semiconductor's president & CEO Shaker Sadasivam.

www.epigan.com
www.sunedisonsemi.com

EpiGaN's board gains Imec veteran to advise on expansion of GaN-on-Si epitaxial product portfolio and services

EpiGaN nv of Hasselt, near Antwerp, Belgium, which supplies commercial-grade gallium nitride on silicon (GaN-on-Si) epitaxial wafers for the power switching, RF power and sensor markets, says that Lou Hermans has joined its board of directors as an independent member in an advisory role. Hermans will add his broad expertise in founding and growing semiconductor startups to implementing EpiGaN's expansion and its growing portfolio of GaN-on-Si products and services.

In 2007, Hermans co-founded CMOSIS NV of Antwerp Belgium, a provider of CMOS image sensors and solutions, where he served as chairman of the board, VP marketing & sales and chief operating officer.

Lou Hermans, new board member.

Incorporated in 2010, EpiGaN was founded by chief executive officer Dr Marianne Germain, chief technology officer Dr Joff Derluyn and chief operating officer Dr Stefan Degroote as a spin-off of nano-electronics research center Imec of Leuven, Belgium. The founders jointly developed GaN-on-Si technology at Imec, part of which has been licensed to EpiGaN. The firm now develops and delivers GaN-on-Si and GaN-on-SiC epiwafers to device makers worldwide for power switching, RF power and sensor applications, specifically shipping epitaxial (Al,Ga)N heterostructures grown on silicon substrates up to 200mm in diameter.

"Lou has a far reaching experience and expertise in successfully growing semiconductor startup companies," says Germain. "We are now taking our next expansion step as the GaN market is accelerating its transition from R&D activities to full-fledged commercial production and application," she adds.

"Being an Imec spin-off and knowing the EpiGaN founding team from my time at Imec, I have always been following with great interest the development of EpiGaN, its products and services offered," comments Hermans.

www.epigan.com

AKHAN deploys 200mm manufacturing process in new diamond-based chip fab

Diamond semiconductor firm to deliver initial products to first commercial customer in Q1/2016

After relocating its global headquarters from Chicago, AKHAN Semiconductor Inc is deploying 200mm manufacturing equipment and process in its new production facility in Gurnee, IL, USA (formally opened in November), continuing its preparation for delivering diamond semiconductor based-technology products to the firm's first commercial customer this quarter.

AKHAN Semiconductor Inc was formed in early 2013 as a subsidiary of AKHAN Technologies Inc, which was founded in 2007 by 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.

"The proven, high-yielding 200mm semiconductor manufacturing process is proving ideal for the production of a wide range of semiconductors — sensors, MEMS, analog, power management — that are embedded in the rapidly growing number of connected devices, from smartphones and tablets to cars, home appliances, wearables, and commercial and industrial applications," says AKHAN's chief operating officer Carl Shurboff.

According to market research firm Gartner Inc, the number of Internet-connected devices (i.e. the Internet of Things) will grow from 6.3 billion in 2016 to over 20 billion in 2020.

This explosion in connected products is driving high global demand for all types of new semiconductors to power the new era of connected computing, says AKHAN. Industry association Semiconductor Equipment and Materials International (SEMI) noted in its 'Global 200mm Fab Outlook to 2018' that 200mm fab capacity is expected to grow from 5.2 million wafer starts per month in 2015 to over 5.4 million in 2018.

"The timing for our diamond-based semiconductor technology's market debut could not be better," believes AKHAN's CEO Adam Khan. "By using man-made diamonds at the core of our new chip technology, we are ushering in a new generation of semiconductor solutions that operate at higher temperatures, are thinner and require less power. These are exactly the attributes required for all the products that make up the Internet of Things."

AKHAN reckon that its 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. On the commercial side, the firm is already developing new diamond windows for industrial, defense and aerospace applications.

AKHAN's technology is based on a process using man-made diamond rather than silicon to produce chip materials. It is a result of the marriage of two breakthroughs: the ability to use nanocrystalline diamond (NCD) films and a new doping process the makes it possible to use NCD as a semiconductor material.

AKHAN says that it is currently actively hiring to staff its new facility, which is expected to employee 100 people in the next two years.

www.akhantech.com

Plextek RFI adds GaN power amplifier design expert

Plextek RF Integration of Cambridge, UK, which designs and develops RFICs, MMICs and microwave/millimeter-wave modules, has strengthened its capabilities with the addition of Robert Smith to its team of design engineers.

"We are seeing increasing demand for our design skills from right across the industry, in applications ranging from defence and aerospace through wireless technology and satellite communications to test and measurement," notes CEO Liam Devlin.

Smith brings GaN power amplifier (PA) design experience to his new role. He was previously with Thales Nederland, where he designed subsystems for active phased-array naval radar. In addition to RF design skills, his role with Thales also provided experience of moving designs from development to production, and in design considerations for component reliability.

Prior to joining Thales, Smith completed a PhD at Cardiff University (sponsored by Roke Manor Research) during which he investigated the design and implementation of broad bandwidth, high-efficiency RF PAs. His research included developing push-pull amplifiers using GaN transistors at microwave frequencies using load-pull measurement techniques. Smith presented details of his work at the ARMMS RF and Microwave Society Conference in April 2013, for which he received the best paper award. He also published two papers on broadband balun and PA design at the IEEE International Microwave Symposium.

"His experience will complement and enhance our existing skills portfolio as well as helping us to continue to grow our sales," says Devlin.

www.plextekrfi.com

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SAMCO launches ALD system for gate oxides in wide-bandgap power devices

SAMCO Inc of Kyoto, Japan, a supplier of plasma etch, chemical vapour deposition (CVD) and surface treatment systems to compound semiconductors device makers, has launched an atomic layer deposition (ALD) system focusing on gate oxide formation of silicon carbide and gallium nitride power devices.

SAMCO designs and manufactures dry etching systems, PECVD, and UV-ozone and plasma cleaning systems, delivering processing solutions for wide-bandgap semiconductor devices such as RF devices, LEDs, laser diodes and power devices.

SAMCO's new AL-1 ALD system deposits pinhole-free AlO_x and SiO_2 films, which are optimal for the gate oxide in GaN MOSFET, GaN MOS-HFET and 4H-SiC MOSFET devices. The system features precise film thickness control at the atomic-layer level (1.2Å per cycle at a deposition temperature of 350°C). The deposited AlO_x film (with a breakdown voltage of 7.5MV/cm) also provides what is claimed to be excellent step coverage (with an aspect ratio of 32:1, width of 1.25μm and depth of 40μm) with just 103nm-thick oxide films.

SAMCO says the AL-1 is capable of depositing uniform oxides on an 8" wafer or three 4" wafers and is suitable for R&D and pilot production.

To strengthen its turn-key solutions for next-generation power device production, on 1 December SAMCO also signed a distributor agreement with Epiluvac AB of Lund, Sweden (which produces SiC CVD systems used in power device research).

www.samcointl.com

SAMCO to distribute Epiluvac's silicon carbide CVD systems in Japan, Taiwan, Singapore, Malaysia and Philippines

Epiluvac AB of Lund, Sweden — which was founded in 2013 and produces silicon carbide (SiC) chemical vapour deposition (CVD) systems used in power device research — has signed an international distributor agreement granting SAMCO the exclusive distribution rights in Japan, Taiwan, Singapore, Malaysia and the Philippines.

SAMCO sells its dry etching and CVD systems in Asia, Europe and North America in addition to gaining market share within Japan. The firm's dry etching and plasma CVD technology serves applications involving wide-bandgap semiconductor materials (e.g. RF devices, LEDs, lasers, and power devices). In particular, SAMCO has recently focused on selling production systems for GaN and SiC power devices.

Having combined Epiluvac's SiC CVD system with its existing product lineup of plasma CVD, dry etching and surface treatment systems, SAMCO says that it now offers a 'one-stop solution' for SiC power device applications.

www.epiluvac.com

SOI wafer maker Soitec refutes SiGen's patent infringement complaint to ITC

Soitec of Bernin, near Grenoble, France, which makes engineered substrates including silicon-on-insulator (SOI) wafers, says that it is defending its rights in an investigation by the US International Trade Commission (ITC) instituted on 18 September based on a complaint filed by Silicon Genesis Corp (SiGen) of San Jose, CA, USA (which was founded in 1997 to provide engineered substrate process technology for the semiconductor, display, optoelectronics and solar markets) directed to SOI wafers sold and imported into the USA by Soitec. US-made SOI-based chips are used in smart phones, tablets, servers, cars and networks, notes Soitec.

In its notice announcing the investigation (337-TA-966) the ITC made clear that the agency "has not yet made any decision on the merits of the case", says Soitec. SiGen has only satisfied the commission's administrative requirements for filing a complaint, it adds.

"We are confident that this case will die on the merits, and relatively soon, with a finding of no violation," says Jacques Elie Levy, Soitec's group general counsel and senior VP legal & industrial property. "Soitec respects the intellectual property rights of third parties. The asserted patents are not infringed by Soitec. In fact, SiGen initially asserted eight patents against our products in the ITC investigation and has now agreed to withdraw its claims on three of those patents," he adds.

"SiGen as a patent assertion entity does not develop and manufacture SOI wafers, and cannot supply the US market with these critical products — and almost certainly cannot satisfy the ITC's domestic industry requirement," states Levy.

The case is not due for a final decision until at least 2017.

www.sigen.com

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5N Plus appoints senior VP of Umicore's Electro-Optic Materials as president & CEO

Specialty metal and chemical products firm 5N Plus Inc of Montreal, Québec, Canada has appointed Arjang J. (AJ) Roshan as president & CEO, effective 15 February. He replaces Jacques L'Ecuyer, who co-founded the firm in 2000 and has been president & CEO since then (growing sales of more than $500m in 2014) but is stepping aside (as announced on 3 November).

Roshan has more than 20 years of international and executive experience closely related to 5N Plus' line of business, having worked for global materials technology and recycling group Umicore for the last 18 years. Initially focused on the Automotive Catalysts Business, since 2012 Roshan has been senior VP of Umicore's Electro-Optic Materials business unit (claimed to be the global leader in development, production, recycling and refining of germanium-related products including substrates for space industry, LED and photovoltaic applications, in addition to infrared transparent materials and high-purity chemicals and metals).

5N Plus provides purified metals such as bismuth, gallium, germanium, indium, antimony, cadmium, selenium and tellurium, and 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.

Following a global search, Roshan was selected mainly due to his track record in both sustainably growing businesses in markets including Asia Pacific, Europe and North America in addition to transforming troubled ventures facing challenges ranging from unsustainable cost structure and shifting competitive landscape to those burdened by misaligned business models and deteriorating margins. In both situations Roshan has demonstrated leadership qualities that have yielded outstanding results, says 5N Plus.

"Our key criteria was to attract an accomplished executive with a proven track record for impeccable leadership and ability to maximize inherent value within a company so as to deliver consistent and competitive results," says chairman Jean-Marie Bourassa. "Moreover, we sought a global leader with the ability to enable, empower and inspire our people in order to transform challenges into a viable source of opportunity," he adds. "Roshan met all the desired criteria, in addition he has demonstrated the skills required to lead appropriate change-initiatives across large-scale corporate cultures."

"While the industry is facing various challenges, I strongly believe that 5N Plus has the right DNA to turn these challenges into a source of viable opportunity," says Roshan. "Having been engaged in the same industry it is evident that 5N Plus has established itself as a company with an outstanding pedigree."

www.5nplus.com

5N appoints vice-chairman of National Bank of Canada as chairman

The 5N Plus board of directors has appointed Luc Bertrand as its new chairman. He succeeds Jean-Marie Bourassa, who continues to serve on the board and as chair of the Audit & Risk Management Committee (a position he already holds).

Bertrand is vice-chairman of National Bank of Canada (a position he has assumed since February 2011), where he is responsible for developing and maintaining relations with corporate, institutional and government clients in Canada. He also acts as strategic advisor to management, particularly on matters pertaining to government relations and capital market regulations.

During his career, Bertrand has held various management positions in the financial services industry. From 2000–2009, he was president & CEO of Montreal Exchange Inc and held the post of VP & managing director of Institutional Equity Sales at National Bank Financial from 1998 to 2000.

Bertrand is also an active member of boards of directors and industry committees. He currently serves on the board of the International Finance Centre of Montréal, and is also chairman of the board of the Montreal Canadiens/CH Group Inc. Bertrand also serves on the board of TMX Group and was previously CEO of Maple Group Acquisition Corp. In recent years, he has been a director of the Canadian Derivatives Clearing Corp, vice-chairman of the board of Boston Options Exchange, chairman of the board of the Montréal Climate Exchange, and a director of the Natural Gas Exchange.

"Bertrand is greatly respected in the business community having, among other things, consolidated Canada's international standing in the derivatives market when he was with Montreal Exchange Inc, and having lead different consortiums which were successful in acquiring the TMX Group in 2012 and the Montreal Canadiens/CH Group in 2009," say Jacques L'Ecuyer, retiring president & CEO of 5N Plus.

"I am very pleased by the nomination of Luc Bertrand, who is very well established in the financial markets," says upcoming president & CEO Arjang Roshan. "This will facilitate my work and will be most beneficial for 5N Plus," he believes. "I look forward to working with him as we lead the company towards its next phase of development."

EVG sees power device & RF applications driving demand for wafer bonding solutions for engineered substrates

EV Group of St Florian, Austria (a supplier of wafer bonding and lithography equipment for MEMS, nanotechnology and semiconductor applications) says that over the past year it has seen a significant increase in demand for its wafer bonding solutions for engineered substrates, driven partly by the rapid growth in the power electronics and radio-frequency device markets (where, due to their unique material properties, engineered substrates offer key performance benefits, such as high carrier mobility and reduced power loss/leakage).

For the past several years, the engineered substrate market has mainly been driven by RF applications, including mobile electronic devices such as smart phones and Internet-connected tablet computers, says EVG. Mobile communications is expected to continue to spur significant demand for engineered substrates over the next several years — particularly for RF front-end applications — as a result of the global adoption of 4G and transition to the Internet of Things (IoT). At the same time, the need for improved performance in power devices utilized in adapters, electric vehicles, power inverters and other power electronic devices and applications is also driving up growth in engineered substrates such as silicon carbide (SiC) and gallium nitride (GaN).

"Wafer bonding provides the most cost-effective and highest-yielding method for producing engineered substrates," says director of business development Dr Thomas Uhrmann. "EVG is well positioned to capitalize on this growth and support the evolving needs of engineered substrate manufacturers," he adds. "We helped pioneer the engineered substrate market with the introduction of our first silicon-on-insulator (SOI) production wafer bonder more than two decades ago. Over the years, we have enabled our customers to continually innovate in this market."

EVG has a complete suite of fusion wafer bonding solutions for different engineered substrate applications:

- the EVG850 automated production bonding system for silicon-on-insulator (SOI) and direct wafer bonding has been continually enhanced to meet tighter industry specifications for newer SOI technologies such as fully depleted silicon-on-insulator (FD-SOI).
- the EVG850LT LowTemp plasma-activated automated fusion bonder provides wafer annealing at temperatures below 400°C, enabling its use for bonding a variety of substrate materials with different coefficient of thermal expansions (CTEs) that are not compatible with higher-temperature fusion bonding processes using an interfacial oxide layer.
- the EVG580 ComBond automated high-vacuum covalent wafer bonding system combines several technology breakthroughs to enable the formation of bond interfaces between heterogeneous materials at room temperature while achieving what is claimed to be excellent bonding strength and electrical conductivity.

www.evgroup.com/en/markets/soi_engineered_substrates

k-Space reports record annual sales of RHEED analytical systems, up 43% year-on-year

k-Space Associates Inc of Dexter, MI, USA (which supplies thin-film metrology tools for the semiconductor, compound semiconductor and solar markets) has reported record annual sales for its kSA 400 product line of RHEED (reflection high-energy electron diffraction) analytical systems, up 43% in new system installations in 2015 compared with 2014.

The kSA 400 system combines a high-resolution, high-speed and high-sensitivity camera with RHEED-specific acquisition and analysis software. The firm attributes the increase in sales partially to increased installations on deposition chambers operating at higher pressures than typical UHV systems.

"The use of RHEED guns with differential pumping has allowed RHEED to penetrate higher-pressure deposition technologies that were previously off limits," says kSA's technical sales engineer Dr Carrie Andre. "This advancement in RHEED has increased the potential market for kSA 400 systems," she adds. "By supplying a variety of high-performance lenses, the kSA 400 can be customized for various chamber geometries and can best analyze the smaller-size RHEED images generated in higher-pressure deposition chambers."

"This was our first product when the company started in 1992, and it has developed and evolved over the years to keep pace with technological advancements in hardware, as well as the requirements and requests of our users," notes CEO Darryl Barlett. "We are in the fifth generation of the kSA 400, and have multiple software upgrades each year to add features that enable further process optimization for our customers," he adds. "It is this constant improvement and our dedicated technical support that keeps customers coming back for more systems."

www.k-space.com

IQE on track to achieve full-year revenue growth

Second-half revenue to be up on first half, as photonics and technology licensing offsets wireless weakness in Q4

In an update on current trading and confirms its expectations for full-year 2015, epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK says that it is on track to achieve year-on-year revenue growth, with second-half revenue expected to be up sequentially over first-half 2015.

The widely reported weakness in the mobile and smartphone markets has impacted wireless wafer sales in the fourth quarter, but this has been offset by higher non-wireless revenues, including from photonics and technology licensing, demonstrating the increasing robustness of IQE's business model, the firm says. It adds that this has given the board confidence that financial performance for the full year remains in line with its expectations, which should result in net debt of about £25m by end-December 2015.

The market updates of key wireless customers have reflected mixed performance in second-half 2015, and recent announcements have highlighted broad weakness within the mobile and smartphone segments. Nevertheless, the outlook for 2016 and beyond remains positive, says IQE, due to increasing global connectivity and the continuing growth in data traffic.

The photonics business has continued to perform strongly, delivering significant double-digit revenue growth, driven by a wide array of end-market drivers including data centers, optical communications and a broad range of sensing applications.

The InfraRed and CMOS++ segments have also performed well, in line with expectations, and first pilot-production revenues have been generated from Solar. During 2015, IQE entered into two joint venture arrangements, in Singapore and the UK (which have started positively), and IQE has licensed additional IP during second-half 2015 to enable acceleration of the joint venture business plans. The firm is also continuing to explore additional licensing opportunities to take advantage of the increased IP portfolio that it has acquired and developed during the last two years.

"The results reflect continued delivery of our revenue diversification strategy," says chief executive Dr Drew Nelson. "Despite areas of weakness in the wireless market during the final quarter, the group has been able to mitigate the impact through higher revenues in other areas of the business," he adds. "In line with its strategic plans, the group is continuing to develop a broad IP portfolio through both internal development, and selective transactions such as the recent cREO deal. These foundations are increasingly enabling growth across the diverse markets for compound semiconductor technologies, including Photonics, Solar, Power, InfraRed and CMOS++. This is also creating complementary IP licensing opportunities. As a result, the board remains confident of continued growth in our business."

The firm will report its full-year 2015 results on 22 March.

www.iqep.com

IQE and Cardiff University to help spearhead £50m UK Compound Semiconductor Applications Catapult

IQE and Cardiff University are to help spearhead a new £50m UK national Compound Semiconductor Applications Catapult to develop and manufacture next-generation compound semiconductors.

Announcing the £50m funding (£10m per year up to 2020–21) following a meeting in South Wales with IQE and Cardiff University, Chancellor George Osborne said that the investment will create a new compound semiconductor hub of excellence in South Wales as part of a UK network of Research and Development Catapults.

"It will bring together scientists and businesses with expertise," said Osborne to Cardiff business leaders.

In August, IQE and Cardiff founded the Compound Semiconductor Centre, which will form a key resource for the new Catapult. The partnership aims to help to transform leading-edge research at Cardiff University's Institute for Compound Semiconductors (ICS) — to be built on the University's new £300m Innovation Campus — into new technologies and products.

"The launch of the £50m catapult is fantastic news for high-level manufacturing in Wales," believes IQE's CEO & president Dr Drew Nelson. "The Compound Semiconductor Catapult will help provide the critical mass to launch the first compound semiconductor hub of its kind in the world, taking great academic research and seamlessly turning it into high-volume manufacturing, securing a global industrial and manufacturing platform for Wales and the UK," he adds.

In November, the Welsh Government announced a £12m funding package to support the construction, fit-out and purchase of capital equipment for Cardiff University's Institute for Compound Semiconductors. The UK's Research Council Partnership Investment Fund has invested £17.3m to support the ICS. Also, through the Welsh Government's £50m Sêr Cymru program, last May professor Diana Huffaker of University of California Los Angeles (UCLA) was appointed ICS director (starting this January).

http://compoundsemiconductorcentre.com

RF and microwave component packaging developer RJR Polymers changes name to RJR Technologies

RJR Polymers of Oakland, CA, USA has changed its name to RJR Technologies Inc in order to reflect its growing role as a developer and high-volume manufacturer of liquid crystal polymer (LCP) air-cavity plastic packaging (ACP) for RF and microwave applications.

"Over the last few years our company has transformed from a developer of packaging components and materials, including epoxy-coated components and sealing systems, for mostly custom projects to an advanced developer of high-performance packaging technologies for high-volume semiconductor suppliers," says president & CEO Wil Salhuana. "Today we sell standard air-cavity plastic (ACP) and RQFN packages that offer a compelling value proposition in terms of high performance, low cost and faster time-to-market," he adds.

RJR Technologies has already shipped millions of units of its new second-generation ACP2 packages to manufacturers in the RF market. The firm adds that, over the next few years, its industry-standard ACP packages promise to deliver similar benefits to applications in the gallium nitride (GaN) market and RF energy applications, such as lighting, automotive ignition systems and consumer microwave appliances.

In today's highly competitive wireless infrastructure market, base-station manufacturers need devices capable of supporting high linearity, higher average output power and wider operating bandwidths, notes RJR Technologies. By reducing thermal resistance and parasitic effects, the ACP2 packaging supports higher levels of performance than existing ceramic packages while delivering the low cost and shorter development cycle of a plastic package, the firm claims. For example, by replacing ceramic packages with ACP2 using a copper thermal base rather than an expensive composite-type metal, the packaging costs of RF power transistors can be reduced by as much as 50% while improving thermal dissipation by 30%, it adds.

"The rising performance requirements and increasing price pressures of today's RF market are driving a migration to packaging that uses less expensive copper thermal bases and that calls for an air cavity rather than an over-molded solution," says Salhuana. "While over-molded solutions can use copper, they pay a penalty in performance. So the migration to a copper thermal base is quickly making ceramic packaging solutions in the RF market obsolete."

RJR Technologies' ACP technology differs from traditional air-cavity ceramic (ACC) packaging by using a lid and ringframe constructed of LCP instead of traditional ceramic materials. This design enables the ringframe to be attached to the flange using RJR's proprietary high-performance epoxy adhesives, whereas the ceramic package has to be brazed, which creates a very rigid structure. Using RJR epoxies reduces the stress and distortions of the flange because the firm designs its epoxies to allow a certain amount of flexibility. The in-strip solution offers numerous benefits, it is claimed: it eliminates the variability of sizes of the singulated package (because RJR uses a standard lead frame outline as a carrier solution to reduce variability in the manufacturing lines); it supports automation of the manufacturing process (using a cassette-to-cassette solution); and it allows customers to use RJR's fully automated sealing system (based on the cassette-to-cassette assembly process), increasing units-per-hour (UPH) and substantially reducing the customer's labor cost.

RJR claims that this approach has a significant impact on package performance and cost. Lower stress on the flange allows equipment manufacturers to use thinner matching capacitors that reduce RF losses at both the gate and the drain, and end up producing higher gain and efficiency than comparable ceramic packages. As a result, designers using the ACP2 packages can deliver better performance than those using traditional ceramic packaging and, at the same time, reduce cost, the firm adds.

www.rjrtechnologies.com

Riber appoints interim chairman of Executive Board

Riber S.A. of Bezons, France, which makes molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells, says that, during its meeting on 16 December, its Supervisory Board appointed François Morizet as interim chairman of the firm's Executive Board, replacing Frederick Goutard (who had held the post since March 2009).

The Supervisory Board also thanked Mrs Sylvie Dumaine (who did not wish to renew her office as a Supervisory Board member at the firm's combined annual general meeting) for her contribution.

Morizet was a senior manager with KPMG before joining auto equipment maker BTR Sealing Systems group in 1994 as chief financial officer, then auto equipment maker Mark IV Systèmes Moteurs group as CFO then co-CEO.

During the combined annual general meeting, Didier Cornardeau and Gérard Nicoula were appointed as members of the Supervisory Board (with Cornardeau subsequently made its chairman).

www.riber.com

San'an's Aixtron AIX R6 MOCVD order slashed from 50 systems to just three

Partnership to focus on future system generations & other applications; R6 development and qualification focusing on existing customers

Deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany has reached agreement with San'an Optoelectronics Co Ltd (China's largest LED maker) for a substantial cut in the volume of AIX R6 metal-organic chemical vapor deposition (MOCVD) systems that it ordered (in September 2014) from 50 to the three which have already been delivered.

Despite the efforts made by both parties, the customer's specific qualification requirements were not achieved. Both parties have agreed to continue their existing partnership by cooperating on future system generations as well as on systems for other applications.

Aixtron says that it will proceed in marketing and the further development of the AIX R6 Showerhead technology. The focus is now on existing customers that have already achieved or are in the process of achieving qualification.

Impact on revenue and earnings

Based on a broader distribution of revenue for equipment in the silicon industry, power electronics and other optoelectronic applications, Aixtron expects to generate full-year revenue of about €190m in 2015 (at the low end of its forecast of €190–200m, which had been revised downwards in late October from the initial forecast given in February of €220–250m). Aixtron says that its strategy of diversifying its product portfolio has borne fruit in the first nine months of 2015. The target of an earnings before interest, tax, depreciation and amortization (EBITDA) break-even in second-half 2015 remains in place.

Aixtron expects to generate revenue in 2016 of about the same level as 2015. Results for 2015 will be published as planned on 23 February 2016.

www.aixtron.com

Veeco promotes William J. Miller to president

Epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA says that William J. Miller Ph.D. has been promoted to president, with direct responsibility over all of Veeco's business units and central R&D. He will also oversee global manufacturing operations, a responsibility he assumed in 2015.

Miller has served as executive VP, Process Equipment since 2011, where he guided the strategic direction and product development for Veeco's etch and deposition product lines.

"Bill is a proven leader and has played a pivotal role in executing Veeco's growth strategies," comments chairman & CEO John Peeler. "Bill was instrumental in catapulting our metal-organic chemical vapor deposition (MOCVD) business to the leadership position we enjoy today," he adds.

Miller joined Veeco in 2002 and has held a series of technology and operational leadership roles with increasing levels of responsibility. He was executive VP, Compound Semiconductor from July 2010 until December 2011. Previously, he was senior VP & general manager of Veeco's MOCVD business from January 2009. From January 2006 to January 2009, Miller was VP, general manager of Veeco's Data Storage equipment business.

Prior to joining Veeco, Miller worked for Advanced Energy and Exxon, holding various engineering and operations leadership positions. Miller previously earned his doctoral, master's and bachelor's degrees in Mechanical Engineering from the University of Pennsylvania.

www.veeco.com

Riber receives two orders for research MBE systems

Riber S.A. of Bezons, France, which manufactures molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells, has received two orders for research MBE machines.

The Fraunhofer HHI (Heinrich Hertz Institute) in Berlin, Germany (a research center for mobile and stationary communication networks) has ordered a gas-source MBE 412 system, to be used for terahertz photonics applications. Riber says that the MBE 412 has been chosen for its high level of flexibility, its reliability and its capacity to produce extremely complex and very high-quality semiconductor materials on large-format substrates on a reproducible basis from gas and solid sources. The system will be delivered to Fraunhofer HHI in 2016.

Riber has also sold a Compact 21 MBE system to a leading laboratory in USA, which will help to expand its research capabilities for new gallium nitride (GaN) structures. The order, recorded in November, will be delivered in 2016.

www.riber.com

Veeco wins advanced packaging system orders

Veeco Instruments Inc of Plainview, NY, USA has received multiple orders from a leading foundry in Asia for its Precision Surface Processing (PSP) WaferStorm system (a platform that provides wafer processing solutions for advanced packaging applications).

Veeco's flux cleaning technology will process wafers for fan-out wafer-level packaging (FO-WLP) production. Fluxing is critical to both wafer bumping and joint formation processes because it removes oxide layers and other impurities to ensure a clean metallic interface for the next assembly step. As bump pitches become finer, removing flux residues has become more challenging, says Veeco. The firm adds that its proprietary technology is well suited for removal of flux residues from even the tightest spacing.

In its latest report, market anaysis firm TechSearch International projects that FO-WLP unit volume will grow at a compound rate of 87% over the next five years. According to TechSearch, FO-WLP is an attractive solution that allows companies to continue taking advantage of the powerful economics of die shrink, while also meeting the small-form-factor, low-profile package requirements of mobile devices.

"As the complexity of the packaging process increases, our differentiated technology enables customers to more tightly control the flux removal process resulting in higher yields," says Herman Itzkowitz, senior VP & general manager of Veeco Precision Surface Processing (PSP), formerly Solid State Equipment Corp (SSEC), acquired in December 2014. "As part of Veeco's global reach, we've been successful in penetrating new customers in Asia for advanced packaging applications," he adds. "In addition to securing business with a leading Asian foundry this quarter, we've also received initial system orders from an Asian OSAT [outsourced semiconductor assembly & test] customer and believe that our process flexibility and expertise will enable us to expand the business in 2016."

Since its acquisition, the PSP business continues to promote single-wafer wet etch, clean and surface preparation equipment. Veeco's product portfolio addresses a wide range of advanced packaging applications. The WaferStorm platform offers flexible solutions for thick-film removal, flux clean and through-silicon via (TSV) clean. The WaferEtch system enables selective etching required for TSV reveal, under-bump metallization and redistribution layer processes. Veeco says its global footprint and customer connectivity, notably in Asia, are helping to capitalize on PSP's growing technology and business.

www.veeco.com/products/precision-surface-processing-waferstorm

LayTec in-situ power for RF and power electronics

GaN/Si-, GaN/SiC- and SiC/SiC-based devices and related MOCVD processes are currently garnering increased interest due to the expected growth in the power electronics markets. In-situ metrology system maker LayTec AG of Berlin, Germany says that, following this trend, it has further customized its in-situ metrology products for these processes and materials. The firm says that these tools help to fully exploit the intrinsic advantages offered by wide-bandgap materials and to manufacture competitive devices with high-yield and cost-efficient processes.

www.laytec.de/power-rf-electronic

Mitsubishi uses LayTec in-situ monitoring to grow crack-free GaN-on-silicon high-electron-mobility transistors

The main challenge of growing gallium nitride-based high-electron-mobility transistors (HEMTs) on silicon substrates is the lattice mismatch between GaN and AlGaN that causes a high tensile stress and often leads to cracks. Now, by using an EpiCurve TT tool from in-situ metrology system maker LayTec AG of Berlin, Germany to monitor surface roughness, growth rate and wafer bowing, Mitsubishi Electric Corp has reported the growth of crack-free low-bowing GaN-on-Si HEMTs by incorporating a GaN buffer layer doped with iron (GaN:Fe), leading to improvements in the breakdown voltage and power-added efficiency (Atsushi Era et al, 'Growth of crack-free GaN on Si HEMTs with Fe-doped GaN using un-doped GaN interlayer', ICSCRM proceedings (2015)).

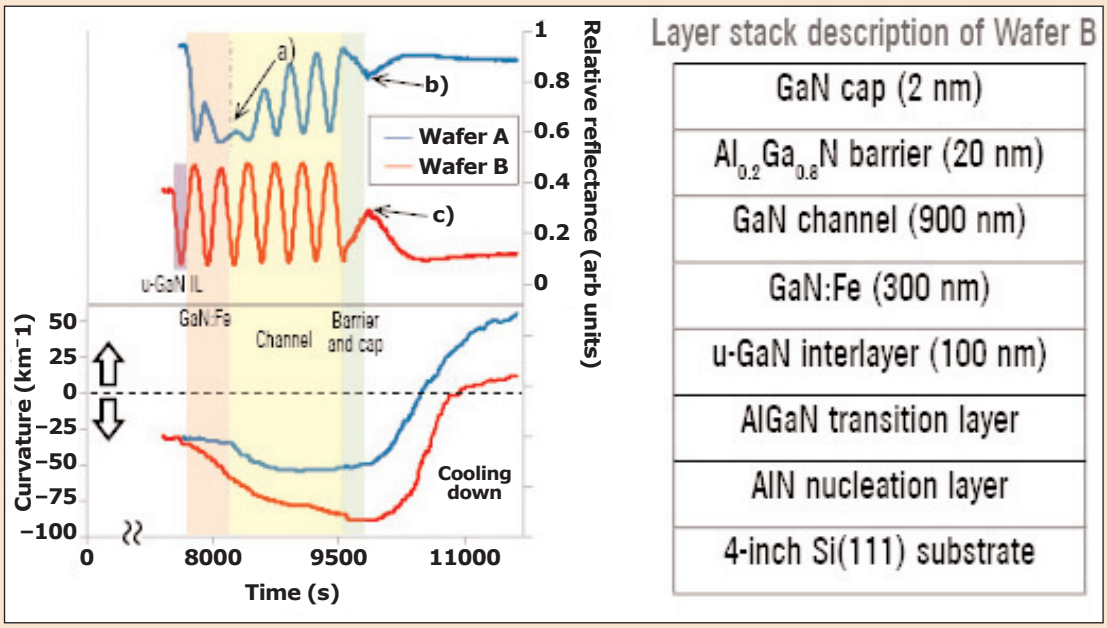
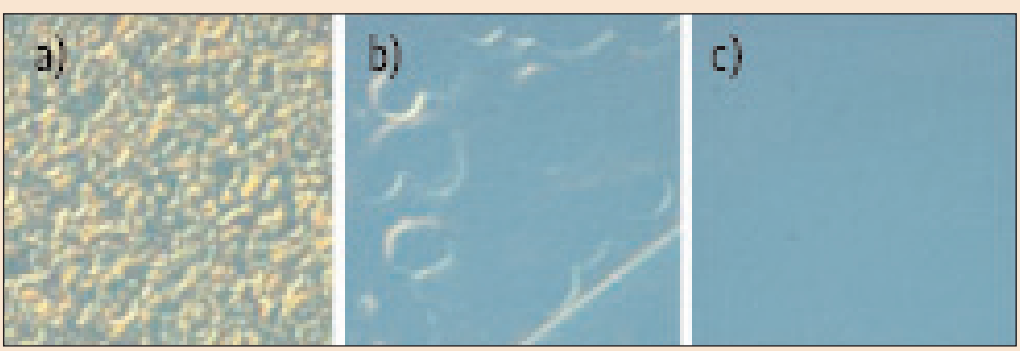


Fig 1: In-situ measurements with EpiCurve TT: (left) reflectance at 950nm and curvature signals during growth of wafers A and B; (right) layer stack for wafer B.

Figure 1 (left) shows reflectance and curvature measurements during the growth of wafers A and B. The reflectance of A has a clear slump during the GaN:Fe growth, which indicates a rough surface of the GaN:Fe layer. The compressive stress during the GaN growth of wafer A is obviously insufficient to compensate the tensile stress during cool-down. The result is cracking over the whole area of wafer A. This is confirmed by the respective atomic force microscopy (AFM) images of surface morphologies (a) and (b) in Figure 2.

To suppress three-dimensional (3D) island growth in the GaN:Fe, wafer B is grown with a 100nm-thick undoped GaN interlayer (uGaN IL) prior to GaN:Fe growth (Figure 1-right). The reflectance of wafer B shows no slump, which indicates that the GaN:Fe layer grows nicely in two-dimensional (2D) mode. The compressive stress is well balanced, so wafer B is nearly flat after cool-down. Its smooth, crack-free surface is confirmed by atomic force microscopy (AFM) — see Figure 2(c). Furthermore, the electron-transfer characteristics of a device fabricated on wafer B exhibit ideal pinch-off behavior.

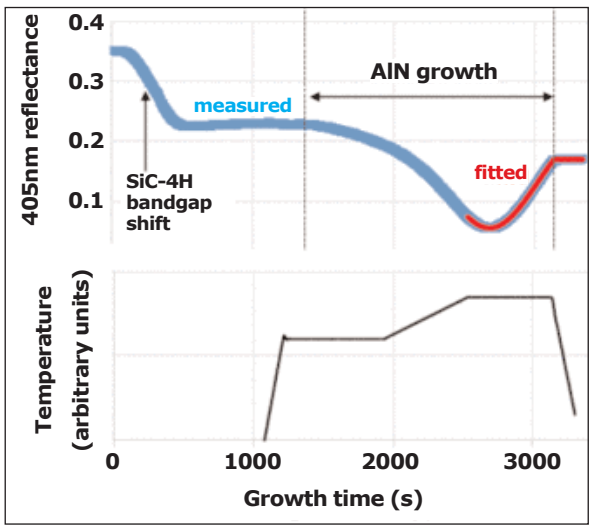
www.laytec.de/power-rf-electronics



LayTec expands EpiNet library's high-temperature nk database and real-time analysis for GaN/SiC-4H HEMTs

AlGaN/GaN and InAlN/GaN structures combine high electron mobility and high critical electric field strength and are excellent platforms for the production of next-generation RF and power electronics devices such as high-electron-mobility transistors (HEMTs), notes in-situ metrology system maker LayTec AG of Berlin, Germany. Their theoretical nearly three-orders-of-magnitude lower specific on-resistance compared with silicon-based devices could enable an at least 10-fold reduction in power losses, device size and cost.

Typically, the best performance is achieved on semi-insulating silicon carbide (SiC) substrates. However, the metal-organic chemical vapor deposition (MOCVD) growth of the AlGaN and AlInGaN structures on large SiC-4H wafers needs complex growth recipes for strain management and tight statistical process control (SPC) to obtain high process yields.



For this technology, LayTec has therefore expanded its high-temperature nk database and implemented additional real-time analysis routines to feed SPC systems with highly accurate in-situ data.

In the example pictured, the initial AlN layer is grown on SiC-4H is performed at very high wafer temperature (measured by Pyro 400 with ±0.5K accuracy) in a sophisticated three-temperature process. This ensures significant defect reduction for the subsequent HEMT growth, says LayTec. Despite the varying wafer temperature in this AlN buffer growth process, the latest real-time analysis function of EpiNet library allows the firm's tools to reach ±0.5nm accuracy in real-time AlN film thickness measurement. This has been achieved by tightly correlating the absolute SiC-4H wafer temperature with high accuracy SiC-4H and AlN nk optical data and implementing analysis algorithms that separate reflectance changes caused by temperature ramping from the AlN growth effects, says LayTec.

www.laytec.de

Showa Denko boosts Taiwan high-purity ammonia production from 2500 to 3500 tons per year

Total production capacity raised to 7000 tons per year, targeting growth in East Asia and ASEAN region

Tokyo-based Showa Denko K.K. (SDK) has expanded high-purity ammonia production capacity at a plant in Taiwan (owned by its manufacturing subsidiary) from 2500 tons per year to 3500 tons per year.

SDK has three sites for producing high-purity ammonia, in Japan (1500t/y at SDK's Kawasaki Plant), China (2000t/y at joint venture Zhejiang Quzhou Juhua Showa Electronic Chemical Materials Co Ltd) and Taiwan (now 3500t/y at Taiwan Showa Chemicals Manufacturing Co Ltd in Tainan City). Total production capacity has hence now been raised to 7000 tons per year.

SDK has been producing and selling high-purity ammonia in Taiwan since 2005 (for use in forming nitride films in the production of compound semiconductor components such as LEDs as well as LCD panels). Sales in Taiwan have been increasing as the market for LEDs and LCD panels in that region has been growing, says the firm. Furthermore, demand for high-purity ammonia is expected to increase in the ASEAN region in the future.

SDK has three sites for producing high-purity ammonia, in Japan (1500 tons per year), China (2000 tons per year) and Taiwan (now 3500 tons per year. Total production capacity has hence now been raised to 7000 tons per year

The market for electronic materials and components has been growing, focused on East Asia, says SDK. Moreover, the amount of high-purity gases used in production is expected to continue rising due to progress in the miniaturization and multilayer structures of integrated circuits and the development of LCDs toward higher definition, SDK believes.

SDK says that, in its new medium-term business plan 'Project 2020+' (starting in January), it has positioned its electronic-material-processing high-purity gas business as a 'growth-accelerating business'.

www.sdk.co.jp

Advanced Vacuum APEX SLR system expanding device processing at NASA's JPL

Plasma process equipment maker Plasma-Therm LLC of St Petersburg, FL, USA says that a new Apex SLR ICP (inductively coupled plasma) etch system from its Advanced Vacuum division in Lomma, Sweden (which supplies vacuum solutions including thin-film plasma etch and deposition systems) was recently installed at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, CA, USA, expanding the fabrication capabilities of the site's Microdevices Laboratory (MDL).

The MDL continues to update its wafer-level plasma processing equipment set with this system, the sixth overall from Plasma-Therm and Advanced Vacuum, and the third in the last two years. These systems are used to make critical components for NASA explorations, including detectors to map background cosmic radiation for better understanding of the universe's beginnings, solid-state lasers used in detection of carbon dioxide and methane on Earth, Mars and other planets, and infrared sensor arrays for terrestrial and extraterrestrial imaging.

The MDL has a multitude of both internal and external users, and thus Apex's ease of operation and the system's reliability are important performance requirements, says Plasma-Therm. Recently, the Apex SLR and other systems were on display to the nearly 14,000 attending JPL's annual open house.

Industrial fabrication facilities are usually designed for mass production using a single set of standard processes. However, operations at MDL, which develops unique devices for space applications, must be much more versatile, involving research, development, and small-scale production of a broad range of devices, wafer sizes, wafer thicknesses, and material families.

Plasma-Therm says that the Apex SLR provides the capabilities that MDL and other research facilities need to process a variety of materials, including dielectrics, metals, polymers, compound semiconductors, and superconducting materials. The recently installed Apex system is process-qualified with fluorine-based chemistries to etch dielectrics and superconducting materials.

"Our relationship with NASA's JPL goes back many years," says Dr David Lishan, Plasma-Therm's principal scientist & director, Technical Marketing. "With each system that is used to make new sensors and high-performance devices, we anticipate being part of exciting and often unexpected science."

www.advanced-vacuum.com

Ferrotec's Temescal e-beam evaporator systems chosen for GaAs foundry WIN's third fab expansion

Materials, component and precision system supplier Ferrotec Corp of Santa Clara, CA, USA, whose Temescal division of Livermore, CA, USA makes electron-beam-based evaporative coating systems for metallization and compound semiconductor manufacturing, says that WIN Semiconductors Corp of Tao Yuan City, Taiwan — the world's largest pure-play provider of gallium arsenide (GaAs) wafer foundry services — has selected Temescal systems for its next stage of expansion by ordering multiple electron-beam evaporators for metal deposition. A total of $8.4m in orders for Auratus enhanced UEFC series Temescal systems has been placed in 2015.

Temescal systems have been the preferred e-beam system since WIN Semiconductors' inception in 1999, says Ferrotec. With its third fab expansion, WIN has selected multiple Auratus enhanced deposition systems — Ferrotec's newest generation of patented Temescal UEFC series evaporators, employing contact-free, magnetic drive High Uniformity Lift-off Assembly (HULA) wafer carriers — for the manufacturing of HBTs (heterojunction bipolar transistors) and pHEMTs (pseudomorphic high-electron-mobility transistors). Ferrotec says that the superior cost of ownership (COO) of its systems with patented HULA planetary rotating domes and conic chambers were key factors for the selection of the Temescal systems.

"Continued growth of mobile devices and those advances supporting the Internet of Things (IoT) provide WIN with a good market platform for this next phase of growth," says Steve Chen, senior vice president at WIN. "With about 60% of market share in GaAs foundry, WIN has the proven track record of manufacturing GaAs and GaN devices with highly complex designs," he adds. "Likewise, with Temescal systems representing over 60% of e-beam evaporator market share in the GaAs market, Ferrotec is also a leader that has demonstrated innovative technologies to address the technical requirements of GaAs device manufacturers".

www.winfoundry.com
www.temescal.net
www.ferrotec.com

SETi acquires commercial operations of fellow UV LED firm Nitek

SETi to be exclusive North America distributor of Seoul Viosys' UVA LEDs

Sensor Electronic Technology Inc (SETi) of Columbia, SC, USA, which manufactures deep-ultraviolet (DUV) LED devices and modules emitting at wavelengths of 230–355nm for healthcare, life science, environmental, military and disinfection applications, has acquired the commercial operations of Columbia-based UV LED developer and manufacturer Nitek Inc. The transaction combines two complementary companies to become what is reckoned to be the world's largest UV-focused LED developer and manufacturer, along with the lowest cost of ownership.

Founded in 2004, Nitek has developed technology to manufacture deep UV LEDs in a cost-effective, high-volume process which, when implemented with SETi's technology, leads to the highest-performance LEDs at the industry's lowest cost, it is claimed.

"This acquisition increases SETi's DUV epi capacity, while also bringing additional technology to reduce our costs," says SETi's president & CEO Emmanuel Lakios. "The net result is that it allows us to reduce the adoption time of cost-sensitive volume markets such as water and air disinfection," he adds.

Prior to the acquisition, Nitek had the exclusive North America distribution rights for the UVA LED product line of South Korea's Seoul Viosys. In August, UV LED firm Seoul Viosys Co Ltd acquired a majority stake (over 50%) in SETi. Hence, as part of the acquisition of Nitek, SETi also gains the exclusive rights for North American distribution of Seoul Viosys' UVA LEDs, offering its customers a complete range of UV LEDs spanning the entire spectrum from UVA to UVC.

www.s-et.com
www.nitekusa.com
www.seoulviosys.com

SETi and Psoria-Shield to commercialize Psoria-Light system for UVB phototherapy

SETi to integrate new 308nm LED manufacturing process in light source delivering over 400mW

SETi has signed a long-term agreement with Psoria-Shield Inc (PSI), a subsidiary of hybrid healthcare company Wellness Center USA Inc, to further develop the UV LED light source used exclusively in the Psoria-Light (PL 1000) system made and sold by PSI. The development is fundamentally based on increasing performance and reducing unit cost.

SETi plans to integrate its new (308nm) LED manufacturing process that emits up to 2mW of UVB power at 20mA drive current in a new high-power light source delivering over 400mW of optical power. This performance plus associated price/performance improvements aim to enhance the LEDs for UVB dermatology treatments.

PSI is a phototherapy company that has developed, manufactures and distributes the Psoria-Light phototherapy system. The PL 1000 uses targeted high-dosage UV LEDs with both cost and safety benefits to that of a conventional excimer laser, it is claimed. The result is an FDA-cleared system that is said to be simple to use and requires no special laser room, no laser certification or special operator qualifications.

"A major advantage of our LED-based technology is its solid-state reliability and reduced maintenance coupled with it being a class 2 product, which does not require a physician to clinically provide the treatment," says John Yorke, managing director of Psoria Development Corp (PDC). "It can be delivered by office staff and be in compliance with existing billing codes. This allows offices and doctors to be more efficient. We believe the treatment and use of UVB LEDs will become the industry standard," he adds. "The PL 1000 is highly portable and can be moved from room to room, with no special power requirements," Yorke notes.

"Similar improvements have been made to power, lifetime and price/performance to our other 230nm to 340nm LED wavelengths," says SETi's president & CEO Emmanuel Lakios. "Of particular market demand is our germicidal 275nm LEDs."

SETi now believes that — along with its recent in-house increase in wafer capacity, the acquisition of Columbia-based UV LED developer and manufacturer Nitek Inc in December, and its strategic relationship with South Korea's Seoul VioSys (which makes 340–405nm-wavelength UVA LEDs), making SETi the only firm that covers the entire UV spectrum of LEDs from 230nm to 405nm — its LEDs are the most cost-effective, highest-performing products on the market and will see high adoption rates in 2016.

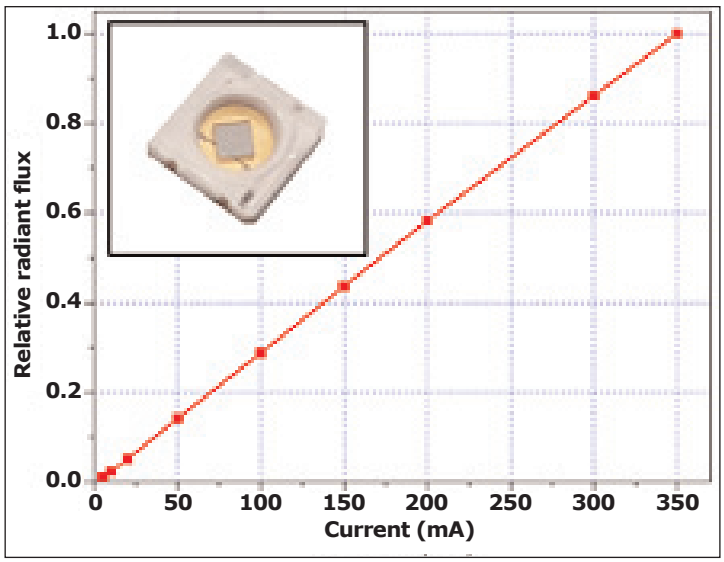
www.wellnesscenterusa.com

SETi launches high-power 275nm SMD LED with up to 30mW optical power

Sensor Electronic Technology Inc (SETi) of Columbia, SC, USA, which manufactures deep-ultraviolet (DUV) LED devices and modules emitting at wavelengths of 230–355nm, is launching a new addition to its SMD family to meet the needs of those seeking high power from a small footprint.

The new SS35DF227513 LED has a wavelength centered at 275nm and delivers 30mW of optical power at 350mA and 10mW at 100mA. With a low cost of ownership, it has been developed for water sterilization, medical, analytical instrumentation and biochemical analysis.

"Our launch of our high-power UV products is part of our strategy to meet our customers need for increasing output power at UV wavelengths, nominally 275nm," says president & CEO Emmanuel Lakios.



SETi's new SS35DF227513 30mW 275nm-wavelength UV LED.

Our launch of our high-power UV products is part of our strategy to meet our customers need for increasing output power at UV wavelengths

The new LED is complementary to other SMD-footprint products offered by SETi. In addition, the package has been re-designed with lower thermal resistance to accommodate the higher operating powers of the new device.

The new SS35DF227513 is now fully available for sampling and in high-volume manufacturing volumes.

www.s-et.com

Soraa launches full-visible-spectrum 230V large lamps

Soraa Inc of Fremont, CA, USA, which develops solid-state lighting technology built on 'GaN on GaN' (gallium nitride on gallium nitride) substrates, has launched a line of full-visible-spectrum LED 230V large lamps. From narrow spot to flood, the PAR20, PAR30 short/long-neck, PAR38 and AR111 LED lamps are said to produce high peak intensity, provide flawless beam definition and smooth beam edges, and have exceptional color (CRI of 95 and R9 of 95) and whiteness rendering. The lamps are also customizable with the company's SNAP System.

"Lighting designers and customers have been asking for powerful, high-quality large lamps," says George Stringer, senior VP of global sales & marketing, who adds that Soraa's Point Source Optics and Violet-Emission 3-Phosphor technology enable low power consumption, unique narrow-spot beams.

Soraa says that its Point Source Optics technology produces high-intensity and uniform beams. The optics technology enables the offering of 8°, 9° and 10° narrow-spot PAR versions with double the peak intensity of other LED makers, it is claimed.

The new line of LED 230V large lamps includes the PAR30 long-neck model.

Soraa says that its Violet-Emission 3-Phosphor (VP_3) LED technology enables the rendering of colors and whiteness. Utilizing every colour in the rainbow, especially deep red emission, VP_3 Vivid Color renders warm tones accurately, and achieves a color-rendering index (CRI) of 95 and deep red (R9) rendering of 95.

Also, unlike blue-based white LEDs without any violet emission, the VP_3 Natural White is achieved by engineering the violet emission to properly excite fluorescing brightening agents including natural objects like human eyes and teeth, as well as manufactured white materials such as clothing, paper and cosmetics.

Designed for seamless fixture integration, Soraa's PAR and AR111 lamps are compatible with a wide variety of dimmers and are suitable for use in enclosed, non-ventilated indoor and outdoor fixtures.

The PAR lamps are available in 8°, 9°, 10°, 25°, 36°, 50° and 60° beam angles as well as 2700K, 3000K, 4000K, and 5000K color temperatures. The AR111 lamps are available in 9°, 25°, 36° and 60° beam angles.

Additionally, Soraa's 8°, 9° and 10° lamps work with the firm's magnetic accessory SNAP System. With a simple magnetic accessory attachment, beam shapes can be altered and color temperature can be modified, increasing design and display possibilities.

www.soraa.com

Seoul wins patent case and agrees royalty-bearing licenses

South Korean LED maker Seoul Semiconductor Co Ltd says that it has prevailed in a series of patent invalidation actions against Japanese lens maker Enplas Corp and has also concluded royalty-bearing licenses regarding LED technology with North American television makers.

Canadian electronics firm Curtis International Ltd and Seoul Semiconductor have resolved a patent lawsuit filed by Seoul Semiconductor in US Federal District Court, asserting infringement of Seoul's patents based upon Curtis's sales of LED backlighting unit products. As part of the settlement, Curtis has agreed to respect Seoul's intellectual property and pay for a royalty-bearing license for any covered products and to cease using unlicensed LED products. The seven asserted patents cover a wide range of technologies including (but not limited to) backlighting units, LED packaging, LED chips and epitaxial layers and black hole lenses.

In addition, Seoul Semiconductor has recently won a series of other victories in patent disputes regarding backlight technology for LED and lens products. In July, it obtained a final judgment in which US-based Craig Electronics acknowledged infringement of all of Seoul's asserted patents and their validity. Craig also agreed to pay for a license and to stop using unlicensed, infringing LED products.

Seoul Semiconductor has recently won a series of other victories in patent disputes regarding backlight technology for LED and lens products

Seoul also filed inter partes review (IPR) petitions against three backlight lens patents owned by Japanese lens maker Enplas. All three IPR petitions were instituted by the US Patent Trial and Appeal Board (PTAB). In September and October, the PTAB issued final written decisions invalidating all the instituted claims for all three patents, finding them to be unpatentable on anticipation and/or obviousness grounds. It is uncommon for the PTAB to invalidate all the instituted claims of three patents, says Seoul Semiconductor.

www.SeoulSemicon.com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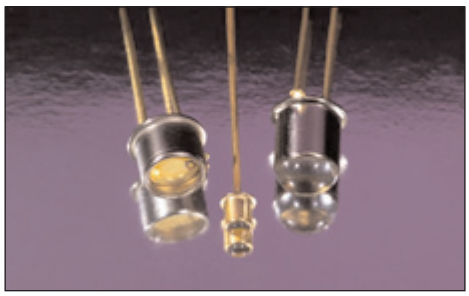
Marktech launches high-power 950nm emitters for optical switches, sensors and scanners

Visible and infrared LED sensor product maker Marktech Optoelectronics of Latham, NY, USA, whose capabilities span wafer growth through finished packaging and custom solutions, has introduced the latest in its series of high-power 950nm LED emitters, with typical power output up to 25mW.

Optimized for optical switches and sensors, the MTE9460 series is available (through distributor Digi-Key) in six standard packages — miniature ceramic packages (MTE9460MC and MTE9460CP), plastic SMD (MTE9460MT), TO-18 metal can (MTE9460WC) and plastic domed and flat top (MTE9460N1 and MTE9460N2) — with varying viewing angles and power outputs.

"This LED series yields superior results in critical sensing and scanning applications," claims chief technology officer Vince Forte. "As an example, many night-vision and surveillance/security cameras use IR LEDs to illuminate an area, making it visible in total darkness. These higher-power LEDs allow a greater area to be illuminated and create clearer pictures," he adds.



Marktech's new series of high-power 950nm LED emitters.

Another use for LED emitters is machine vision systems. "Our precision die placement ensures the highest quality and reliability, as well as extreme accuracy in high-speed applications," says Forte. "Faster testing speeds and higher-resolution analysis is a continual requirement for machine vision systems," he adds. "The higher output signal and low noise level of our 950nm LEDs ensures a more accurate reading."

Marktech also offers an extensive LED sensor product lineup targeted at industrial markets, specializing in high-accuracy applications. The MTE9460 series die, which utilizes the latest chip technology to achieve these high-power readings, can be configured into a number of TO can and lens standard options based upon application needs. In addition, Marktech can offer a variety of COB or custom array packaging.

www.marktechopto.com

Everlight delivers 0.2-Watt mid-power LEDs with luminous efficiency up to 205lm/W

Everlight Electronics Co Ltd (Taiwan's largest LED assembly manufacturer) says that, by using plastic materials with high reflection/lifetime and improved optical structures, its new 5630KK5D and 5630KK6D series mid-power (0.2W) LEDs are optimized to obtain what is claimed to be the industry's highest luminous efficiency of 205lm/W (5000K), meeting the demands for high performance in commercial lighting lamps and fixtures.

Without modifying the circuit and PCB layout, the LED's brightness is efficiently increased. So, the number of LEDs or amount of power that is used is reduced, save energy for lighting applications. Available in industry-standard 5.6mm x 3.0mm packages, both LEDs allow power consumption of less than 11W when used to design a 2000lm finished product, it is reckoned, greatly reducing power consumption in a broad range of commercial lighting applications such as office lighting.

Everlight's 5630KK6D LED series.

The 5630KK5D series LED (with luminous efficiency of 195lm/W) is already being mass produced. The 5630KK6D series LED (with luminous efficiency up to 205lm/W) is beginning mass production in December. Samples of both are available for reference.

www.everlight.com

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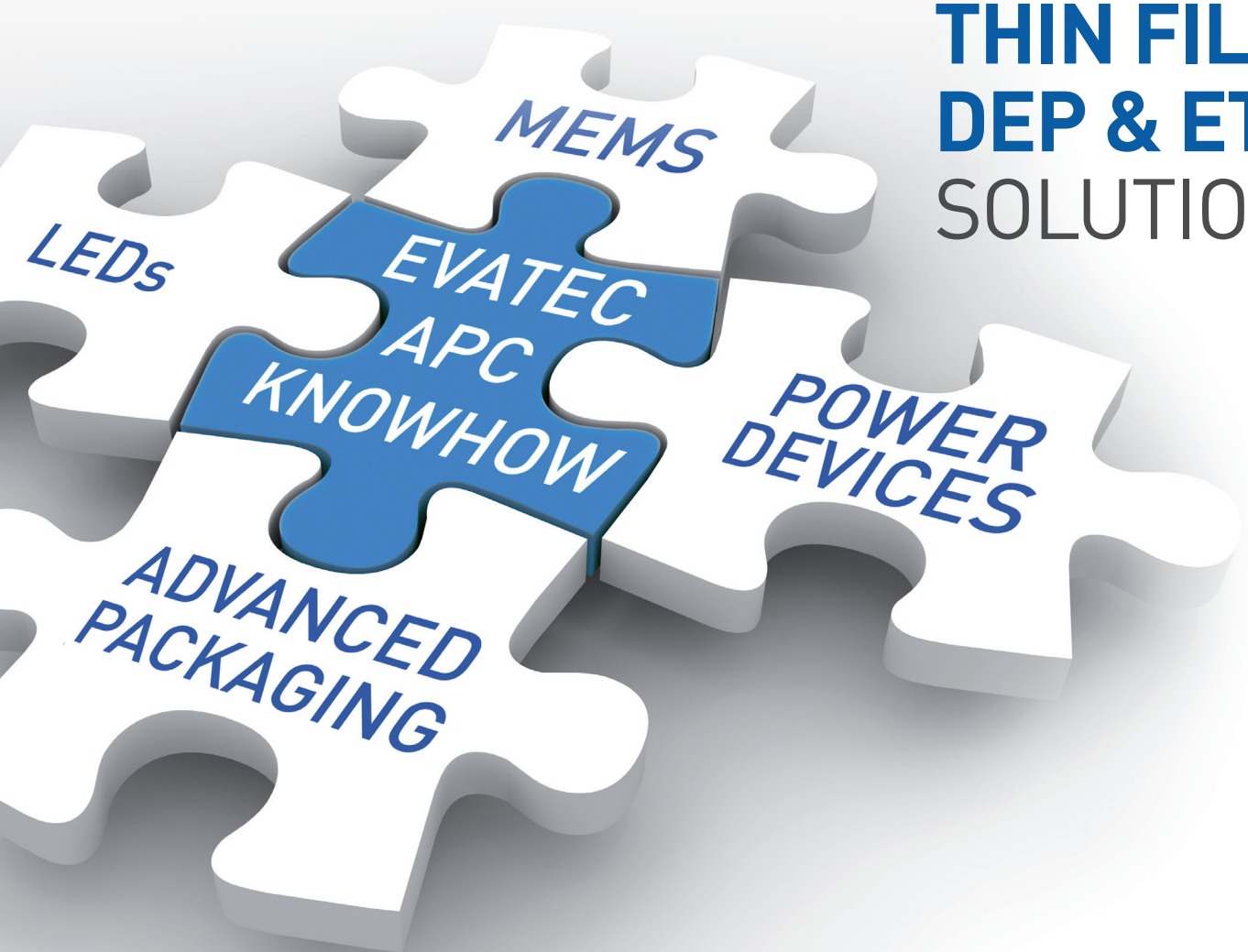

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www.evatecnet.com

SemiLEDs' quarterly revenue falls a further 5%

Worsening losses drive sale of HQ and move to fabless model

For fiscal first-quarter 2016 (ended 30 November 2015), LED chip and component maker SemiLEDs Corp of Hsinchu, Taiwan has reported revenue of $3m, up 3.5% on $2.9m a year ago but down 5% on $3.1m last quarter.

Gross margin was –49%, better than –53% a year ago but worsening from –33% last quarter.

Operating expenses have been cut further, from $2.9m a year ago and $1.9m last quarter to $1.7m, due mainly to selling, general & administrative (SG&A) expenses falling further from $2.15m a year ago and $1.34m last quarter to $1.09m, while R&D expenses have risen slightly from $0.49m to $0.6m (though still less than $0.75m a year ago). Despite this, operating margin has fallen back from –94% last quarter to –106% (though still better than –152% a year ago).

On a non-GAAP basis, net loss was $3.3m, better than $3.9m a year ago but worse than $2.8m last quarter.

Cash used in operating activities was $0.6m, down from $2.7m a year ago up slightly from $0.56m last quarter. Capital expenditure has risen slightly, from $275,000 last quarter to $341,000 (but still almost half the $0.6m a year ago). Hence, free cash flow was –$0.9m, worsening slightly from –$0.87m last quarter (but still much better than –$3.3m a year ago). During fiscal 2015, cash and cash equivalents fell from $4.8m to $3.5m (compared with $8.7m a year ago).

"We are moving toward a fabless business model to focus on the less capital-intensive component business," says chairman, president & CEO Trung Doan. "This should help us to improve gross margin and lower capital spending and R&D expenses," he adds.

On 10 December, SemiLEDs entered into a Building Purchase Agreement to sell its headquarters for $5.2m. The sale is scheduled to close on 31 December 2017. SemiLEDs received a cash downpayment of $3m in December 2015. "This cash injection has provided us additional working capital to execute our fabless strategy," says Doan.

SemiLEDs also entered into a Foundry Services and Licensing Agreement (effective end-December 2015) with an ODM partner to assist with restructuring epiwafer and fab chip manufacturing operations at the firm's Chu-Nan site. "The ODM partner will work with us to ODM vertical chips for us using our vertical technology beginning in March," says Doan. "We expect to consign certain equipment and transfer a significant number of our employees related to the manufacturing of vertical LED chips to our ODM partner," he adds. "This partnership is expected to allow us have a steady source of LED chips with competitive and favorable price for our packaging business, expand our production capacity for LED components, and strengthen our product portfolio and technology."

www.semileds.com

Epistar's chairman receives Pan Wen Yuan Award

At the Shangri-La's Far Eastern Plaza Hotel in Taipei, Taiwan in early December, Lee Biing-jye, chairman of LED chip supplier Epistar Corp, was honored with the 2015 Pan Wen Yuan Award, in the technology sector. Previous recipients of the prize include Taiwan Semiconductor Manufacturing Co (TSMC) chairman Morris Chang, Delta Electronics' chairman Bruce Cheng, Acer Inc's founder Stan Shih, and Quanta's chairman Barry Lam.

"Lee started from zero, and made Taiwan into the world leader in semiconductor electronics it is today," reckons former vice president Vincent Siew. Between 1991 and 1993, Lee and his team developed the first AlGaInP light-emitting diode (LED) and laser diodes (LDs) in Taiwan. In 1996, Lee co-founded Epistar, the nation's first company to research and produce blue and red LED emitters. Epistar now ranks first in high-power LEDs and third in blue laser diodes.

Award recipient Lee Biing-jye (second from right) with this year's prize convener and former Taiwan premier Liu Chao-shiuan (left), former Epistar vice president Vincent Siew (second from left) and Pan Wen Yuan Foundation's chairman Shih Chin-tay (right). (Christine Chou, The China Post).

"It has been a tough time for the industry and we do not know when the next LED killer application will appear yet," commented Lee.

However, when asked about his views on global lighting market, Lee expressed optimism in seeing rapid growth in the near future. Within two years, energy saving light bulbs will disappear completely in the USA, predicts Lee. "Reaching a market penetration rate of 30–40% should not be a problem [for solid-state lighting]."

www.epistar.com.tw

www.chinapost.com.tw/taiwan/business/2015/12/08/452915/Epistar-Chairman.htm

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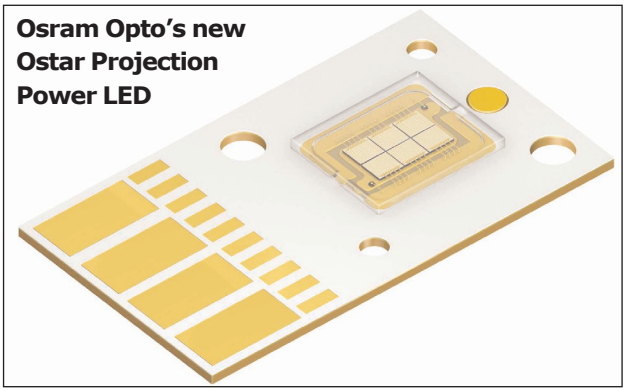
FerroTec

Osram's new Ostar Projection Power LED boosts output beyond 2500lm despite smaller package

Osram Opto Semiconductors GmbH of Regensburg, Germany says that, as a more efficient successor to the P3W LED (with more output from a smaller package), its new Osram Ostar Projection Power LED light source enables users to equip even mainstream projectors rated at more than 2500lm exclusively with LED lighting for the first time. As a monochrome LED, it is available in the colors red (the LE A P3W 01), converted green (the LE CG P3A 01) and blue (the LE B P3W 01).

The external dimensions of the new Ostar Projection Power have been reduced to 27mm x 16mm x 2.1mm and are now the same as those of the compact sister LEDs (the P1W and P2W). The firm's latest UX:3 and thin-film chip technologies and production methods are also used for the new P3W 01. Pulsed at a current of 36A (at 25°C), typical brightness is 4500lm (red), 11,000lm (green) and 33W (blue). The firm reckons that it has not been possible before to generate such high luminous flux and radiant intensity from such a small surface area. The typical electrical output is 121W (red), 128W (green) and 128W (blue).



Osram Opto's new Ostar Projection Power LED

LED projectors now 100 times brighter than in 2005

Osram Opto says that, due to the new LED, standard office projectors with luminous intensities of 2500–3500lm can now have LEDs as the sole light source for the first time. "In the past ten years the brightness of projectors equipped solely with LEDs has been increased by a factor of 100," says Wolfgang Schnabel of Product Marketing LED at Osram Opto. "It is the result of years of research and development," he adds. "Our customers have made huge progress in system development, and we have in chips and packages."

Standard office projectors with luminous intensities of 2500–3500lm can now have LEDs as the sole light source for the first time. In the past ten years the brightness of projectors equipped solely with LEDs has been increased by a factor of 100

High brightness from small surface

One red, one green and one blue Ostar Projection Power can be used as the light sources in a projector. The monochrome LEDs each consist of six chips with an area of $2mm^2$ operated in parallel. Osram developers are using a new type of connection between the chip and the heat-sink that results in a small thermal resistance R_{th} of <0.5K/W. Heat can therefore be dissipated better and the system can be operated up to its maximum output limit. The heat-sinks can also be made smaller, which in turn leads to a more compact design for the projectors.

The Ostar Projection Power LED is already available on request for first customer projects. Volume start-up is planned for the end of January.

www.osram-os.com

Osram grants Taiwan's Unity Opto royalty-bearing license to produce white LED packages; patent litigation dismissed

Lighting manufacturer Osram GmbH of Munich, Germany has granted Taiwan's Unity Opto Technology Co Ltd a royalty-bearing license to produce white LED packages under Osram core patents covering phosphor conversion technology.

This technology is widely used in the LED industry for the generation of white light based on a semiconductor chip emitting blue light that is partially converted into one or more other colors by suitable phosphor materials.

The agreement with Unity Opto follows numerous license agreements between Osram and other producers of white LED packages. In total, more than 20 globally active LED makers are licensed under Osram's core LED patents.

Osram and Unity Opto have also agreed to dismiss the pending patent litigation that Osram had brought against Unity Opto's customer ASUS in Germany. The District Court in Düsseldorf had awarded Osram an injunction and found that ASUS had to compensate Osram's damage caused by the patent infringement.

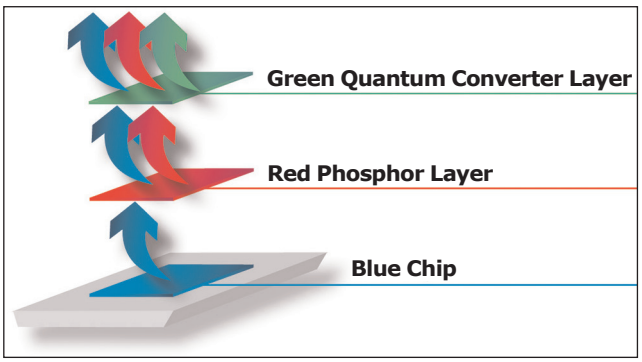
"Osram has built up a very strong patent position," says Dieter Boss, Osram's head of Licensing. "We welcome Unity Opto as a licensee under our White LED License Program," he adds. "To LED producers not licensed by Osram but still making use of our patents, we would like to send the message that Osram will continue to vigorously enforce its patents."

Osram unveils conversion technology for better coverage of color space in Ultra HD TV backlighting LEDs

Osram Opto Semiconductors GmbH of Regensburg, Germany has unveiled new Quantum Colors conversion technology — developed in part in the SSL4EU and Hi-Q-LED projects funded by the European Union (EU) and the German Ministry of Education and Research (BMBF) — that it claims will set new standards in LED backlighting for TV displays, in offering much better coverage of the color space, significant cost savings compared with conventional quantum dot sheets, and zero cadmium usage.

For many years leading TVs makers have been demanding an ever broader color space, notes the firm. With the advent of Ultra HD, the TV standard is once again moving to a larger color triangle. Quantum Colors was developed for precisely this standard. Initial customer projects are in progress, and the technology is scheduled for backlighting LEDs for the mass market by the end of 2016.

Quantum Colors technology is based on a green quantum converter layer that is combined with red phosphor layer on a blue-light-emitting chip, and does not require any cadmium. Advantages over quantum dot sheets (which have been used up to now for high-quality color rendering in TV backlighting) include what is claimed to be superior coverage of the color space due to a narrow green peak with a full width at half maximum (FWHM) of only 30nm. Color space standards such as DCI can be covered 100% and REC2020 more than 80%. Also, the technology does not require the system or any other components to be adapted, simplifying production processes and the entire system.



Quantum Colors combines a blue chip, red phosphor layer and green quantum converter layer.

Compared with solutions based on quantum dot sheets, costs can be halved, it is reckoned. "For a 55" Ultra HD TV with 100% DCI coverage, the complete cost of the light source can be as low as €55, based on our Quantum Colors technology," says Peter Lenz, product marketing LED at Osram Opto. "The cost of just the quantum dot sheets in existing solutions is twice as high [according to report 'The Price of QD Material is Falling, But Not Enough from DisplaySearch', issued on 6 February]."

Another advantage is the constant color throughout the life of the LED, says the firm. Quantum dot sheets take on a bluish tinge over time. As far as lifetime is concerned, Quantum Colors LEDs should last at least 30,000 hours; initial tests have produced positive results, concludes Osram Opto.

www.osram-os.com

Osram launches Duris S 5 Color LEDs for color-mixing consumer lighting applications

For smart lighting solutions and colored lighting applications, Osram Opto Semiconductors GmbH of Regensburg, Germany has launched Duris S 5 Color LEDs — available in four color versions: Red (620nm), Amber (610nm), Green (545nm) and Deep Blue (450nm) — in an industry-standard 3.0mm x 3.0mm epoxy-based package with an emission angle of 120°.

Usable in color-mixing systems as well as in combination with packaged phosphor-converted white LEDs, all Duris S 5 Color versions are based on the same chip technology using phosphor conversion to generate the saturated red, amber and green colors. They hence all feature the same electrical behavior and are compatible with the Duris S 5 White LED, simplifying driver design. In addition, the red and amber Duris S 5 versions are claimed to be best in their class for lumen maintenance and temperature stability between 25°C and 85°C, reducing the complexity of color management in different conditions.

Osram Opto says that the use of red and amber in combination with white LEDs can compensate for missing colors in the white spectrum, increasing the color rendering index (CRI) with rich Ra values.

The green color versions offer high luminous efficacy of 170lm/W (three times higher than that of comparable standard green color LEDs, it is reckoned). This reduces assembly costs, as fewer LEDs are needed (to achieve the same brightness) and PCB design can be more flexible.

The typical forward voltage V_f (at a forward current of I_f=150mA) is 6.2V. Brightness levels are hence high: 28lm for red, 45lm for amber, 170lm for green and 420mW for deep blue.

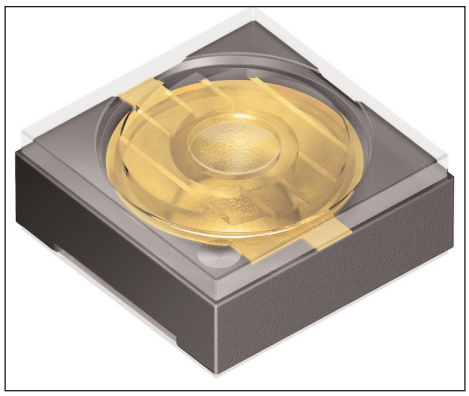
www.osram-os.com/osram_os/en/products/product-catalog/leds-for-general-lighting/duris-s-5

Osram launches lower-profile infrared LEDs with tilted emission for mobile iris scanning

Osram Opto Semiconductors GmbH of Regensburg, Germany says that its new Oslux SFH 4786S infrared LED (IRED) enables iris recognition systems to be made less complex and with lower profiles. At 1.6mm high, the new IRED is about a third thinner than its predecessor. Also, its direction of emission is slightly angled, so there is no need for the usual mechanical aids to ensure correct geometrical alignment.

Recognizing different iris patterns from one person to the next is one of the most reliable biometric identification methods, says Osram Opto. The technology has recently been adopted in smartphones and tablets to protect them against unauthorized access.

In 2014, Osram Opto launched the Oslux SFH 4780S (claimed to be the first IRED that enabled compact and reliable iris scanners to be integrated into mobile devices). The 2.4mm-high SFH 4780S is optimized primarily for maximum light extraction whereas the new SFH 4786S features the same high light extraction performance but its height has been reduced to only 1.6mm (while maintaining the same footprint) to meet the demand for extremely low-profile emitters in designs where very little height is available.



The new infrared SFH 4786S LED provides the basis for low-profile systems for iris scanners. Due to the new slight sideways tilt of its direction of emission, the emitter no longer has to be mechanically aligned with the field of view of the camera.

A completely new feature is the 8° tilt in the emission direction of the SFH 4786S. The slightly sideways emission characteristic is beneficial for the field of view of the camera mounted a slight distance away. The firm say that the performance of the overall system is significantly better than one with an emitter slightly emitting vertically upwards. "Up to now, mechanical means have been used in iris scanners to tilt the IRED slightly," says Chris Goeltner, product marketing manager, IR. "However, this additional expense is no longer needed with the SFH 4786S. This greatly reduces the level of complexity in designing iris scanners."

Designers also benefit from the broader emission angle of +13°, which allows a larger area to be illuminated at the customary working distance for iris scanners in mobile devices. The radiant intensity of the SFH 4786S is typically 1750 milliwatts per steradian (mW/sr) at a current of 1A.

Like the SFH 4780S, the SFH 4786S emits light with a wavelength of 810nm. In this spectral range, it is possible to achieve high-contrast images for all iris colors. The chips are of Nanostack design, which provides two emission centers per emitter, resulting in maximum optical output.

Both IREDs are based on the highly efficient Oslux package, which focuses the light tightly with its reflector and an appropriate internal lens. Osram Opto says it is capable of providing high radiant intensities and also of being easy to process due to its flat surface. Also, the thermal resistance of the package is just 25K/W.

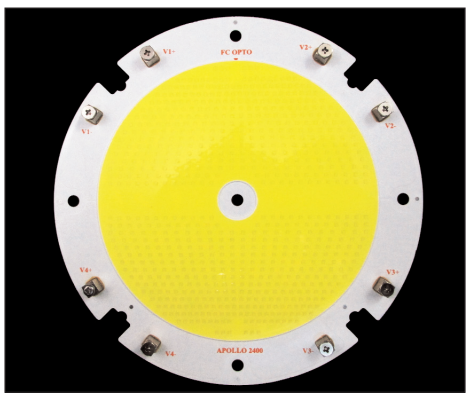
The SFH 4786S is available now upon customer request. Volume production is planned to start at the end of January.

www.osram-os.com

Flip Chip Opto launches 2400W chip-on-board LED

LED lighting technology firm Flip Chip Opto Inc of Fremont, CA, USA has launched what it claims is a first-in-class 2400W high-power LED flip-chip chip-on-board (COB) LED as part of its flagship Apollo series based on the firm's patented 3-pad Pillar Metal Core Printed Circuit Board (P-MCPCB) technology.

The Apollo series represents Flip Chip Opto's high-powered flip-chip COB lineup. The Apollo 2400 reaches a maximum power of 2433.6W, achieving a thermal resistance of



0.003ºC/W and a luminous flux of more than 230,000 lumens, based on a 80CRI (color rendering index) and 5K CCT (correlated color temperature), making it suitable for extreme applications such as stadium lighting, nautical spotlighting, outdoor industrial needs, and underground operations.

The Apollo 2400 is claimed to be unique due to its thermal properties, allowing designers to maximize lumens-per-dollar by reducing the form factor of the light fixture, fixture optics, and number of fixtures.

www.fcopto.com

Osram Opto launches IRED in low-profile Synios package for eye tracking in mobile devices

Osram Opto Semiconductors GmbH has launched the SFH 4770S, which it claims is the most compact infrared LED (IRED) in the high-power class. Its low height is especially beneficial in smartphones and tablets, says the firm, because its high optical output of 1200mW (typical) and broad emission characteristics make it suitable for facial recognition and eye-tracking systems that can activate applications in response to eye blinking instead of the usual double-click.

The basis for the new emitter is the compact (2.7mm x 2.0mm x 0.6mm) Synios package (introduced in 2014 for LEDs in the visible spectral range for automotive applications), which provides optimum light extraction. The SFH 4770S is the first component in which this package has been used for infrared emitters. Installed in the IRED is a 1mm^2 emitter chip with a wavelength of 850nm in which two emission centers are provided with the aid of nanostack epitaxial technology. Overall, the component delivers a typical optical output of 1200mW at a current of 1A from only one chip.

With a height of only 0.6mm, the SFH 4770S is claimed to have a lower profile than any IREDs previously available in its output class, meeting the need for broad homogeneous illumination in a limited space (particularly in mobile devices such as smartphones and tablets). "Compared to the Oslon, previously our most compact high-power IRED, we have managed with Synios to reduce the footprint by almost one-third and the height by around one quarter," says product marketing manager Chris Goeltner.

The emission angle of 120° ensures that the target area is evenly illuminated. Even with this emission characteristic, due to its high overall output the SFH 4770S achieves a typical radiant intensity of 375mW/sr (milliWatts per steradian) at 1A. This makes it suitable for facial recognition and eye-tracking systems, since they need the user's face to be brightly and uniformly illuminated, adds the firm.

Osram Opto says that the Synios package is also suitable for injecting light into external optics or light guides. Another important property for all applications is the thermal stability of the SFH 4770S, adds the firm; thermal resistance (R_{th}) is a maximum of 9K/W.

The Synios SFH 4770S is already available on request for first customer projects. Volume start-up is planned for the end of January.

www.osram-os.com

GaNo Opto launches first commercial silicon carbide UV avalanche photodiodes

Appropriate termination and surface passivation techniques critical for low leakage current and high avalanche gain to allow single-photon-counting mode

GaNo Optoelectronics Inc of Yangtze River Delta Economy Park, Jiangsu Province, China — which offers UV sensors and modules based on wide-bandgap semiconductors including nitride (GaN) and silicon carbide (SiC) — has released what it claims are the first commercial SiC-based ultraviolet avalanche photodiodes (APDs). The intrinsically visible-blind APD can work in either linear or Geiger mode with UV photon counting capability.

SiC UV APDs have attracted much attention from both academics and industry because of their potential applications in corona discharge and flame detection, UV fluorescence, UV astronomy, UV ladar (lidar) and communication, as well as the detection of jet engines and missile plumes, says GaNo Optoelectronics.

Traditionally, bulky photomultiplier tubes (PMTs) must be used in these applications, where the UV signals to be detected could be very weak. SiC APDs are a promising alternative to replace PMTs, when ruggedness, compactness, low cost, long lifetime and low voltage operation are needed. However, the implementation of SiC UV APDs is very challenging due to substrate or epi-related material defects, relatively poorly modeled device operation, and immature device processing technology.

Most recently, GaNo Opto has started volume production of high-performance SiC APDs with what is said to be high gain up to 10^6 and the capability of single-photon counting combined with a low dark-count rate of ~1Hz/mm^2 at room temperature. Under particular conditions, the device could even conduct single-UV-photon counting at high temperatures up to 150ºC, it is reckoned.

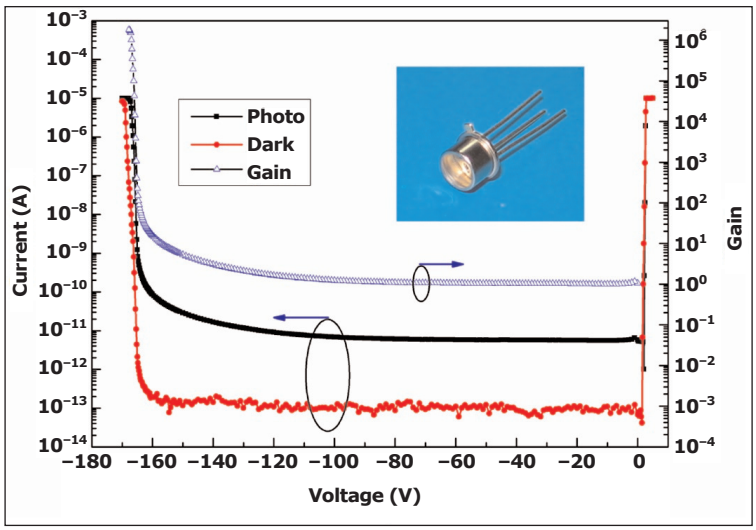


Fig. 1 Room-temperature photo and dark current characteristics of the SiC APD.

"It has been well accepted that wide-bandgap semiconductor is the most suitable material for making UV photodetectors," says GaNo Opto's chief technology officer Dr Hai Lu, who is also distinguished professor at Nanjing University. "Although commercially available silicon APDs demonstrate moderate quantum efficiency in the UV wavelength range, they require highly expensive optical filters to achieve a high UV/visible rejection ratio as their peak response stays within the visible wavelength range. In addition, Si APDs with very low dark counts were only demonstrated when they were cooled to liquid nitrogen temperatures," he notes.

"Our process shows that appropriate termination and surface passivation techniques are critical for realizing SiC APDs with low leakage current and resulting high avalanche gain, both of which are necessary for the device to operate in single-photon-counting mode," Lu continues. "Leakage current as low as in sub-pA level is achieved at 98% breakdown voltage," he adds.

"Our next step is to develop UV imaging arrays based on SiC APDs. In this case, uniformity among each APD pixels and scalability would be the main technological barriers," Hai reckons. "New implantation and dopant activation sequences, and backend processing techniques are being developed to achieve this goal."

www.gano-UV.com/en

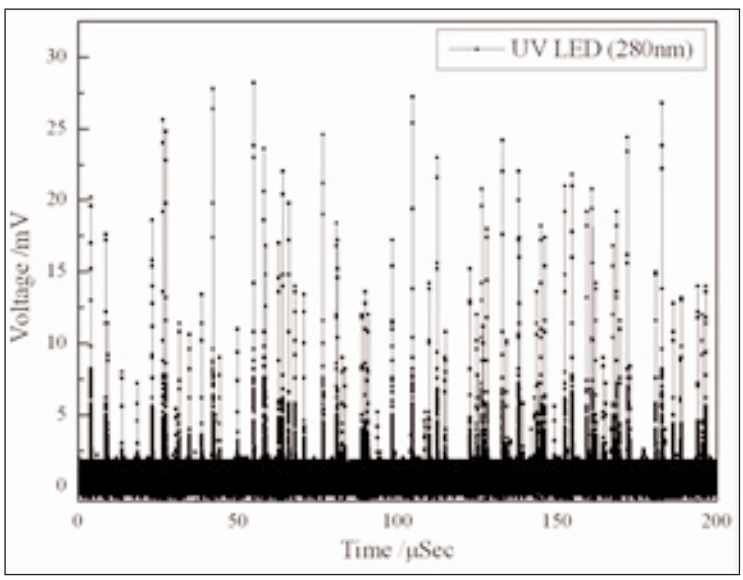
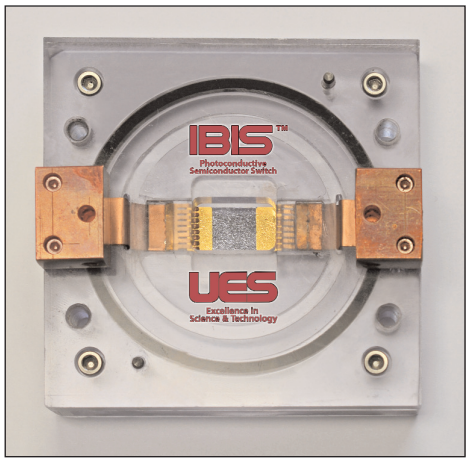


Fig. 2 Real-time photon counting spectrum of the SiC APD.

Award for UES' photoconductive semiconductor switch

Science & technology research firm UES Inc of Dayton, OH, USA says that its IBIS photoconductive semiconductor switch (PCSS) has been selected by an independent judging panel and the editors of R&D Magazine as a winner of a 2015 R&D 100 Award in the IT/Electrical category. An R&D 100 Award recognizes the 100 most technologically significant products introduced in the past year.

Advanced pulsed power switching technologies such as IBIS PCSS enable future nuclear weapon effects (NWE) experimentation capabilities and concepts for the active interrogation of special nuclear materials (SNM). The gallium arsenide (GaAs)-based IBIS PCSS device handles up to 75kV operating voltage, with a total current of ~1kA. Individual channel current has been measured at around 20A/channel at 1kA, with a rise time of 600–800ps. The device has functional dimensions of just 1–2cm per side, and can be triggered with low incident energies of 50–150μJ/cm^2. UES says that the specifications of the patent-pending technology significantly extend the operation windows of currently available PCSS technology, maintaining stringent CSWAP constraints.



UES' IBIS photoconductive semiconductor switch.

UES says that it achieved the honor by:

- proposing to and winning consecutive Small Business Innovative Research (SBIR) and Rapid Innovation Fund (RIF) awards from the Defense Threat Reduction Agency (DTRA); and
- converting the technology developed in the SBIR process to an electromagnetic pulse generator for nuclear pulse simulation, in partnership with L3 Inc.

"I'm grateful for the consistent partnerships and support from Hoa Nguyen of DTRA, and Doug Weidenheimer at L3," notes the device's inventor Dr Rabi Bhattacharya.

"This recognition highlight UES' core strengths of developing and incubating an innovative technology, and working well with key stakeholders to bring it to reality," says CEO Dr Nina Joshi.

www.ues.com/content/emerging

UCLA develops first terahertz VECSEL laser

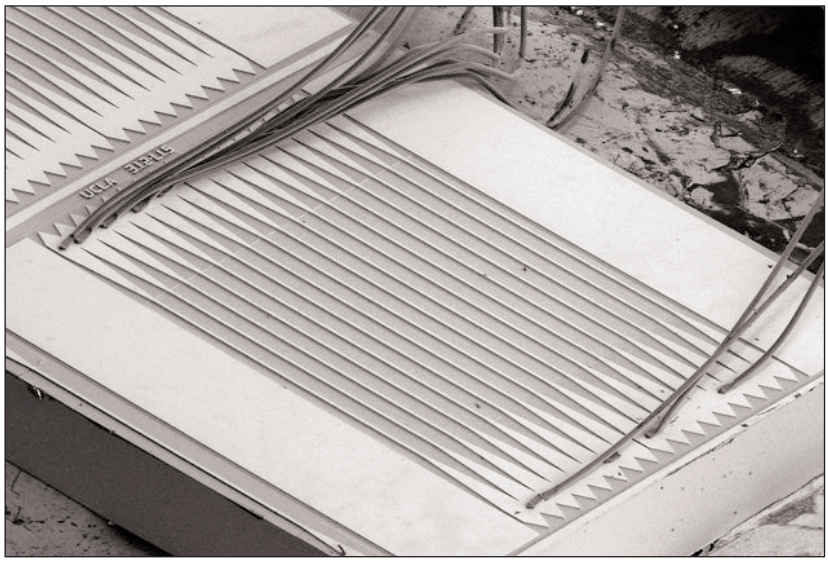
Amplifying reflectarray metasurface mirror could create new class of lasers for aerospace and law enforcement

Funded by the US National Science Foundation (NSF), researchers at the Henry Samueli School of Engineering and Applied Science at University of California, Los Angeles (UCLA) have identified a new way to make a semiconductor laser that operates at terahertz frequencies (Luyao Xu et al, 'Metasurface external cavity laser', Appl. Phys. Lett. 107, 221105 (2015)).

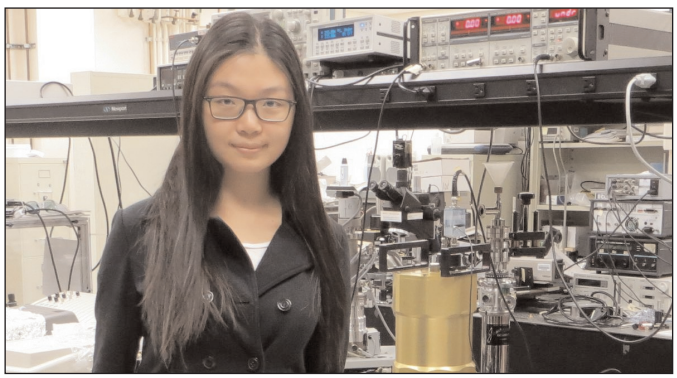
Using the UCLA Nanoelectronics Research Facility for device fabrication, a team led by UCLA associate professor of electrical engineering Benjamin Williams (and including an engineer at Northrop Grumman Aerospace Systems) has created the first vertical-external-cavity surface-emitting laser (VECSEL) that operates in the terahertz range. VECSELs that use visible light have been used extensively to generate high-powered beams, but the technique has not previously been adapted for terahertz frequencies.

The terahertz range of frequencies (between microwave and infrared on the electromagnetic spectrum) can be used to analyze plastics, clothing, semiconductors and works of art without damaging the materials being examined; for chemical sensing and identification; and to investigate the formation of stars and composition of planetary atmospheres. The researchers say that their new development could lead to a new class of high-quality powerful lasers for use in space exploration, military and law enforcement efforts and other applications.

To make it possible to build an external cavity laser with a high-quality beam, the researchers created a VECSEL with a 'reflectarray metasurface mirror', comprising an array of many small antenna-coupled laser cavities such that, when a terahertz wave hits the array, it doesn't 'see' the cavities but rather is reflected as if it were being reflected from a simple, flat mirror. Unlike a simple mirror, however, the mirror amplifies terahertz waves as well as reflecting them.



Unlike a simple mirror, the metasurface amplifies terahertz waves as well as reflecting them.



Lead author Luyao Xu.

The VECSEL approach provides a route to have higher output powers simultaneously with excellent beam quality

"This is the first time a metasurface and a laser have been combined," says Williams. "The VECSEL approach provides a route to have higher output powers simultaneously with excellent beam quality in the terahertz range," he adds. "The metasurface approach further allows one to engineer the beam to have the desired polarization, shape and spectral properties."

Creating a beam that is symmetrical and straight over large distances and changing thermal conditions is a challenge for many semiconductor lasers but particularly for terahertz quantum cascade lasers, which normally use metal laser cavities with dimensions much smaller than the wavelength.

"By using this amplifying meta-surface as part of the external cavity, not only can we improve the beam pattern but we can also introduce new functionality to this laser with different cavity designs," says Luyao Xu, a graduate researcher in Williams' lab and lead author of the study. "For example, by using a free-standing wire-grid polarizer, or filter, as a second mirror, we could optimize the lasers' output power and efficiency simply by rotating the polarizer."

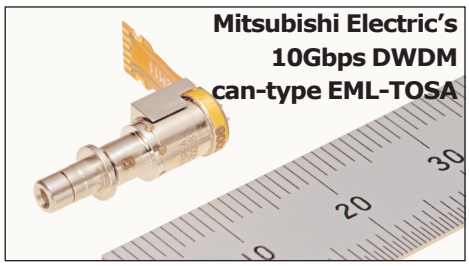
The researchers say that they are already working on several new designs to further advance the technology.

http://scitation.aip.org/content/aip/journal/apl/107/22/10.1063/1.4936887
www.ee.ucla.edu/~bwilliam

Mitsubishi Electric launching 10G DWDM can-type EML-TOSA optical transmitter module to reduce power consumption in radio access networks

On 1 February, Tokyo-based Mitsubishi Electric Corp starts shipping the new Model FU-615REA 10Gbps optical transmitter for high-speed, large-volume data transmission between base-stations and central offices in radio access networks within mobile telecommunication systems.

The new module, which comprises an electro-absorption modulator laser (EML) and a transmitter optical sub-assembly (TOSA), reduces fluctuations in optical wavelengths for dense wavelength-division multiplexing (DWDM). In LTE and LTE-Advanced fourth-generation (4G) mobile systems, DWDM has attracted attention as a means of reducing the power consumption of optical transmitter modules that transmit



Mitsubishi Electric's 10Gbps DWDM can-type EML-TOSA

data between base-stations and central offices.

The module, which has external dimensions complying with the 10Gbps Miniature Device Multi Source Agreement (XMD-MSA), features a cylindrical can-type — not box-type — profile suitable for mass production.

Mitsubishi Electric says that, due to an optimized EML structure, its new can-type TOSA can operate at what is claimed to be an industry-leading maximum temperature of up to 95°C. This helps to reduce the power consumption of the thermoelectric cooler by about 50% compared to Mitsubishi Electric's existing FU-612REA model EML-TOSA (for 10G DWDM over 40km reach). Power consumption of the thermoelectric transducer is less than 0.5W. This in turn helps to reduce the power consumption and size of optical transmission network equipment.

Also, the optimal EML structure reduces fluctuations in optical wavelengths due to operating temperatures, enabling compatibility with DWDM (contributing to increased traffic capacity). Specified wavelengths are 1529.55–1561.42nm (ITU grid: C-band, 100GHz spacing). The transmission reach is 25km.

www.mitsubishielectric.com/

II-VI Inc acquiring EpiWorks and Anadigics for combined $110m

Expands technology platforms and production capacity to address fast-growing markets for semiconductor lasers

Engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA has signed agreements to acquire two firms — EpiWorks Inc and Anadigics Inc — that will expand its technology platforms and production capacity for semiconductor lasers with a scalable 6-inch epitaxial growth and wafer fabrication platform, positioning it to serve fast-growing markets addressed by vertical-cavity surface-emitting lasers (VCSELs). The firm says that VCSELs provide unique advantages in applications in consumer electronics, data centers, sensing, medical and industrial markets, and are expected to grow at greater than 20% annually.

EpiWorks of Champaign-Urbana, IL, USA (which manufactures epitaxial wafers for optical components, wireless devices and high-speed communication applications) is described as conducting "high-volume epitaxial growth of compound semiconductor wafers for electronic and photonic device applications". Revenue in 2015 was about $14m. Its 25,000ft^2, Class 1000 cleanroom epi foundry should provide significant expansion of II-VI's product portfolio. EpiWorks' expertise is reckoned to dovetail with II-VI's core competencies as an engineered materials company.

"Demand for high-performance semiconductor solutions used in communications, data-center, cloud and advanced sensor applications continues to increase," says David Ahmari, who will remain responsible for EpiWorks' sales, marketing & technology. "EpiWorks has been adding capacity to address market growth and emerging photonics applications, however demand forecasts outpace our ability to add capacity organically. By merging with II-VI, EpiWorks has access to substantial expansion capital, a global footprint and sales support around the world. This will allow us to rapidly deploy our technology to the market and increase our market penetration," he adds. "Our goal is to provide our customers the most complete range of semiconductor solutions in the industry along with global scale. Teaming with II-VI allows us to go beyond the typical epiwafer foundry model by offering not just scale but a level of sophistication, flexibility and capability needed in our industry as it is scaling and evolving."

EpiWorks will operate as the separate division II-VI EpiWorks. II-VI plans to expand production in Illinois. Access to metal-organic chemical vapor deposition (MOCVD) capacity at other II-VI sites also offers EpiWorks' customers additional capacity, flexibility and redundancy, it is reckoned.

"We have a creative, multi-year plan for capacity, new capabilities and novel products that cover a wide range of industries and markets," notes EpiWorks' CEO Quesnell Hartmann, who will continue as general manager of the EpiWorks business unit.

EpiWorks has been adding capacity to address market growth and emerging photonics applications, however demand forecasts outpace our ability to add capacity organically. By merging with II-VI, EpiWorks has access to substantial expansion capital, a global footprint and sales support around the world

"The vision is to drive the semiconductor technology roadmap by offering a broad-based platform that can serve the diverse needs of today's semiconductor devices and applications. Not only will we target next-generation performance, but we will use new technology and methods to aggressively reduce costs in high-volume products," he adds. "Our industry is at a crossroads, and those who can innovate and scale will certainly build a sustained advantage. By joining with II-VI, we have the resources and capability to make this vision a reality."

Broadband wireless and wireline communications component maker Anadigics Inc of Warren, NJ, USA is described as a "high-volume foundry unmatched in the production of 6-inch gallium arsenide (GaAs) wafers". The acquisition adds capacity more quickly and economically than building it from new, notes II-VI, which believes that controlling a scalable infrastructure is critical for extending its Laser Enterprise product portfolio technology and positioning II-VI as the world leader in VCSEL technology. As of 3 October 2015, Anadigics had year-to-date (nine months) revenue of $46m and net assets of about $28m.

II-VI agreed to acquire Anadigics for $0.66 per share net in cash (an increase of $0.31 per share over the 11 November deal for affiliates of GaAs Labs LLC to acquire Anadigics for $0.35 per share). On 12 January, Anadigics announced that the $0.66 per-share offer from II-VI had been determined by its board of directors to constitute a 'superior offer'. GaAs Labs subsequently declined to submit a further amended acquisition proposal. On 15 January, in accordance with the

terms of the II-VI merger agreement, the termination fee that was owed by Anadigics to GaAs Labs under the GaAs Labs merger agreement was paid to GaAs Labs by II-VI.

"VCSELs address the need for increasingly intelligent human-machine interfaces such as gesture recognition in consumer electronics products as well as the growing demand for short-reach high-speed optical connectivity in data centers worldwide," comments II-VI's chairman & CEO Francis J. Kramer. "Our engagement with key customers in these and other markets has been sufficiently compelling to lead us to believe that this investment is needed now."

The acquisition of EpiWorks is valued at $43m in cash (due at closing) plus a $6m earn out. The acquisition of Anadigics is valued at $61m in cash due at closing. The combined value of the acquisitions together is $110m in cash (financed from available cash and borrowings under II-VI's credit facility). Both acquisitions are expected to close within 60 days. On a non-GAAP basis, II-VI expects the transactions to be accretive to continuing operations from second-half 2017. For the quarters preceding that, the transaction is expected to be dilutive due to investment in the 6" platform. II-VI will give an update on the financial expectations when the transactions close.

The EpiWorks transaction is subject to the approval of its shareholders. The holders of shares representing 83% of the votes have already signed support agreements to vote in favor of the acquisition.

For the Anadigics transaction, a tender offer for all outstanding common stock must begin within 10 business days and remain open for at least 20 business days. A majority of the outstanding shares must be tendered to complete the acquisition. One-time expenses of up to $10m ($0.15/share) may be incurred over the next four quarters to fully integrate core operations into II-VI's Laser Solutions Segment. Following closing, II-VI aims to move rapidly to serve customers, integrate key operations and reduce operating losses.

The [Anadigics] acquisition adds capacity more quickly and economically than building it from new, notes II-VI

II-VI is updating its guidance for fiscal second-quarter (ended 31 December 2015) to revenue of $189–191m and earnings per share (EPS) of $0.28–0.30 (including the extension of the R&D tax credit). The firm further expects to continue its share repurchases after it reports its results for the quarter to end-December 2015.

www.ii-vi-photonics.com
www.epiworks.com
www.anadigics.com
www.gaaslabs.net

EpiWorks to manufacture epiwafers for POET's monolithic optoelectronics process platform

MOCVD-based development and supply agreement to provide more manufacturable alternate path to MBE

POET Technologies Inc of San Jose, CA, USA — which has developed the proprietary planar optoelectronic technology (POET) platform for monolithic fabrication of integrated III-V-based electronic and optical devices on a single semiconductor wafer — and EpiWorks Inc of Champaign-Urbana, IL, USA (which manufactures epitaxial wafers for optical components, wireless devices and high-speed communication applications) have announced a multi-year development and production supply agreement.

EpiWorks will manufacture wafers for POET's monolithic optoelectronics process platform using its metal-organic chemical vapor deposition (MOCVD) production toolset.

"This partnership is POET's latest advance in its lab-to-fab commercialization initiative in calendar 2016," says POET's CEO Dr Suresh Venkatesan. "Utilizing high-performance, manufacturable epiwafer technology is a key to this initiative, and we are happy to be working with EpiWorks for MOCVD-based development and production," he adds. "We are pleased with the early promising results EpiWorks demonstrated with MOCVD, which will provide a more manufacturable alternate path to molecular beam epitaxy (MBE) techniques and accelerate our technology maturity. To build on our recent successes working together, we formalized this supply agreement to enable further acceleration of our program," Venkatesan continues.

This partnership is POET's latest advance in its lab-to-fab commercialization initiative in calendar 2016

"By establishing a development and supply agreement, our companies expect to be working closely together for several years, allowing the technology to continuously and rapidly improve long after it is scaled into production," says EpiWorks' Quesnell Hartmann.

www.epiworks.com
www.poet-technologies.com

II-VI Inc expands manufacturing assembly capacity for 980nm pump lasers

New laser sub-assembly plant in Philippines supplements existing Switzerland capacity; China module assembly capacity expanded

Engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA has announced the expansion of its 980nm pump laser assembly lines with a new facility in Calamba, Philippines and additional manufacturing capacity in Shenzhen, China.

The continued growth in wired and wireless internet traffic is driving a rapid expansion of the optical communications infrastructure worldwide, notes the firm. II-VI's 980nm pump lasers are the engines of optical amplifiers that are used to boost the power of the transmitted optical signal at periodic intervals along each transmission line in terrestrial and submarine fiber-optic links. With this additional capacity, II-VI can hence respond to the rising demand for its 980nm pump laser modules.

II-VI Inc's facility in Shenzhen, China.

"This additional manufacturing capacity allows us to address the strong growth in demand for 980nm pump lasers from our customers worldwide," says Simon Loten, general manager of the II-VI Pump Laser Division. "With this investment we continue to demonstrate our long-term and stable commitment to serve our customers globally in the growing optical communications market," he adds.

The new II-VI manufacturing facility in Calamba, Philippines, houses automated assembly lines and expands the laser sub-assembly manufacturing capacity already available in Zurich, Switzerland. Laser sub-assemblies are shipped to II-VI operations in Shenzhen, China to complete the pump laser module assembly.

The manufacturing capacity increase in the Philippines and China will begin contributing to II-VI's 980nm pump laser production output in first-quarter 2016 and will be fully operational in second-quarter 2016.

II-VI Inc announces ultra-compact optical components and amplifiers for CFP2-ACO transceivers

Engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA has announced a portfolio of ultra-compact optical components that enable the emerging CFP2-ACO (analog coherent optics) pluggable transceiver form-factor.

The CFP2-ACO transceiver provides a cost-effective solution for bandwidth upgrades of data-center interconnects and metro/regional networks. This transceiver's small form factor also increases system interconnect density.

II-VI is now offering a portfolio of small, hybrid and tunable optical components as well as optical amplification solutions that are designed to meet the compact physical requirements of CFP2-ACO and other high-density transceivers.

These components are said to boost optical signal strength, equalize the optical spectrum, maintain optical polarization states, filter out optical noise, and prevent undesired optical reflections.

The portfolio includes:

- 980nm uncooled pump lasers in an 8-pin mini-DIL package;
- integrated isolator and gain flattening filter (IGFF) hybrid devices;
- integrated isolator and wavelength-division multiplexer (WDM) devices;
- tunable optical filters for optical noise suppression;
- prismatic polarization maintaining couplers; and
- miniaturized custom amplifiers.

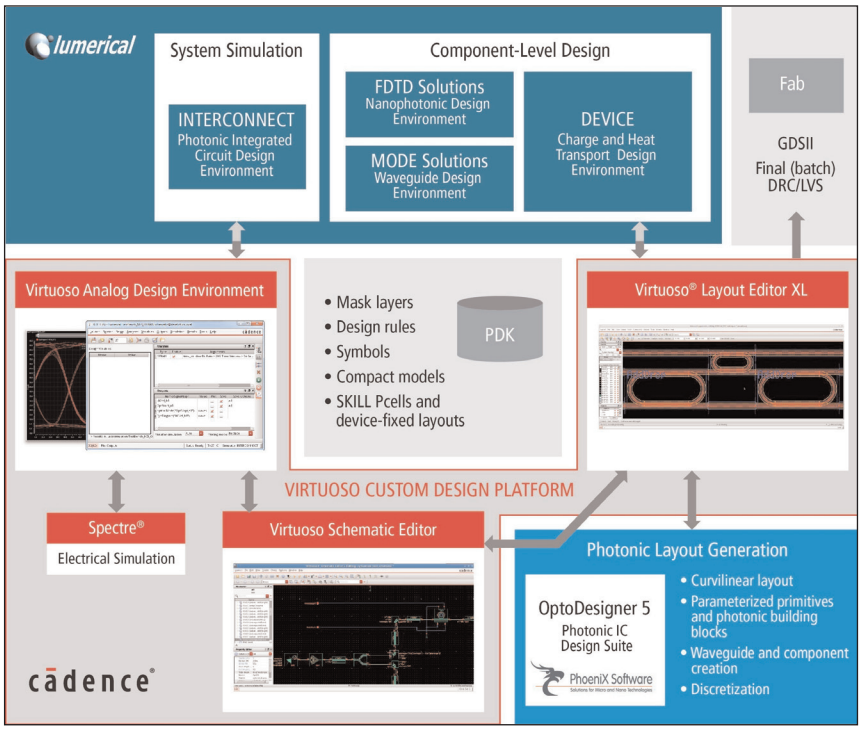
"II-VI serves the CFP2-ACO market with the smallest commercially available 980nm pump laser in the world, a multi-function micro-optics packaging platform, unique wavelength-tunable components and novel optical amplifier subsystem solutions," claims Dr Sanjai Parthasarathi, vice president, Product Marketing & Strategy, Optical Communications Group. "While already a market leader in standalone amplification for high-bit-rate transmission, II-VI now expands into integrated amplification for the rapidly growing CFP2-ACO market," he adds. "We believe that we have the smallest EDFA designs with the lowest power consumption in the industry today."

The new portfolio of ultra-compact components for CFP2-ACO applications is Telcordia qualified and commercially available now.

www.ii-vi-photonics.com

Cadence collaborates with Lumerical and PhoeniX Software to offer Virtuoso platform-based design flow for electronic/photonic ICs

Cadence Design Systems Inc of San Jose, CA, USA has collaborated with Lumerical Solutions Inc of Vancouver, BC, Canada and PhoeniX B.V. of Enschede, The Netherlands to jointly develop an integrated electronic/photonic design automation (EPDA) environment for photonic integrated circuits (PICs). Built around the Cadence Virtuoso custom design platform, the EPDA environment enables schematic or layout-driven design flows for photonic and electronic circuits, photonic component parameter extraction and model generation, photonic circuit simulation and photonic mask layout implementation for both monolithic and hybrid 3D-IC photonic circuits.



To improve productivity, designers can capture the optical circuit in Virtuoso Schematic Editor and then use the Virtuoso Analog Design Environment to simulate the design with Lumerical's INTERCONNECT, a time- and frequency-domain mixed-signal photonic circuit simulation engine similar to SPICE that is designed to account for multi-mode, multi-channel circuits prevalent in integrated photonics. The close integration with the Virtuoso Analog Design Environment can offer interactive analysis, easy design and parameterization for fast PIC exploration, including yield analysis, says Cadence.

PIC mask layout designs present unique challenges as photonic components and circuits are very sensitive to geometry and require all angle design capabilities, notes the firm. PhoeniX Software's OptoDesigner photonic chip design suite is available within the Virtuoso environment, giving designers access to all OptoDesigner parameterized primitives and photonic building blocks that enable interactive or scripted waveguide and component creation.

Finally, to populate the photonic process design kit (PDK) compact model library or to create a simulation model for a custom device, the integration can also support model parameter extraction of passive and active components from the Virtuoso physical layout using these Lumerical component-level solvers: FDTD Solutions, MODE Solutions and DEVICE.

"Integrated photonics will only reach its potential if designers can confidently and reliably design, model and optimize their systems using the familiar workflows of analog and mixed-signal IC design tools," says Lumerical's director of product marketing Bill De Vries. "Lumerical's integration with the Virtuoso environment creates a PDK-driven design flow where circuit designers can use integrated photonics technology alongside electronics to address complex applications without first having to design and optimize fundamental active and passive elements," he adds.

"By integrating PhoeniX Software's OptoDesigner with the Cadence Virtuoso environment, we can offer designers a complete and integrated design flow, supporting highly efficient design of photonic ICs within the industry standard for IC custom layout," says PhoeniX Software's director of sales & marketing Niek Nijenhuis. "This collaboration can support the transition of R&D projects into manufacturing and bring the semiconductor industry into the era of the photon," he adds.

"Our goal is to improve the productivity and streamline the flows by bringing the necessary design and simulation capabilities for photonic integrated circuits into the Virtuoso environment," states Wilbur Luo, senior group director, product management, Custom IC and PCB Group at Cadence. "By collaborating with Lumerical and PhoeniX Software, we are jointly delivering an integrated platform that can drive the widespread deployment of cost-effective, high-performance optical links in data-centers and wide-area optical networks to meet the increasing traffic demands from mobility, video, data, and cloud services."

www.cadence.com/news/photonics
www.lumerical.com
www.phoenixbv.com

MACOM completes acquisition of FiBest

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 completed its acquisition of Japan-based FiBest Ltd (a merchant-market component supplier of optical sub-assemblies) — announced on 17 November — in an all-cash transaction valued at about $60m.

"We are now better positioned to enhance the strategic value we deliver to customers by providing all of the technology, products and packaging to further extend MACOM's preeminent position as a leading supplier of optical networking components," believes MACOM's president & CEO John Croteau.

"This transaction also significantly expands our addressable market in data centers for 100G data rates and beyond, while further unlocking a robust sales channel for MACOM in an estimated $500m RF and microwave component market in Japan," he adds.

MACOM funded the purchase price of the acquisition with cash on hand.

www.fibest.com
www.macom.com

Fabrinet names former Emcore president & CEO Hong Hou as chief technical officer

Thailand-based Fabrinet Co Ltd, which provides optical packaging and precision optical, electro-mechanical and electronic manufacturing services to original equipment manufacturers of complex products (such as optical communication components, modules and subsystems, industrial lasers and sensors), says that Dr Hong Q. Hou has joined it as executive VP & chief technical officer.

Hou has extensive technical and executive-level experience in the semiconductor and fiber-optic communication industries. In 1998 he co-founded the photovoltaic division of Emcore Corp of Albuquerque, NM, USA (which has used Fabrinet as a contract manufacturer of optical components) and led the commercialization of high-efficiency multi-junction solar cell technology for space power applications. From March 2008 to January 2015, he was Emcore's president, CEO and a director. From January to June 2015 he served as a venture partner at ARCH Venture partners, and from June to this January he served as chief operating officer of AXT Inc of Fremont, CA, USA (which makes gallium arsenide, indium phosphide and germanium substrates and raw materials).

Hou has a Ph.D. in Electrical Engineering from University of California at San Diego, and has completed executive management courses at Stanford Graduate School of Business. Early in his career he did research at AT&T Bell Laboratories and the Sandia National Laboratories. He holds eight US patents and has published over 200 technical articles.

"Hong brings vast technical and executive level experience to Fabrinet at a time when the fiber-optics industry is poised for growth greater than ever in its history," notes Fabrinet's CEO Tom Mitchell.

www.fabrinet.com

Source Photonics ships 10,000th single-mode 100G QSFP28 module

Optical communication product maker Source Photonics Inc of West Hills, CA, USA has shipped its 10,000th single-mode 100G QSFP28 module.

Source Photonics began production shipments of 10km QSFP28 LR4 and 2km QSFP28 LR4-Lite modules in first-quarter 2015 after an introduction and sampling program with several leading customer-partners throughout 2014. Major applications for this first-to-market technology include Cloud scale and Web 2.0 data centers worldwide and represent the first single-mode 100G modules deployed in data centers, signifying the beginning of the transition from a 10G/40G data-center architecture to a 25G/100G architecture.

"Potential market opportunity for 100G optics in mega data centers has been making headlines over the last 3 years, attracting many new suppliers and technologies," notes Vladimir Kozlov, CEO & founder of LightCounting Market Research. "The early shipments data from Source Photonics clearly shows that this opportunity is real," he adds. "We expect that shipments of these products will exceed 100,000 units in the first 6–9 months of 2016."

Due to high demand, Source Photonics expects to leverage a vertically integrated operations infrastructure to meet the needs of customers as QSFP28 moves deeper into the data-center fabric.

Source Photonics is also exhibiting its full portfolio of 100G products and demonstrating next-generation technologies from its broadening portfolio of higher-speed products in booth 2709 at the Optical Fiber Communication Conference and Exposition (OFC 2016) in Anaheim, CA, USA (22–24 March).

www.sourcephotonics.com

GigOptix raises Q4/2015's revenue outlook by 4%

Rising order backlog driving Q1/2016 revenue level with Q4/2015

GigOptix Inc of San Jose, CA, USA (a fabless supplier of analog semiconductor and optical communications components for fiber-optic and wireless networks) says that it expects record revenue for fourth-quarter 2015 of about $11.1m, up 6% on last quarter and 23% on $9m a year ago (and 4% above 19 October's guidance of $10.7m).

Based on the preliminary revenue outlook for Q4/2015, GigOptix expects record full-year revenue of about $40.4m for 2015, up 23% on 2014's $32.9m (and above 19 October's guidance of $40m).

GigOptix says that continued robust demand across all of its High Speed Communications (HSC) product line (primarily for its 40Gbps QSFP+ devices used in Web 2.0 OEMs data-center links) and enhanced demand for its Industrial ASIC devices used in legacy and new Internet-of-Things (IoT) applications, has resulted in both fourth-quarter 2015's higher-than-forecasted revenue and the strong bookings for first-quarter 2016.

GigOptix says that, with the better-than-forecasted preliminary Q4 revenue and the continuously improving margin performance, non-GAAP earnings per share should be about $0.05 in Q4/2015 (up from $0.03 a year ago) and a record $0.19 for full-year 2015 (up from $0.04 for 2014).

GigOptix will release full results for Q4 and full-year 2015 on 8 February.

www.gigoptix.com

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

GigOptix 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, and provide 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 I^2C interface for control, monitoring, fault, and status detection. The 1MHz I^2C 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 I^2C 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.

GigOptix wins $6.1m order from aerospace & defense product supplier

GigOptix has booked a $6.1m order with what it says is one of the world's leading suppliers of advanced aerospace and defense technology to deliver advanced ASIC products with applications in avionics for the next two years, starting in fourth-quarter 2015.

This follows the $7.9m order announced in May from another major supplier in the same industry.

"The significant orders we have received this year from world-class suppliers of advanced aerospace and defense products are a clear confirmation of the leadership that GigOptix has in the field of high-speed and mixed-signal RF products and its broad offering of advanced mixed-signal ASIC solutions," says Dan Takise, director of global sales & marketing for ASIC products. "GigOptix offers ASIC solutions spanning from structured ASIC to full-custom advanced mixed-signal designs, which support many high-valued markets such as optical communications, wired/wireless networking, and consumer," he adds.

Finisar's sales driven by higher-than-expected growth in 10G tunable transceivers & wavelength-selective switches

Telecom growth offsetting drop in 40 Gigabit Ethernet transceivers for datacoms

For its fiscal second-quarter 2016 (ended 1 November 2015), fiber-optic communications component and subsystem maker Finisar Corp of Sunnyvale, CA, USA has reported revenue of $321.1m, up 8% on $297m a year ago and up 2.3% on $314m last quarter (and towards the upper end of the guidance range of $304–324m).

Datacom product sales rose by just $0.5m (0.2%) from last quarter, as the growth in 100 Gigabit Ethernet transceivers was offset by a decline in 40 Gigabit Ethernet transceivers (after a record quarter for 40G last quarter).

Telecom product sales rose by $6.6m (8.2%) from last quarter (rather than the forecast of being relatively flat), driven mainly by the growth in 10G tunable transceivers and wavelength-selective switches.

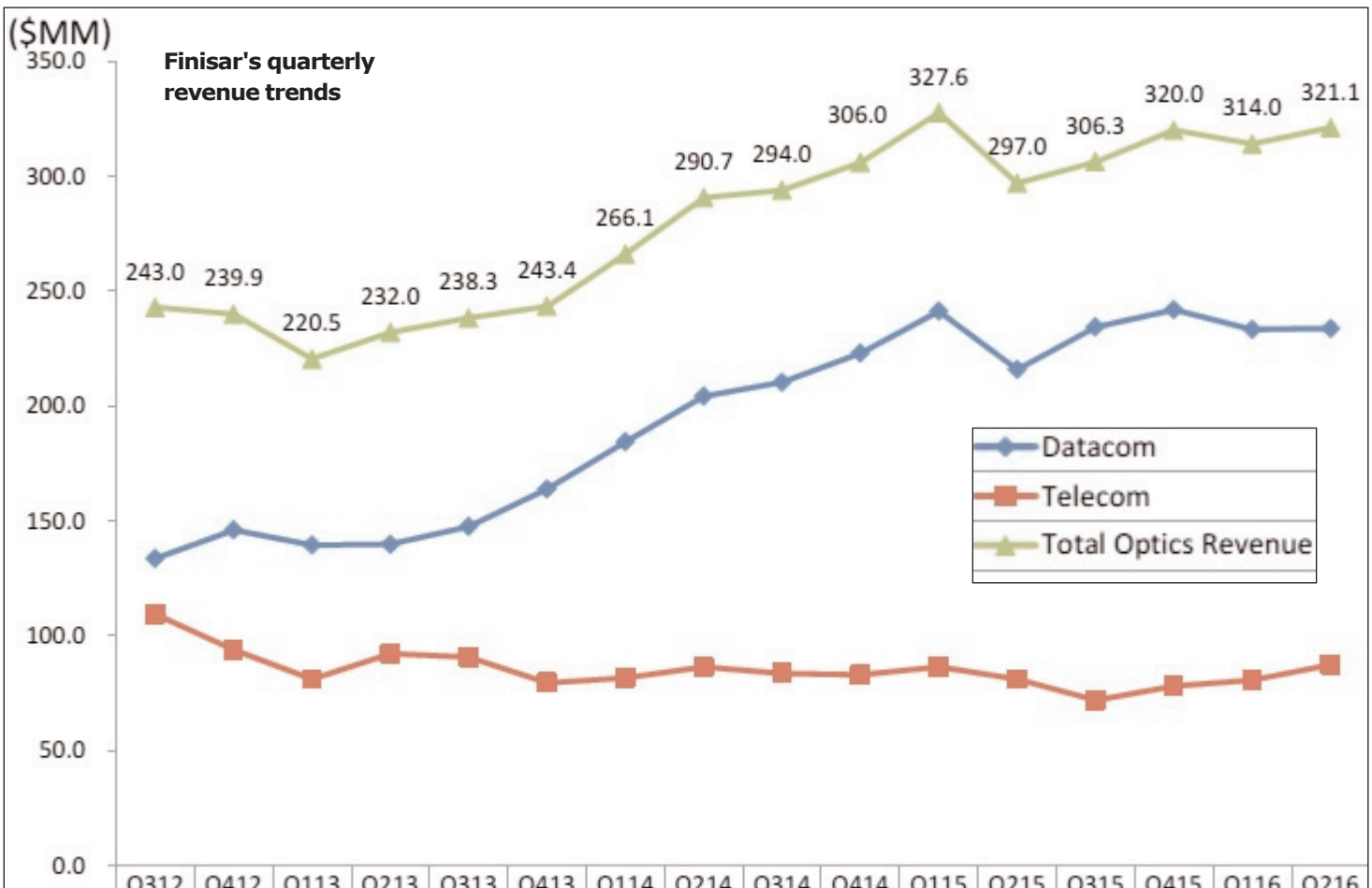
Finisar again had two 10%-or-greater customers, but the top 10 customers fell back from 60.7% of total revenue last quarter to 58.2%.

On a non-GAAP, gross margin has fallen further, from 31.1% a year ago and 30.2% last quarter to 30%.

Operating expenses were $68m (21.2% of revenue, better than the expected 21.4%), down from $68.4m (21.8% of revenue) last quarter (and 22.7% of revenue a year ago).

Operating income has risen further, from $25m a year ago (operating margin of 8.4% of revenue) and $26.5m (8.4% of revenue) last quarter to $28.2m (8.8% of revenue, at the high end of the forecast range of 8–9%).

Net income has also risen further, from $23.5m ($0.23 per diluted share) a year ago and $24.5m ($0.23 per diluted share) last quarter to $26.9m ($0.25 per diluted share, at the high end of the fore-cast range of $0.20–0.26).



	Q312	Q412	Q113	Q213	Q313	Q413	Q114	Q214	Q314	Q414	Q115	Q215	Q315	Q415	Q116	Q216
	133.7	146.1	139.5	139.8	147.6	163.9	184.4	204.3	210.4	223.0	241.2	215.9	234.4	242.0	233.3	233.8
	109.3	93.8	81.1	92.2	90.7	79.5	81.6	86.4	83.6	83.0	86.4	81.1	71.9	78.1	80.7	87.4
s Revenue	243.0	239.9	220.5	232.0	238.3	243.4	266.1	290.7	294.0	306.0	327.6	297.0	306.3	320.0	314.0	321.1

Capital expenditure (CapEx) $29.5m, lower than the regular $35m, due to the timing of expenditure related to final build-out of the second building at Finisar's facility in Wuxi, China.

During the quarter, cash, cash equivalents and short-term investments rose by $25.1m, from $495.7m to $520.8m.

For fiscal third-quarter 2016, Finisar forecasts revenue of $300–320m. The firm expects telecom revenue to grow again and strong demand to continue for 10G tunable transceivers and wavelength-selective switches. Demand from China should also remain strong. "We are seeing continued demand for 100 Gigabit Ethernet transceivers, however we expect that growth to be more than offset by reduced revenue in 40 Gigabit Ethernet transceivers," says chairman & CEO Jerry Rawls. "This is due to the lumpiness in demand at multiple large data-centers," he adds. "We also expect a decline in sales of Ethernet transceivers for wireless applications that we include in our datacom bucket." Overall, datacom revenue should decline slightly.

Finisar expects gross margin to be level at about 30%, as the positive impact of favorable product mix is offset by the impact of one month of the annual telecom price reductions that typically take effect on 1 January. Operating expenses should be flat to down slightly, at $67.5–68m. Operating margin is expected to fall to 7.5–8.5%. Earnings per diluted share should be flat to down, at $0.19–0.25. CapEx will be back up to the $35m per quarter expected during the Wuxi facility build-out. However, this should be finished in fiscal 2016, so in fiscal 2017 CapEx should drop to about $30m per quarter.

We are seeing continued demand for 100 Gigabit Ethernet transceivers, however we expect that growth to be more than offset by reduced revenue in 40 Gigabit Ethernet transceivers. This is due to the lumpiness in demand at multiple large data-centers. We also expect a decline in sales of Ethernet transceivers for wireless applications that we include in our datacom bucket. Overall, datacom revenue should decline slightly

"While we expect the remainder of fiscal 2016 to be a bit challenging, we are optimistic about fiscal 2017," says Rawls. "We expect the benefit from the ramp of many new products and associated revenue growth driven by both data-center construction and upgrades and the increased deployment of ROADMs [reconfigurable optical add-drop multiplexers] and 100G and 200G coherent transceivers in the telecom metro market," he adds.

"We continue to believe that the long-term growth prospects of our company and the optical communications industry are positive," continues Rawls. "From our position as the industry leader, we will continue to develop the technology and the next generation of products for both the datacom and the telecom markets. Finisar's revenue is driven primarily by growth in the global demand for bandwidth due to the increasing distribution and use of video, images and digital information. In addition, Finisar continues to benefit from the growth in cloud services, which drives network hardware upgrades of existing data centers and the build-out of new hyper-scale data centers," Rawls concludes.

www.finisar.com

Silicon Valley Bank's chief operations officer appointed as director

Finisar has appointed Michael L. Dreyer to fill an existing vacancy on its board of directors.

The board currently consists of six directors who are elected to staggered three-year terms. Dreyer will serve as a Class III director until the annual meeting of stockholders in 2017.

Dreyer is currently chief operations officer (COO) of Silicon Valley Bank (SVB) and is responsible for bank and non-bank operations worldwide. He oversees SVB's core operations, enterprise project management, client service and information technology teams. Dreyer is also a director of F5 Networks Inc.

Before joining SVB, Dreyer was president & COO of Monitise from August 2014 to September 2015, where he was responsible for the design, build and operations of its technology globally, and he ran the firm's Americas business.

Prior to Monitise, he was global head of technology and chief information officer (CIO) at VISA Inc from 2005 to 2014, responsible for systems and technology platforms. Previously, Dreyer was CIO of Inovant, where he oversaw the development and management of Visa's global systems technology. He has also held executive positions at VISA USA as senior VP of processing and emerging products, and senior VP of commercial solutions.

Additionally, Dreyer held senior positions at American Express, Prime Financial Inc, Federal Deposit Insurance Corporation (FDIC), Downey Savings, Bank of America, and the Fairmont Hotel Management Company.

"His experience in both the finance and the technology industries give him a valuable perspective from which to help guide our company in the years ahead," comments CEO Jerry Rawls.

Emcore's quarterly revenue rises 61% year-on-year

Cable TV strength boosted by growth in merchant chip business

For its fiscal fourth-quarter 2015 (to end-September), Emcore Corp of Alhambra, CA, USA — which provides indium phosphide (InP)-based optical chips, components, subsystems and systems for the broadband and specialty fiber-optics markets — has reported revenue of $23m, up 8.6% on $21.2m last quarter and up 61% on $14.3m a year ago, due to continued strength in components and specialty photonics product lines. Revenue for full-year fiscal 2015 was $81.7m, up 47.1% on fiscal 2014's $55.5m and the highest level achieved for the broadband business since 2008.

Emcore completed the sales of its Space Photovoltaics business in mid-December 2014 to SolAero Technologies Corp and of its Telecommunications Fiber Optics business (the tunable laser and transceiver Digital Products lines) at the beginning of January to NeoPhotonics Corp of San Jose, CA, USA. The continuing Broadband Fiber-Optics business includes products for cable television (CATV) and fiber-to-the-premise (FTTP) networks as well as satellite communications, video transport and specialty photonics for defense & homeland security applications.

"In the Broadband Cable TV segment, for the past five quarters we have seen a significant improvement in the results and outlook," notes chief financial officer Mark B. Weinswig. "In general, after tough times in 2012 and 2013, the Cable TV Optical Network Infrastructure business has seen improving market trends. Emcore is seeing robust activity for new design and prospects that should lead to additional revenue opportunities in the future," he adds.

"In Chip-Level Device products, revenues have grown significantly from two years ago," Weinswig continues. "This quarter we reached more than $4m, the highest level yet achieved."

Gross margin was 41.1%, up from 36.3% last quarter, due to higher revenue, lower unfavorable variances and reserves, and better factory utilization as well as absorption of fixed costs as a percentage of revenue, coupled with a favorable product mix. Full-year gross margin has risen from 21.8% in fiscal 2014 to 35.1% in fiscal 2015 (one of the highest levels achieved for the broadband business). "Gross margins are at the highest levels the company has realized in at least the past five years, reflecting improvements not just in volume but also in operating efficiency," says president & CEO Jeffrey Rittichier.

Operating expenses were $8.2m, cut from $10.3m a year ago though up by $1.4m from $6.8m last quarter due mainly to higher compensation costs associated with hiring new staff plus additional sales & marketing-related activities, in addition to costs associated with year-end work. In sales, general & administrative (SG&A) expenses in particular, Emcore spent more than $800,000 associated with arbitration activities.

On a non-GAAP basis, income from continuing operations was $2.7m in fiscal Q4/2015, an improvement on $2m last quarter (due to higher revenue and gross profits, partially offset by the higher operating expenses) and a loss of $2.5m a year ago. Full-year income was $4.2m, an improvement of $18m from a loss of $13.8m in fiscal 2014.

Nearly 30% of our chip business this year is expected to be from outside of the GPON application in areas where we can add greater value. We fully intend to become a broad-based supplier of chip-level products to the entire telecom industry

"Most importantly, Emcore continuing operations were profitable on both a GAAP and a non-GAAP basis, generating positive cash flow from operations," says Rittichier.

Cash, cash equivalents and restricted cash was $111.9m at the end of the fiscal year, up by $91.2m on a year ago but down further from $114.1m from at the end of last quarter due to a pay-down of certain liabilities and investments in working capital from higher revenue.

"With the improved results and large cash position, the board of directors is continuing to review options to enhance shareholder value," says Weinswig. Currently, the board expects to approve a cash dividend or distribution to shareholders, with the timing and amount to be determined in a few months following completion of the review.

For fiscal first-quarter 2016 (to end-December 2015), Emcore expects revenue to be steady at $22–24m.

"The cable television transmission product business remains strong but consolidation at the MSO and OEM levels has caused a bit of turbulence and some build-up of inventory that is currently winding itself down," notes Rittichier. "When viewed against a backdrop of MSO spending which is uniformly high, we expect any softness to be short-lived, although the relative percentages of CapEx spend can shift between optical infrastructure and customer premises equipment, and as a result be unpredictable," he adds. "Even though we saw just such a swing between Q3 and Q4, orders for our product did not reflect this, resulting in a small build-up of inventory in the channel. We have already seen signs that this situation is resolving itself and our customers are telling us that their fundamentals are strong."

"We've seen strength in our merchant chip business but are ►

mindful of the strong competitive pressure developing in the GPON [Gigabit passive optical network] market," says Rittichier. "Supply of GPON chips has nearly reached demand as of this time and we expect that this will drive our consolidated margins toward the mid-30s going forward," he adds. "Nearly 30% of our chip business this year is expected to be from outside of the GPON application in areas where we can add greater value. Emcore's fab continues to grow in output, but we fully intend to become a broad-based supplier of chip-level products to the entire telecom industry as well as the GPON chips."

"All these products will be able to take advantage of additional improvements that we are making in operating efficiency as we add operating leverage into the chip fab operations through our automation initiatives, and these are simulation test and sort functions, and see the benefit of those projects reflected in reduced costs and improved yields. Additionally, we are starting to install new equipment to modernize our fab and improve its productivity," Rittichier continues.

"Along with the strength in our cable TV and chip products, we've also seen good progress in market adoption for our specialty products, including our Fiber Optic Gyro product line. Leveraging what is largely the same core technology as our cable TV products, we've made significant inroads into the defense business and are getting traction from multiple tier-1 customers. We hope to significantly increase the revenue from these unique, long-lifecycle and high-gross-margin products in fiscal 2016," Rittichier says.

"We have started the transformation of our manufacturing processes to improve operating leverage, cycle times, yield and overall product cost. Already we are in the process of moving our SatCom manufacturing operations to EMS [electronics manufacturing services] assembly & test in order to improve our margins and reduce the footprint of our US assembly operations," says Rittichier. "Outside of these products, we are actively outsourcing more assemblies from Emcore China to EMS suppliers when make-or-buy decisions are favorable to these actions. Our first automation project is expected to be up and running in Alhambra in Q2 even as process automation is simultaneously being introduced into Emcore's Asian manufacturing facilities. Emcore's Asian operations have already been strengthened with the addition of its first automation team and was actually the first of our facilities to complete our Six Sigma Green Belt program. We expect to strengthen Emcore China's team and insert automation and yield improvement projects which are already being developed through the Green Belt projects."

"Overall, the trends in CATV are solid, even with some short-term turbulence, with respect to inventory and upcoming product changes in our customer base. We are developing a roadmap of actions necessary to reduce our breakeven point and transform semi-fixed manufacturing expense to variable product cost," Rittichier concludes.

"While we are implementing new strategies that should improve our operating model in the future periods, those activities will lead to some additional costs in the next couple of quarters, and will take some time to realize," notes Weinswig. "As a result, we would expect our gross margins to be in the mid-30s for the [fiscal] first quarter." Emcore expects similar overall operating expenses in fiscal Q1 (despite an increase in SG&A), but expenses should then start to fall in subsequent quarters.

"Our operating model goal is to be at breakeven level on a non-GAAP basis at $20m per quarter of revenue, depending on product mix and the timing of certain spending," says Weinswig.

www.emcore.com

Emcore's board gains former JDSU CFO Jackson

Emcore has announced the election of Rex S. Jackson to its board of directors.

Jackson has extensive senior management and executive experience in both the corporate finance and legal functions, having served as chief financial officer and general counsel for several public and private firms. Most recently he held key positions at JDS Uniphase Corp (a provider of optical products for telecoms, cable networks, enterprise and data centers), including executive VP & CFO for the past three years through the separation of JDSU into two separate public companies.

Prior to JDSU, Jackson was executive VP & CFO at Symyx Technologies from 2007 to 2010, where he managed the finance, legal, IT and other corporate functions and led the firm's acquisition of MDL Information Systems and subsequent merger with Accelrys. He also previously served as senior VP & acting CFO at Synopsys and held executive positions with Avago, AdForce and Read-Rite. Currently, Jackson serves on the board of directors of Energous (a provider of wire-free portable electronic device charging systems).

"Jackson's accounting and financial expertise, general business acumen and significant executive leadership experience will position him well to make valuable contributions to Emcore and our board of directors," believes chairman Dr Gerald Fine.

Steven Becker has resigned from the board. "On behalf of Emcore and its shareholders, I would like to thank Steve for his service to the company," comments president & CEO Jeffrey Rittichier.

NREL and CSEM jointly set dual-junction one-sun solar cell efficiency record of 29.8%

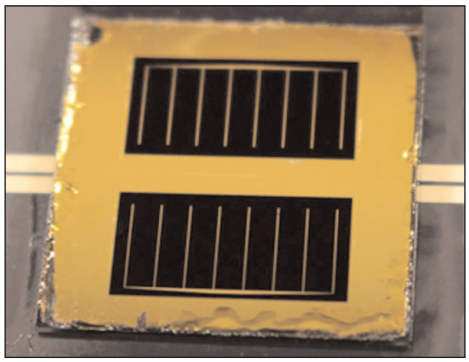
Mechanically stacked GaInP/Si tandem cells exceed theoretical limit of 29.4% for crystalline silicon

The US Department of Energy's National Renewable Energy Laboratory (NREL) and the Swiss Center for Electronics and Microtechnology (CSEM) have jointly set a new record for converting non-concentrated (1-sun) sunlight into electricity using a dual-junction III-V/silicon solar cell (see 'Solar cell efficiency tables').

The newly certified record conversion efficiency of 29.8% was set using a top cell made of gallium indium phosphide (GaInP) developed by NREL, and a bottom cell made of crystalline silicon developed by CSEM using silicon heterojunction (SHJ) technology. The two cells were made separately and then stacked by NREL.

"It's a record within this mechanically stacked category," says David Young, a senior researcher at NREL. "The performance of the dual-junction device exceeded the theoretical limit of 29.4% for crystalline silicon solar cells."

Young is co-author of a paper 'Realization of GaInP/Si dual-junction solar cells with 29.8% one-sun efficiency' (submitted to IEEE Journal of Photovoltaics). Co-authors from NREL are Stephanie Essig, Myles Steiner, John Geisz, Scott Ward, Tom Moriarty, Vincenzo LaSalvia and Pauls Stradins. Essig drew interest from CSEM when she presented a paper 'Progress Towards a 30% Efficient GaInP/Si Tandem Solar Cell' to the 5th International Conference on Silicon Photovoltaics (SiliconPV 2015) in Konstanz, Germany last March.



The GaInP/SHJ tandem cells.

"Silicon heterojunction technology is today the most efficient silicon technology for application in tandem solar cells," believes Christophe Ballif, head of PV activities at CSEM.

"CSEM partnered with the NREL scientists with the objective to demonstrate that 30%-efficient tandem cells can be realized using silicon heterojunction bottom cells, thanks to the combination with high-performance top cells such as those developed by NREL," says Matthieu Despeisse, the manager of crystalline silicon activities at CSEM.

Key to setting the record were a new design for the dual-junction solar cell and the contributions from CSEM. These first collaboration results further indicate that even greater efficiency can be achieved by the combination of NREL and CSEM cells, it is reckoned.

The funding for the research came from the Energy Department's Office of Energy Efficiency and Renewable Energy SunShot Initiative and from the Swiss Confederation and the Nano-Tera.ch initiative.

www.csem.ch
www.nrel.gov
http://onlinelibrary.wiley.com/doi/10.1002/pip.2728/full

First Solar full-year sales to rise to $3.9–4.1bn in 2016

Shipments to rise to 2.9–3.0GW

First Solar Inc of Tempe, AZ, USA, which makes thin-film photovoltaic modules based on cadmium telluride (CdTe) as well as providing EPC (engineering, procurement & construction) services, says that for full-year 2016 it expects net sales of $3.9–4.1bn (compared with $3.5–3.6bn forecasted for full-year 2015), with solar power systems comprising 90–95% and third-party module sales the remainder. Shipments are expected to rise from 2015's 2.8–2.9GW to 2.9–3.0GW.

Gross margin should fall from 24–25% in 2015 to 16–18% in 2016. Operating expenses should be cut from $395–405m to $380–400m. Despite this, operating income is expected to fall from $450–490m to $260–330m.

Capital expenditure of $300–400m will roughly double from 2015's forecasted $175–200m as the firm invests in further advancements in its cost and technology roadmap.

Including a gain of about $200m from the expected sale of an equity method investment and the firm's share of earnings from 8point3 Energy Partners LP (a limited partnership formed in March with solar panel and system maker SunPower Corp of San Jose, CA, USA to own and operate a portfolio of selected solar energy generation assets), earnings per fully diluted share are forecasted to be $4.00–4.50 (compared with 2015's forecasted $4.30–4.50).

Operating cash flow is expected to be $500–700m (not including about $450m from the expected sale of an equity method investment treated as an investing cash flow). Overall, the net cash balance (cash and marketable securities minus expected debt) is projected to rise from $1.3–1.4m at the end of 2015 to $2–2.3bn at the end of 2016.

www.firstsolar.com

Solar Frontier raises thin-film solar cell efficiency record from 21.7% to 22.3%

Advances made to CIS absorber layer and junction formation process

Tokyo-based Solar Frontier — the largest manufacturer of CIS (copper indium selenium) thin-film photovoltaic (PV) solar modules — says that, in joint research with Japan's New Energy and Industrial Technology Development Organization (NEDO) on a standard-size 0.5cm^2 cell, it has set a new record for thin-film solar cell energy conversion efficiency of 22.3%, as verified independently by Germany's Fraunhofer Institute (Europe's largest organization for applied research). This is an increase of 0.6 percentage points over the previous record of 21.7% set in September 2014 by ZSW of Stuttgart, Germany using a 0.5cm^2 cell made of copper indium gallium diselenide (CIGS). "We achieved our latest record through improvements to the CIS absorber layer and junction formation process. This latest advancement brings us a step closer toward realizing Solar Frontier's long-term goal of exceeding 30% efficiency using CIS.

"This is the first time that CIS has crossed the 22% efficiency boundary — a level not yet surpassed by any other thin-film or multi-crystalline silicon technology," notes chief technology officer Satoru Kuriyagawa. "We achieved our latest record through improvements to the CIS absorber layer and junction formation process. This latest advancement brings us a step closer toward realizing Solar Frontier's long-term goal of exceeding 30% efficiency using CIS," he adds. "We would like to express our gratitude to the CIS research consortium organized by NEDO, which includes the National Institute of Advanced Industrial Science and Technology (AIST), for supporting this joint NEDO project."

In addition to the conversion efficiency, several factors determine how much energy a solar module will ultimately generate in real-world conditions and, subsequently, its lifetime cost, notes the firm. Solar Frontier says that its CIS modules generate more energy (kilowatt-hours per kilowatt-peak) compared with crystalline silicon solar modules in real-world conditions.

www.solar-frontier.com

Solar Frontier and TSK to install 5MW CIS PV test facility as part of Kuwait's Shagaya Renewable Energy Project

Tokyo-based Solar Frontier — the largest manufacturer of CIS (copper indium selenium) thin-film photovoltaic (PV) solar modules — and TSK Group of Gijón, Spain (a business group in engineering development and the supply of energy and industrial facilities) have announced plans for a 5MW CIS solar photovoltaic (PV) energy facility in Kuwait. The new installation will be used to evaluate the performance of CIS in Kuwaiti desert conditions as part of the government's Shagaya Renewable Energy Project. Solar Frontier was due to start shipping its CIS modules at the beginning of December and TSK will handle construction as well as operation of the site for the next six years. The new plant is scheduled to begin operating in June 2016.

The Shagaya Renewable Energy Project is part of the Innovative Renewable Energy Research program run by the government entity Kuwait Institute for Scientific Research (KISR). The first stage of this program consists of testing the performance of multiple renewable energy facilities, including PV, concentrated solar power (CSP) and wind.

TSK has been selected to construct the first 10MW PV project (consisting of two 5MW PV plants) as well as a 50MW CSP plant. Solar Frontier's CIS modules comprise one of the 5MW PV facilities and will be compared to a side-by-side crystalline silicon PV plant to help Kuwaiti authorities evaluate the suitability of PV technologies for subsequent phases of the project and other similar facilities to be developed in the future.

"CIS modules are particularly well suited for tough conditions such as in the desert in Kuwait," says Wolfgang Lange, managing director of Solar Frontier Europe. "One of the reasons is because CIS modules are less affected by high temperatures, as indicated by their lower temperature coefficient. When all of the real-world performance advantages of CIS are combined, the result is higher energy yield — or kilowatt-hours per kilowatt-peak — compared to crystalline silicon," he adds. "With the engineering expertise of TSK, we look forward to further demonstrating the performance and quality advantages of our CIS technology outside of the lab and in real-world environments," Lange concludes.

The project with TSK will make Kuwait the 50th country to install Solar Frontier's CIS modules as the solar energy developer continues to expand its global footprint from its manufacturing base in southern Japan.

www.solar-frontier.com

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www.solar-frontier.com

Midsummer's flexible CIGS solar panels installed on sports arena roof

Midsummer AB of Järfälla, near Stockholm, Sweden, a provider of turnkey production lines for manufacturing flexible, lightweight copper indium gallium diselenide (CIGS) thin-film photovoltaic (PV) solar cells, has supplied solar panels to cover the two Tele2 logos on the roof of the new multi-venue Tele2 Arena in Stockholm (one of Sweden's biggest sports and concert arenas). FG Light Energy AB (a subsidiary of Fasadglas AB, one of Sweden oldest companies in the glass and metalwork industry, founded in 1913) was the general contractor and completed the installation of the panels.

Used mostly for concerts and football matches, the multi-purpose Tele2 Arena (which has a retractable roof) has a capacity of up to 33,000 spectators for football matches and 45,000 for concerts. Inaugurated in late 2013, the arena won the 'Best Venue' award in 2014 in the worldwide competition The Stadium Business Awards.

Solar panels covering the Tele2 logos on the roof of the new multi-venue Tele2 Arena in Stockholm.

In Midsummer's solar cells, the CIGS absorber is deposited by sputtering on a 156mm x 156mm stainless-steel substrate, with electrodes on the front to collect current. The cells are then connected in series and covered by a protective plastic layer to form a flexible solar module.

Since a stainless-steel substrate is used, the modules can be made without glass. The CIGS solar modules are therefore much lighter, more flexible and can be made frameless, to suit applications where traditional silicon solar cells cannot be used (e.g. on structures that are uneven, moving or weak).

"This is yet another good demonstrator that our equipment can produce unique products with a high value for the end customer," says Midsummer's CEO Sven Lindström. "The type of membrane roofs normally used on arenas cannot take the load of traditional Si-panels, but the lightweight flexible panels made by Midsummer's equipment can easily be integrated without damaging the membrane," he adds.

www.stadiumbusinessawards.com/2014-winners

www.midsummer.se/sida19.html

Gallium nitride phosphide absorber for silicon-based solar power

Researchers achieve 3x efficiency of best gallium phosphide solar cell to date.

Researchers in the USA have been working on gallium nitride phosphide (GaNP) as an absorbing material for solar power [S. Sukrittanon et al, Appl. Phys. Lett., vol107, p153901, 2015]. The aim of the team from University of California San Diego (UCSD) and Sandia National Laboratories is to create a suitable sub-cell to boost the performance of silicon-based photovoltaic power conversion. Theory suggests that conversion efficiencies up to 45% could be achieved from an AM1.5G solar spectrum with a III-V material on silicon.

Gallium phosphide is one contender for such a top cell since it is near lattice matched (0.37% mismatch) and has a suitable bandgap of 2.26eV. Unfortunately GaP has an indirect bandgap, which makes for inefficient photon conversion to electric power.

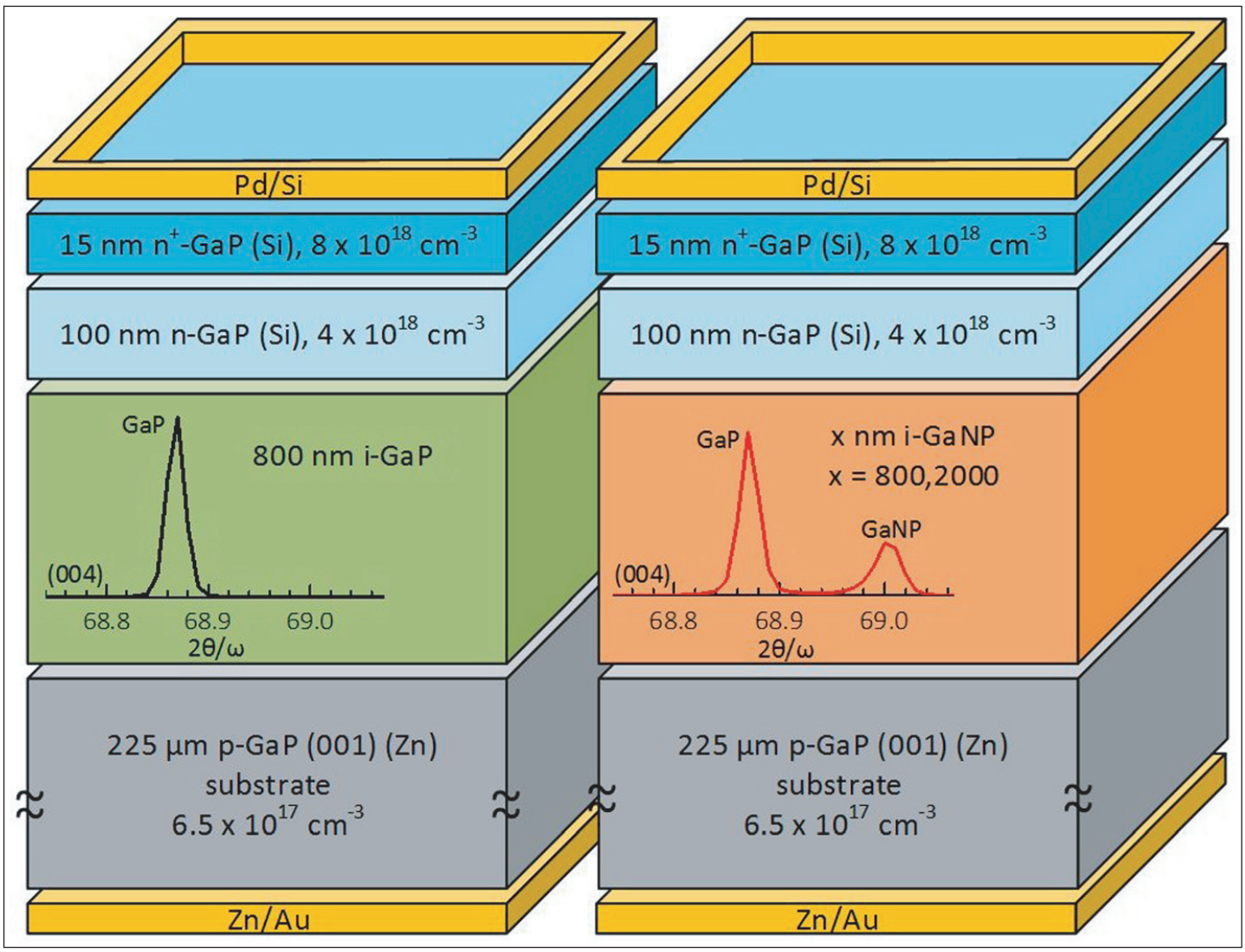

Figure 1. Cross-sections of GaP control and GaNP solar cells. Inset: x-ray diffraction (XRD) spectra.

With the addition of only 0.4% of nitrogen into GaP, giving GaNP, the bandgap becomes direct, shifting absorption coefficients from 10^2–10^3/cm towards 10^4/cm. Further, at a nitrogen concentration of 2%, GaNP becomes lattice matched with silicon.

The UCSD/Sandia researchers achieved efficiencies up to 7.9% without a window layer. The team comments: "This GaNP solar cell's efficiency is 3x higher than the most efficient GaP solar cell to date and higher than other solar cells with similar direct bandgap (InGaP, GaAsP)." They add: "These performance gains are expected to motivate further investigation into the integration of GaNP into future dual-junction solar cells on silicon substrate."

The solar cells were grown on GaP substrates by molecular beam epitaxy (MBE) at 570°C (Figure 1). The GaNP bandgap was ~2.05eV, with the lattice almost matched to silicon. The mismatch from GaP was 0.31%. The nitrogen concentration was around 1.8%, according to x-ray analysis. In fact, GaP has a closer lattice match to silicon than any other III-V semiconductor, note the

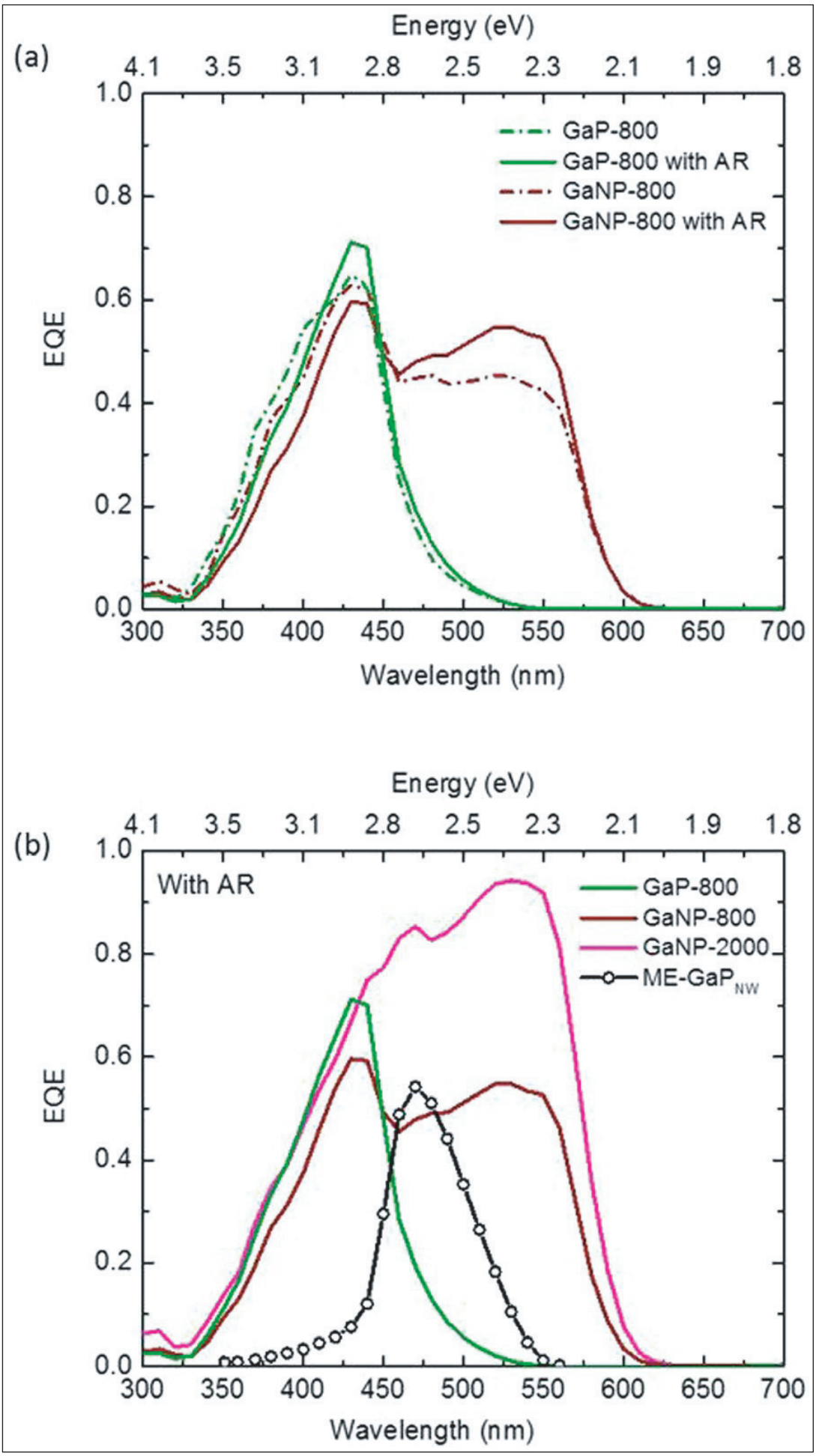

Figure 2. (a) EQE measurements with and without an AR coating of GaP-800 and GaNP-800. (b) EQE measurements with an AR coating of GaP-800, GaNP-800, GaNP-2000, and ME-GaPNW, a device from another group with 2.42% efficiency (without window layer), reported 2012.

Table 1. Performance parameters of GaP-800, GaNP-800, and GaNP-2000 with and without AR coating.

Sample	J_{sc} (mA/cm^2)	V_{oc} (V)	J_{sc}-ratio (%)	FF (%)	η (%)	n-factor
Without AR						
GaP-800	2.69	1.19	30	77	2.5	1.8
GaNP-800	5.52	1.26	42	73	5.1	2.7
GaNP-2000	7.80	1.31	60	71	7.3	2.0
With AR						
GaP-800	3.17	1.19	35	76	2.9	...
GaNP-800	6.08	1.26	46	71	5.5	...
GaNP-2000	8.53	1.33	65	69	7.9	...

researchers.

The n-type layers were designed to act as an emitter layer and a more heavily doped layer to reduce series resistance with the metal contact. The devices did not include a window layer. A control solar cell with GaP absorbing layer was also produced.

The GaNP samples were annealed in nitrogen/hydrogen forming gas at 750° for 30 seconds to suppress defects from nitrogen incorporation, low growth temperature, and RF nitrogen plasma damage.

The material was fabricated into 1mmx1mm solar cells. Further annealing was performed to improve the ohmic contact of the metal layers. An anti-reflective (AR) coating of silicon nitride and silicon dioxide layers was applied to some of the devices.

The current–voltage characteristics were measured in dark and AM1.5G solar condition. The GaNP cell showed a higher ideality (n) factor of more than 2, compared with 1.8 for the GaP cell. This indicated that the GaNP cell suffered from higher Shockley–Read–Hall recombination, reducing efficiency. This was likely caused by defects at GaP/GaNP interfaces.

The current best solar efficiency for GaP devices is 2.9% with a window layer and 2.4% without. These devices had a thicker absorbing layer than the 800nm of the GaP control device, which benefited from an emitter layer that was thinner than the hole diffusion length. To date, our GaNP solar cells exhibit higher efficiency than other wide-bandgap solar cells grown on GaP substrate. InGaP (2.12eV) and GaAsP (1.92eV) solar cells with active layer thicknesses of 2μm achieve efficiencies of only 3.89% and 4.8%, respectively; the low efficiencies partly result from their lattice mismatch, which requires the growth of defective metamorphic buffer

The performance was extracted from the current-voltage behavior (Table 1). Since GaP and GaNP respond to somewhat different wavelengths of the solar spectrum, the ratio of the current density compared with the maximum possible (i.e. for external quantum efficiency of 1) was determined to give a fairer comparison.

The fill factor (FF) of the GaNP devices was slightly lower than for the GaP device, but this was compensated by higher open-circuit voltage (V_{oc}) and short-circuit current density (J_{sc}). (FF = maximum obtainable power/(V_{oc}xJ_{sc}).)

With a thicker 2000nm GaNP layer, both V_{oc} and J_{sc} increased due to the greater light absorption length. The researchers comment: "Our work shows that efficiency is not yet limited by minority carrier diffusion length. Thus, this trend may continue beyond the maximum thickness, 2000nm in GaNP-2000, studied in this work."

Anti-reflective coatings increased Jsc but had little effect on Voc. The best cell with anti-reflective coating and 2000nm GaNP absorbing layer had an efficiency (η) of 7.9%.

External quantum efficiency (EQE) spectra suggested that the anti-reflective coatings reduced efficiency at shorter wavelengths (Figure 2). This was attributed to absorption by silicon nitride, which has a bandgap in the region 2.4–4.7eV. The researchers believe that improvements in EQE can be achieved through "(1) increasing the diffusion length in the emitter region (e.g. optimizing growth conditions), (2) optimizing the emitter thickness, and (3) reducing the front surface recombination velocity (e.g. passivating the front surface, implementing a window layer)."

According to the researchers, the current best solar efficiency for GaP devices is 2.9% with a window layer and 2.4% without. These devices had a thicker absorbing layer than the 800nm of the GaP control device, which benefited from an emitter layer that was thinner than the hole diffusion length.

The researchers conclude: "To date, our GaNP solar cells exhibit higher efficiency than other wide-bandgap solar cells grown on GaP substrate. InGaP (2.12eV) and GaAsP (1.92eV) solar cells with active layer thicknesses of 2μm achieve efficiencies of only 3.89% and 4.8%, respectively; the low efficiencies partly result from their lattice mismatch, which requires the growth of defective metamorphic buffer layers." ■

http://dx.doi.org/10.1063/1.4933317

Author: Mike Cooke

Efficient combination of quantum cascade laser and detectors

Researchers improve bi-functional technology to give pulsed performance comparable to conventional quantum cascade lasers.

Technische Universität Wien (TU Wien) in Austria has improved its bi-functional 6.8μm quantum cascade laser and detector (QCLD) technology [Benedikt Schwarz et al, Appl. Phys. Lett., vol107, p071104, 2015]. It is hoped that monolithic integration of quantum cascade lasers (QCLs) and quantum cascade detectors (QCDs) could lead to compact spectroscopy systems for environmental monitoring and medical applications in the form of trace gas sensing, blood serum analysis, etc.

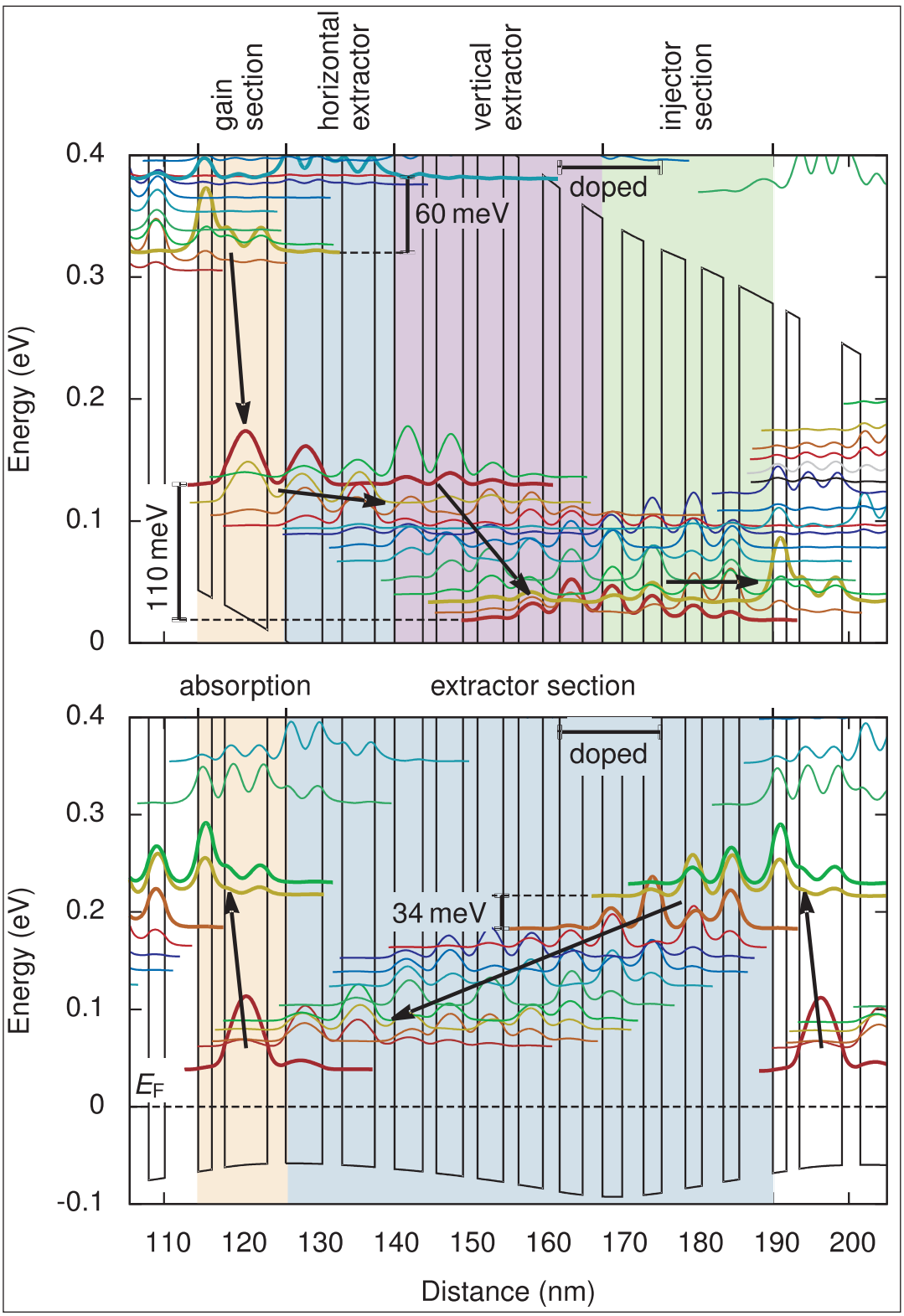

Figure 1. Calculated band diagram of improved bi-functional QCLD for laser bias at maximal wall-plug efficiency (upper) and detector (zero) bias. Detector in thermal equilibrium with Fermi level denoted by dashed line.

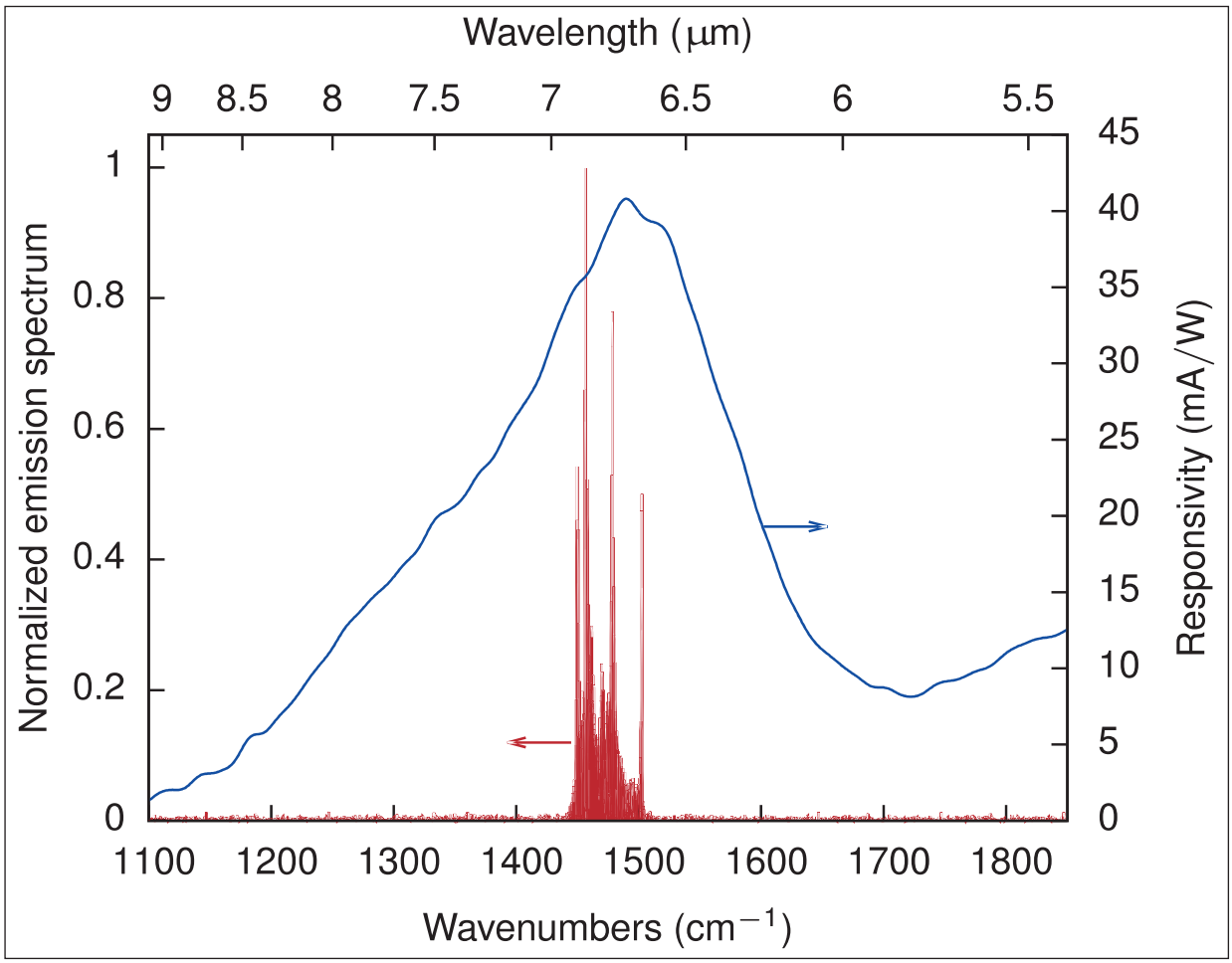

Figure 2. Overlap of emission spectrum and spectral responsivity of quantum cascade laser diode structure.

However, combining efficient lasers and detectors on the same epitaxial material is a challenge since optimum designs for one mode tend not to be so for the other. Also, since the peak wavelengths are bias dependent, it is difficult to maintain spectral overlap between the laser emission and the detector's photoresponse.

The TU Wien researchers comment: "Our previous designs showed room-temperature operation for both the laser and the detector, but were limited to low duty-cycle operation, due to the large threshold current densities and low wall-plug efficiencies." The team has refined its design to give a significantly higher laser performance and now claims that "bi-functional designs can achieve a comparable pulsed performance to conventional quantum cascade lasers".

The QCLD material was grown on indium phosphide (InP) using molecular beam epitaxy (MBE). The design included 35 periods of the active region (Figure 1) and two low-doped indium gallium arsenide (InGaAs) layers for confinement. The lasers and detectors were fabricated with 10μm-wide ridges, silicon nitride insulation, and annealed titanium/gold contacts. The devices were mounted epi-side up on copper with indium bonding.

The researchers report that the new laser device has improved all characteristic parameters by at least a factor of two over previous designs in pulsed mode (100ns at 10kHz). With a 3mm-long Fabry–Perot ridge, the room-temperature current threshold was 3kA/cm^2, compared with 6kA/cm^2 for a previous QCLD device technology. At the same time, the optical output was 470mW (200mW, previously). The total wall-plug efficiency was 4.5%, which falls short by a factor of two or three compared with conventional QCLs with comparable waveguide structure. Some groups have achieved wall-plug efficiencies of up to 50%.

The team comments: "Further improvements can be achieved by applying high- and anti-reflection coatings on the facets, as well as by using buried heterostructure waveguides with InP cladding to decrease the waveguide losses and increase the heat dissipation."

For the detector section, the peak response was 40mA/W at zero bias with a 0.5mm-long ridge (Figure 2). The differential resistance of 1.6kΩ gives a Johnson/thermal noise equivalent power (NEP) of 80pW/√Hz at the peak wavelength. The researchers point out that they were limited to 0.5mm ridges due to the cleaving process. Lithography and dry etch could be used to decrease the length. The team comments: "A length of 15μm would give the optimal Johnson-noise-limited NEP, while slightly longer devices around 50μm give a higher responsivity and are favorable if the noise is limited by other sources."

In an on-chip configuration with a small air gap between laser and detector, the peak absolute photocurrent was 9mA without saturation. ■

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Author: Mike Cooke

II-VI semiconductor green laser diode achieves lower current threshold

Device uses single beryllium zinc cadmium selenide quantum well.

Jijun Feng and Ryoichi Akimoto based in China and Japan have developed low-threshold green and green-yellow laser diodes (LDs) based on a beryllium zinc cadmium selenide (BeZnCdSe) quantum well [Appl. Phys. Lett., vol107, p161101, 2015]. Feng comes from China's University of Shanghai for Science and Technology, and both researchers are associated with Japan's National Institute of Advanced Industrial Science and Technology (AIST).

Feng and Akimoto are seeking to plug the 'green gap' for laser diodes, giving access to display and projector applications. Alternative green-emitting materials such as indium gallium nitride (InGaN) lead to laser diodes with high thresholds and stability problems. Low thresholds can be achieved for blue-green ZnSe, but device lifetimes tend to be short.

Adding beryllium should improve the lifetime by shifting the chemical bonds from highly ionic towards a more covalent character. Previously, BeZnCdSe single quantum well (SQW) laser diodes have achieved 545nm wavelengths. Feng and Akimoto have created laser diodes with even longer wavelengths — green and green-yellow devices emitting ~535nm and ~560nm, respectively.

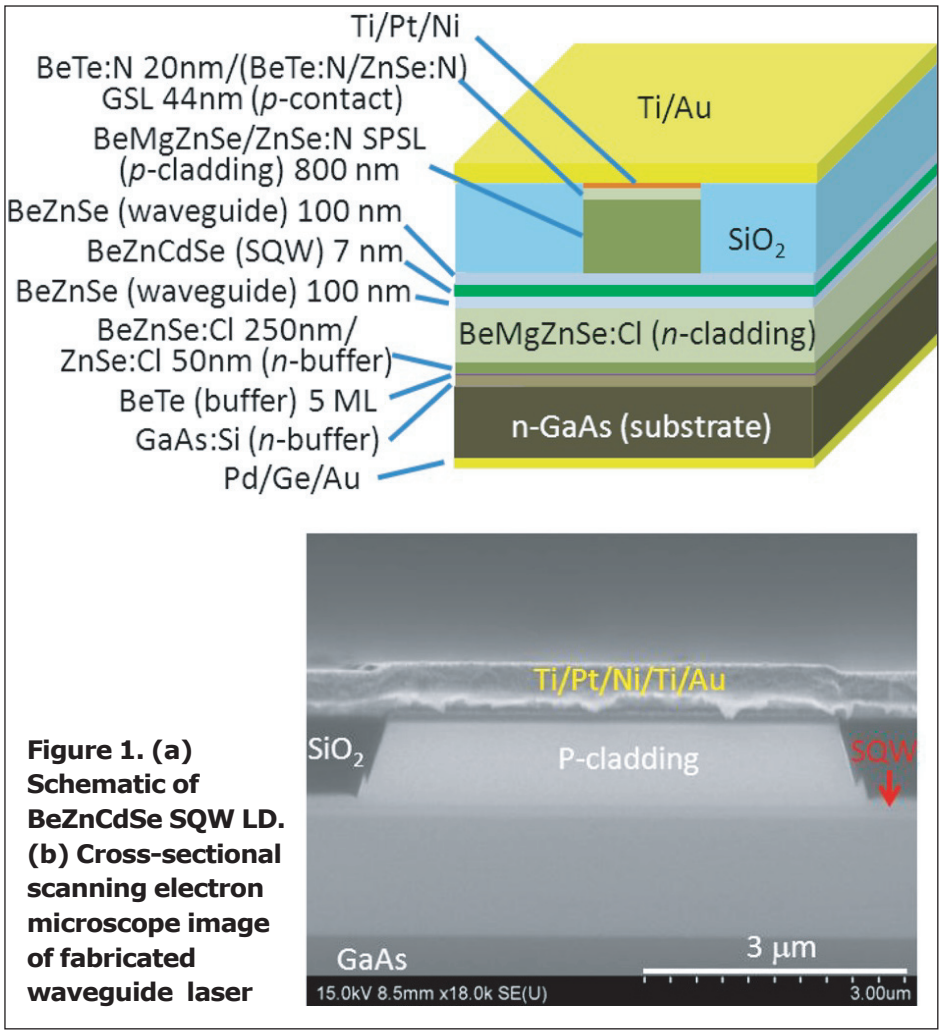

Figure 1. (a) Schematic of BeZnCdSe SQW LD. (b) Cross-sectional scanning electron microscope image of fabricated waveguide laser

Molecular beam epitaxy (MBE) on gallium arsenide (GaAs) was used to create the lasing material (Figure 1). Zinc chloride and nitrogen RF-activated plasma were used to give n- and p-type doping, respectively. Separate chambers were used for III-V (GaAs buffer) and II-VI growth. The BeTe buffer was designed to protect the GaAs buffer surface from Ga_2Se_3 formation, which causes stacking faults.

A separate-confinement heterostructure was used with a $Be_{0.02}Zn_{0.68}Cd_{0.30}Se$ single quantum well between the $Be_{0.03}Zn_{0.97}Se$ optical guiding layers. The n-cladding was $Be_{0.06}Mg_{0.06}Zn_{0.88}Se$. The p-cladding consisted of a short-period superlattice (SPSL) of $6x(Be_{0.10}Mg_{0.14}Zn_{0.76}Se/ZnSe)$. The p-contact consisted of a BeTe/ZnTe pseudo-graded superlattice, where the thickness of the layers is varied.

The ridge waveguide was dry etched using a metal mask of titanium/platinum/nickel that also served as the ohmic p-contact. The ridge was buried with silicon dioxide from plasma-enhanced chemical vapor deposition (PECVD). The structure was finally planarized with chemical mechanical polishing (CMP). A final titanium/gold metal p-electrode was deposited, making contact with the p-ohmic metals, and then the n-contact metals were evaporated onto the back-side of the wafer.

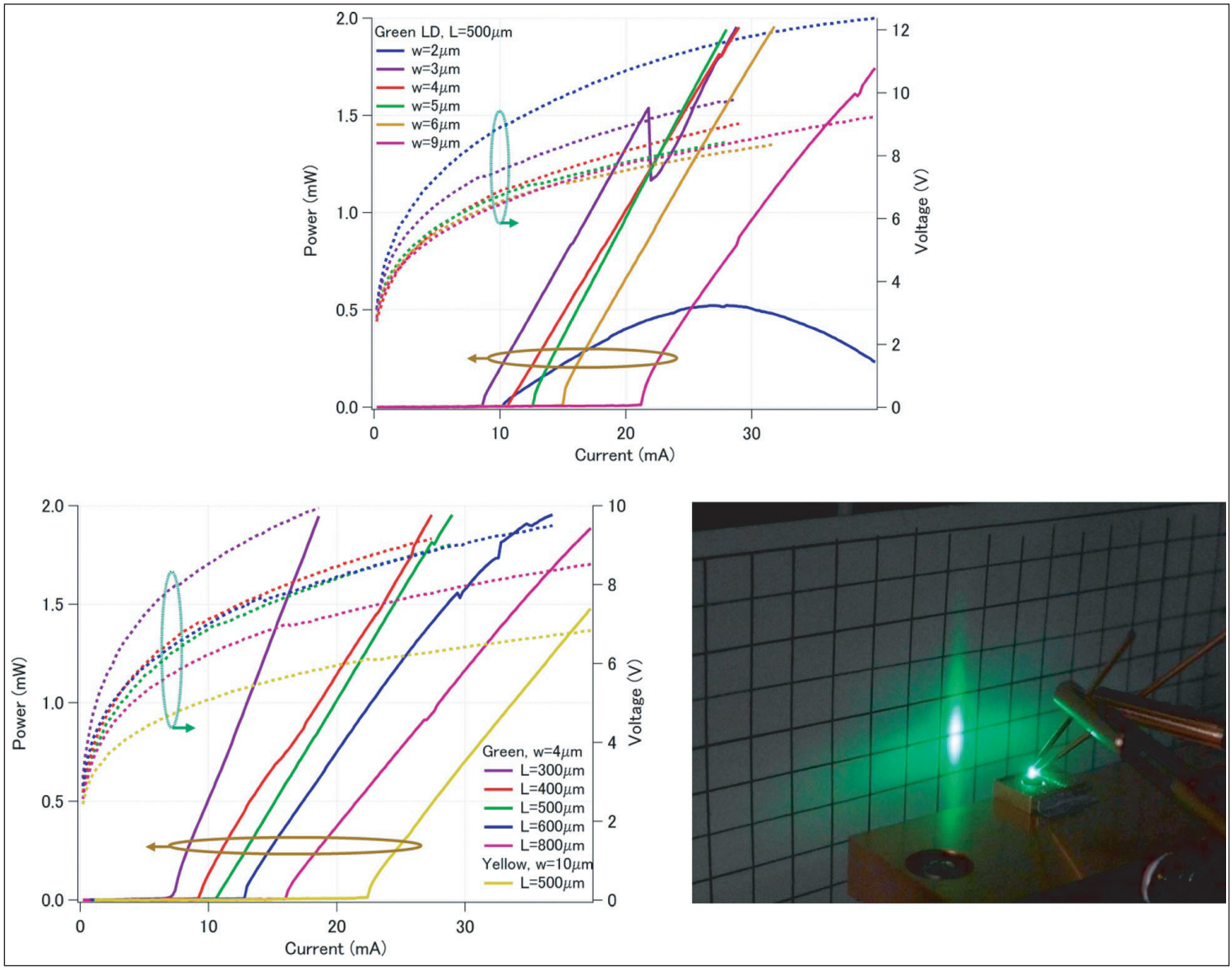

Figure 2. (a) Light output power and voltage–current characteristics with varying mesa width for 500μm-long laser diodes under cw operation at room temperature (25°C). (b) Lasing performance with varying mesa length. (c) Lasing image of 4μm-wide, 500μm-long laser diode with 20mA current. Monitor screen with 5mm-period grid was placed about 10mm before laser diode.

The cavity length was defined by cleaving the device wafers. The facets were coated with a ~90% reflective dielectric structure of four pairs of silicon dioxide and zirconium dioxide layers from electron cyclotron resonance plasma-enhanced sputtering.

The devices were mounted p-side down on ceramic aluminium nitride heat-sinks with gold/tin eutectic bonding.

Under continuous-wave (cw) operation (Figure 2), there is a trade-off between current threshold and lifetime with narrower ridges giving lower thresholds but short time to burn-out from overheating. Green laser diodes with 4μm ridges and 300μm cavity length had current and voltage thresholds of 7.07mA and 7.89V, respectively. The power/current slope efficiency was 0.16W/A per facet. The threshold current represents a 10-fold reduction from previous work giving 68mA (AIST/Hitachi/Sony).

The green-yellow laser diode with a 10μm-wide ridge and 500μm cavity had thresholds of 21.18mA and 6.024V, improving on 94mA and 9.6V in previous work (AIST/Hitachi).

The researchers attribute the improved threshold to more vertical current flow with suppression of lateral carrier spreading.

The series resistance of device is described as 'slightly high'. The researchers suggest that optimizing the p-doping of the short-period superlattice could reduce the resistance. Further improvements could come from quadratic grading, for instance, of the ZnSe/BeTe pseudo-graded superlattice, giving a smooth potential profile for hole injection. Doping the optical waveguide layers could also reduce resistance. ■

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Author: Mike Cooke

Vertical conduction and ultraviolet laser diodes on bulk gallium nitride

Hamamatsu's 356.6nm UV laser diode has a bulk GaN substrate that also enables cleaving, improving far-field pattern.

Hamamatsu Photonics K. K. of Japan has developed 356.6nm-wavelength ultraviolet laser diodes (LDs) on bulk gallium nitride (GaN), allowing a vertical conduction scheme [Yuta Aoki, Appl. Phys. Lett., vol107, p151103, 2015]. The researchers say that there has been no previous report on aluminium gallium nitride (AlGaN) UV LDs on bulk GaN.

Instead, devices grown on sapphire have to adopt a lateral conduction scheme where the electrodes must reach the contact layers from the same side, since the substrate is electrically insulating.

The researchers comment: "The vertical conductive structure is expected to open the path to high-output-power laser diodes." They see potential application in broad-area striped configurations and arrayed as multiple emitters for material processing.

The vertical conduction scheme could also allow junction-down assembly for improved thermal management.

The use of bulk GaN and a vertical conduction scheme also enables cleaving of the crystal wafer to give smooth reflecting facets for the laser cavity. Sapphire substrate laser diodes are difficult to cleave and dry etching is usually adopted, which results in poor shaping of the emitted laser light.

UV LDs are of interest for chemical analysis and material processing. The alternatives such as gas or solid-state lasers suffer from problems with energy efficiency, stability, warming-up time, and compactness.

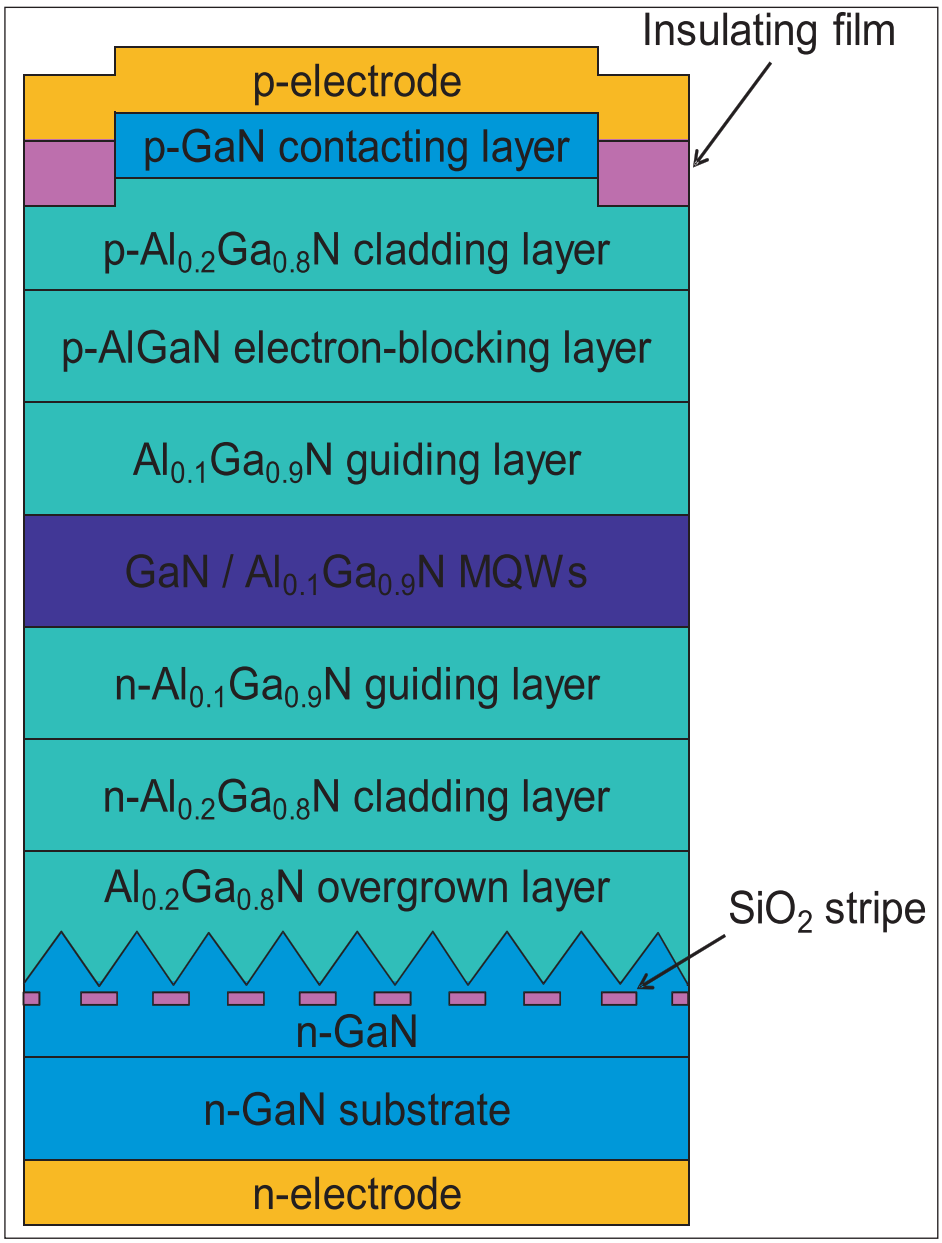

Figure 1. Schematic cross-sectional diagram of GaN/AlGaN multiple quantum well (MQW) UV-LD fabricated on GaN substrate.

The epitaxial structure (Figure 1) was grown on bulk n-GaN using metal-organic chemical vapor deposition (MOCVD). Lateral overgrowth was used to improve crystal quality. This involved creating periodic silicon dioxide stripes and then growing inclined-facet

GaN seed crystals in the region between the stripes. This allowed overgrowth of high-quality, crack-free $Al_{0.2}Ga_{0.8}N$, which formed the template for subsequent layers. The researchers expected the crystal quality to be similar to overgrown layers on sapphire.

The target wavelength was around 350nm, comparable to recent work on sapphire substrates.

The material was fabricated into 1.5μm ridge waveguide laser diodes. The dry etching for the ridge also exposed the p-GaN contact layer for p-electrode deposition. The n-electrode was applied after thinning of the n-GaN substrate to 100μm thickness by grinding and polishing. The mirror facets for the 300μm-long laser cavity were created by cleaving the device wafers. The facets were not coated to increase reflectivity.

The devices were tested at room temperature using 10ns pulses with 5kHz repetition. The threshold current was 250mA (56kA/cm^2). A 359.6nm laser diode on sapphire has achieved 8kA/cm^2 threshold. The Hamamatsu researchers believe that lower thresholds for their device on GaN could be achieved by optimizing the crystal growth and laser design.

The laser output power reached 10mW from one facet at ~300mA. The slope efficiency and external quantum efficiency (EQE) were estimated at 0.24W/A per facet and 14% for both facets, respectively.

The threshold voltage was around 20V, similar to the values obtained on sapphire. The researchers attribute the high voltage to the narrower ridge and short cavity compared with reported sapphire devices.

The spectrum of the emission peak had a full width at half maximum (FWHM) of ~6nm below threshold (190mA) and 0.4nm above threshold (275mA). The above threshold value was close to the resolution limit of the spectrometer. The radiation was strongly transverse electric polarized, as expected from the optical gain characteristics of GaN/AlGaN MQWs and the reflectivity of the facets.

The far-field pattern (FFP) of the laser radiation was Gaussian-like in the horizontal and vertical directions, unlike devices on sapphire, which suffer from severe distortion (Figure 2). The researchers comment: "The deteriorated FFP of the UV-LD on sapphire substrate is considered to be caused by the interference between the direct beam from the mirror facet and the reflected beam from the residual terrace lying down in front of the etched mirror facet. The cleaved mirror facets provide the highly improved FFP." ■

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Author: Mike Cooke

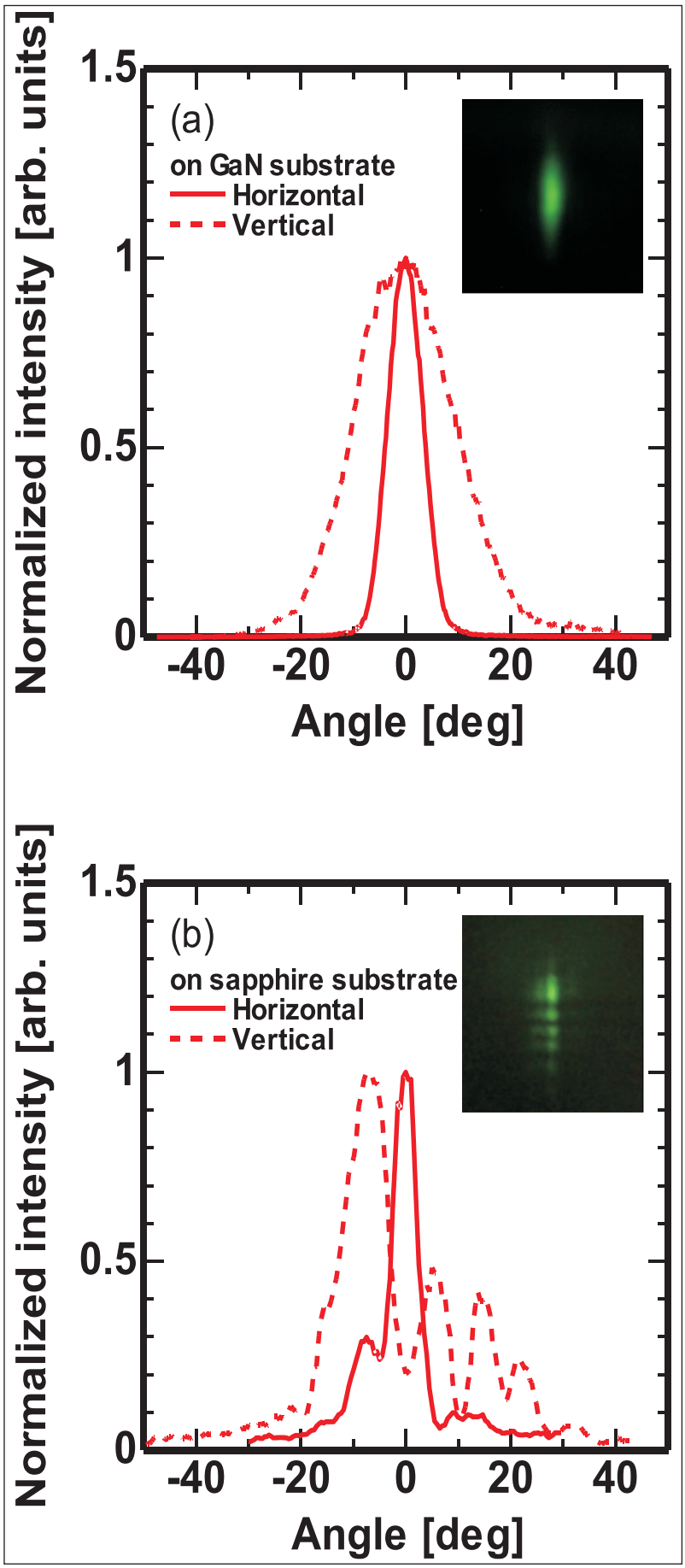

Figure 2. FFPs of UV-LD on (a) GaN substrate (with cleaved mirror facets) and (b) sapphire substrate (with etched mirror facets). Inset: photos of each FFP.

Magnesium ion implantation of gallium nitride

Researchers claim first rectifying light-emitting diode fabrication for p-GaN doping technique.

Hosei University in Japan has claimed the first magnesium (Mg) doping ion implants of gallium nitride (GaN) to show clear rectifying current–voltage behavior, along with ultraviolet (UV) and blue light emission under forward bias [Takuya Oikawa et al, Nuclear Instruments and Methods in Physics Research B, published online 1 August 2015].

Normally, doping of GaN to give p-type hole carriers is achieved during epitaxial growth. This technique is inflexible and results in layers of p-type materials. In mainstream semiconductors, ion implantation is widely used to achieve doping in selected areas of the device through masking that is created in lithography processes. This allows high-performance devices to be created in silicon and silicon carbide.

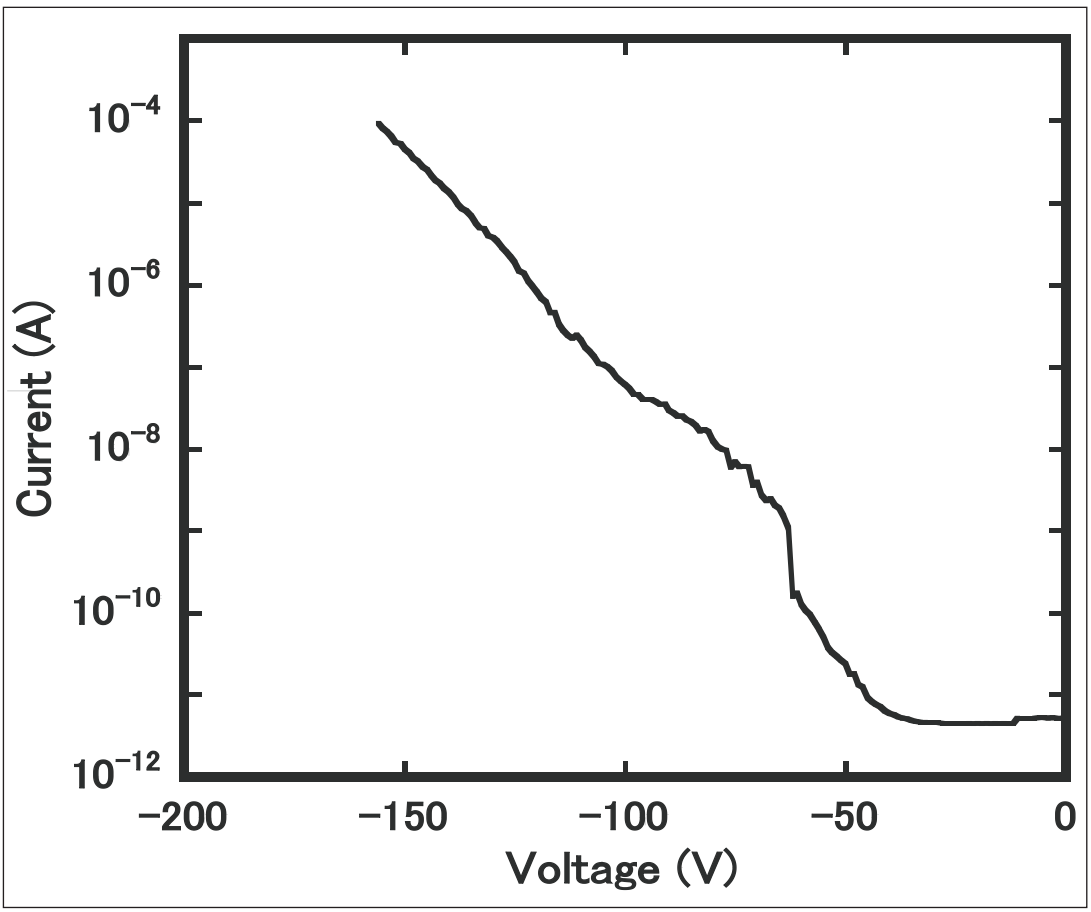

Figure 1. Reverse I–V characteristic of vertical p–n junction diode.

Previous attempts to transfer ion implant technology to GaN has suffered from the high dislocation density of material grown on sapphire or silicon carbide. While Hall measurements suggested that some of these attempts had produced p-type conversion of the material, devices were not fabricated.

The Hosei researchers used free-standing GaN substrates to grow epilayers of lightly doped n-GaN by metal-organic vapor phase epitaxy (MOVPE). The substrates were separated from their growth substrate by void-assisted separation. The silicon doping concentration in the epilayer was $1x10^{15}/cm^3$. The dislocation density was in the $10^6/cm^2$ range, rather than the more than $10^8/cm^2$ for GaN on sapphire or GaN on silicon carbide.

The samples were prepared for implantation by depositing a 30nm cap layer of silicon nitride. The aim of the cap was to give a maximum Mg concentration at the SiN/GaN interface.

The implantation was carried out in two steps with ion energies of 30keV and 60keV. The respective fluences were $3.5x10^{13}/cm^3$ and $6.5x10^{13}/cm^3$. The implants were annealed at 1230°C for 1 minute in nitrogen.

The researchers fabricated vertical p-n diodes with circular palladium electrodes on the p-GaN contact layer and titanium/aluminium electrodes on the GaN substrate back-side.

Photoluminescence study suggested that the p-GaN obtained is similar to that produce in MOVPE processes. "These results indicate recovery of lattice damages caused by the Mg implantation and existence of substitutional Mg acceptors in Ga site," the

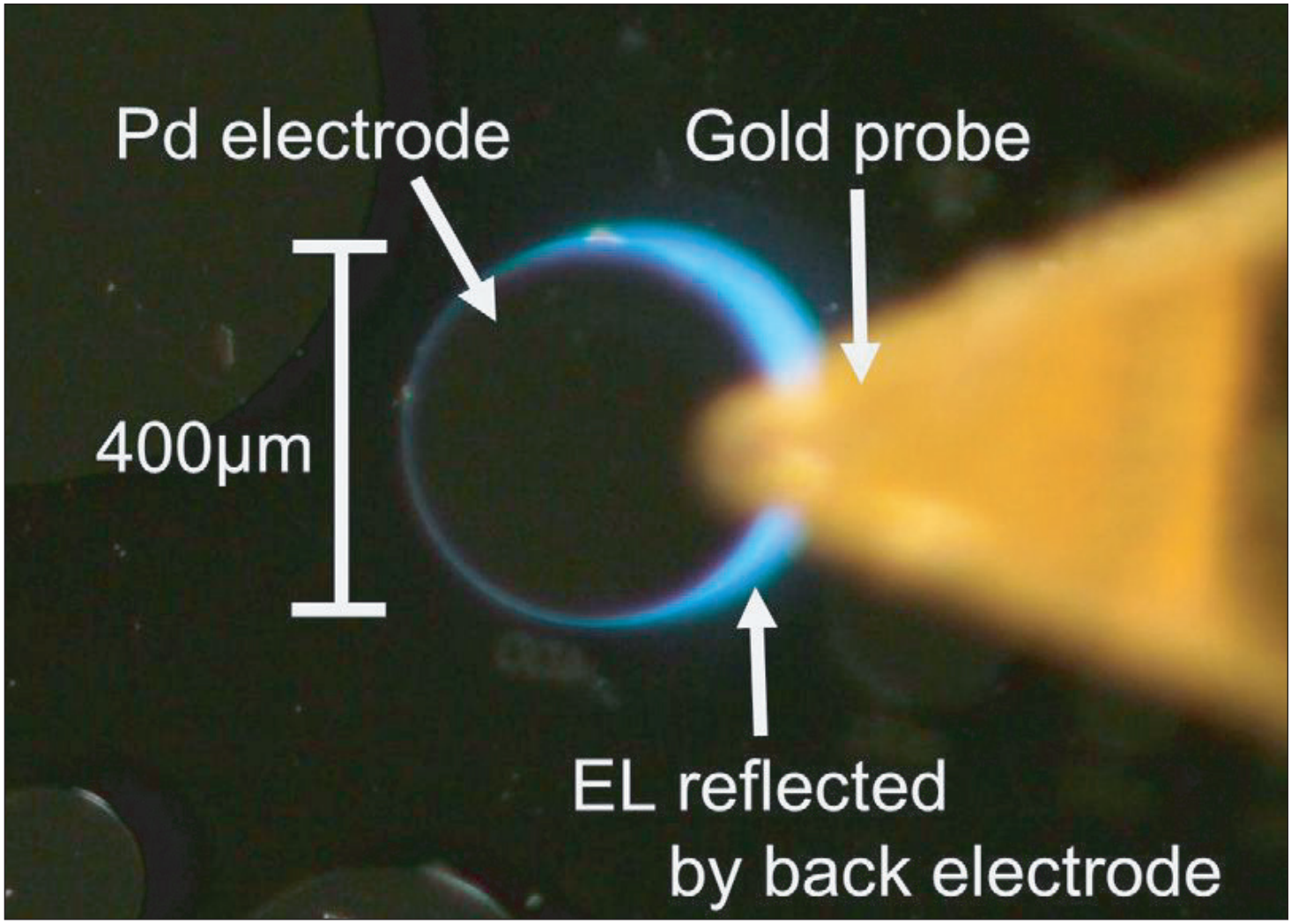

Figure 2. View of light-emitting diode under forward bias. Electrode diameter 400μm.

researchers comment.

The pn diode showed rectifying behavior with 4V turn-on. This is higher than the junction value of 3.3V because of series resistance, mainly from an imperfect ohmic contact between the palladium and p-GaN with a Schottky barrier. The reverse leakage current increased from 10^{-11}A to 10^{-4}A between −50V and the −150V breakdown value (Figure 1). The researchers believe the characteristics can be improved by optimizing the Mg-doping profile and the anneal process.

Electroluminescence was also observed with photon energy peaks at 3.1eV and 2.7eV (Figure 2). The 3.1eV UV-A radiation is attributed to acceptor-bound exciton and donor-acceptor-pair emission. "The other peak seems to be Mg-related blue luminescence," the researchers write. ■

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Author: Mike Cooke

Hole injection from V-pits into indium gallium nitride quantum wells

New mechanism seen at cryogenic temperature may be significant for room-temperature device performance, researchers say.

Researchers at Nanchang University in China have been studying the effect of V-pits in indium gallium nitride (InGaN) light-emitting diodes on electroluminescence [Xiaoming Wu, Junlin Liu and Fengyi Jiang, J. Appl. Phys., vol118, p164504, 2015].

Spectral analysis at low temperature (100K and 25K) showed a broad short-wavelength peak that the researchers attribute to a new hole injection mechanism from the V-pit sidewalls into the c-plane InGaN/GaN multiple quantum well (MQW) structure (Figure 1). The effect was only seen in samples where the aluminium gallium nitride (AlGaN) electron-blocking layer (EBL) was unintentionally doped (UID) (Figure 2).

The researchers comment: "Though this hole injection mechanism is observed in the sample with UID EBL and at cryogenic temperatures, it may also exist in normal devices at room temperature and be significant to the device performance, which deserves intensive study."

The MQWs were grown at the relatively low temperature of 850°C. In InGaN MQW structures, V-pits tend to form above threading dislocations.

At room temperature (300K), V-pits that form on top of threading dislocations are thought to create MQWs with a wider bandgap that act as barriers to carriers reaching the dislocations. If carriers interact with dislocations, they tend to recombine non-radiatively, reducing efficiency.

Previous simulations by the Nanchang team suggested that hole injection could be increased due to lower effective hole barrier height, resulting from reduced piezoelectric charges on semi-polar facets of the V-pits.

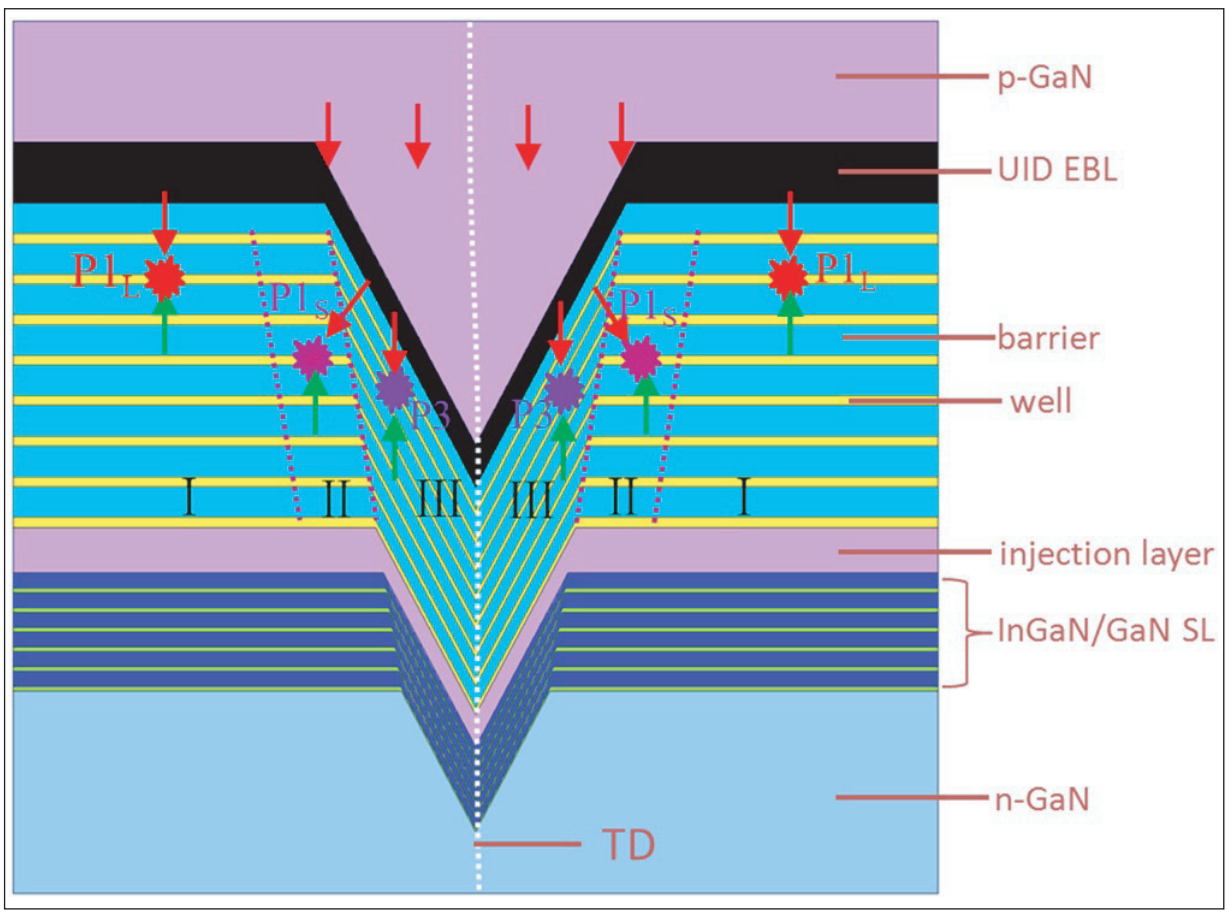

Figure 1. Schematic diagram of hole injection from sidewall of V-pits into c-plane MQWs. Red and green arrows represent hole and electron current, respectively. For clarity, c-plane MQWs between the two dashed lines illustrate regions where emission wavelength is affected by V-pit. In real devices, c-plane MQWs closer to V-pits are more affected by V-pits and there might be no definite boundary.

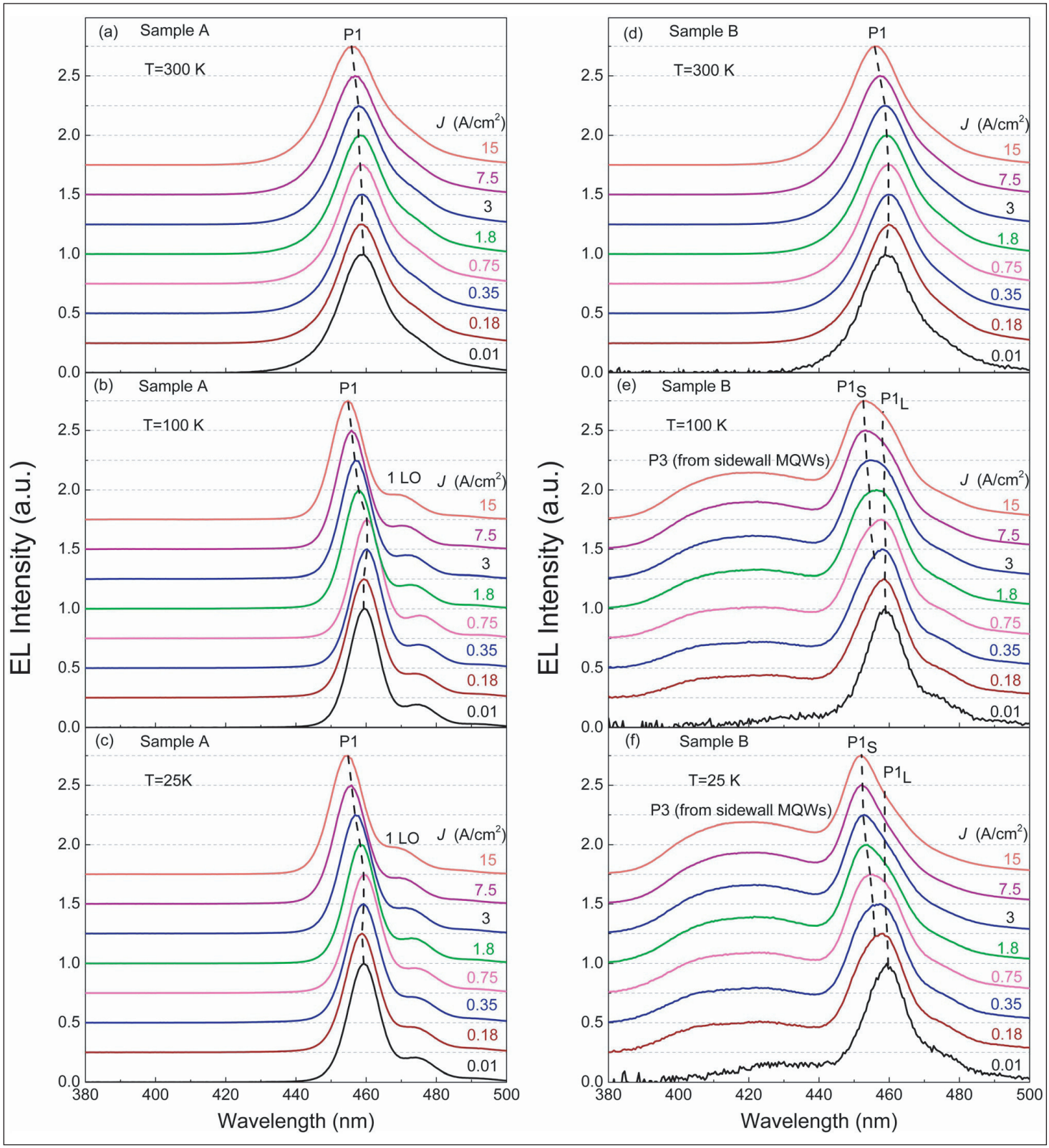

Figure 2. Electroluminescence spectra of samples with heavily doped (A) and UID (B) EBLs at various temperatures. Each spectrum was normalized to its own peak height. Main MQW peak (P1) broadens in sample B at 100K and 25 K. P1S and P1L represent the short- and long-wavelength parts of P1, respectively.

Also, the EBL is much thinner on the V-pit sidewalls — EBLs also partially block hole injection.

The researchers see two factors as blocking hole injection via the V-pits with unintentionally doped EBLs at room temperature:

1. The EBL resistance is not high enough to compensate for the increased barrier of the sidewall MQWs;
2. Increased non-radiative recombination of holes at the dislocations at room temperature, compared with low temperature operation. ■

http://dx.doi.org/10.1063/1.4934503

Author: Mike Cooke

Suppressing current collapse in normally-off gallium nitride transistor

Panasonic embeds p-type drain into gate-injection transistor to avoid collapse before 800V.

Japan's Panasonic Corp has reported the suppression of current collapse up to 800V for a normally-off gallium nitride (GaN) transistor by embedding a hybrid drain in a gate-injection transistor (HD-GIT) structure [Kenichiro Tanaka et al, Appl. Phys. Lett., vol107, p163502, 2015].

The hybrid drain consists of a normal drain and an addition p-type drain with p-GaN deposited on the aluminium gallium nitride (AlGaN) barrier layer. The two drain regions are connected. The researchers see applications as next-generation power transistors for efficient, reliable high-power switching.

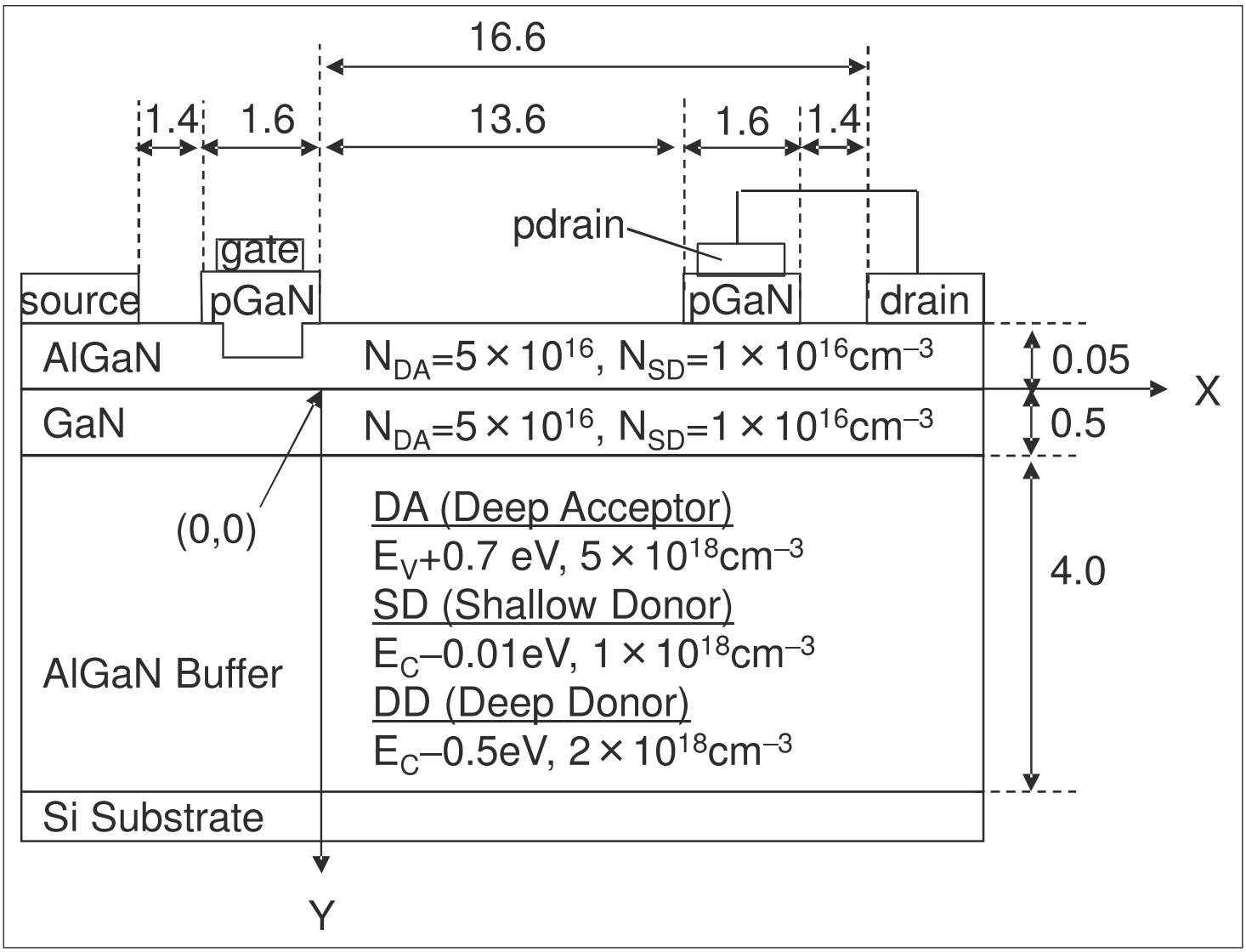

Figure 1. Schematic of HD-GIT. Device dimensions indicated in μm. Energy levels and concentrations of traps employed in simulation also shown.

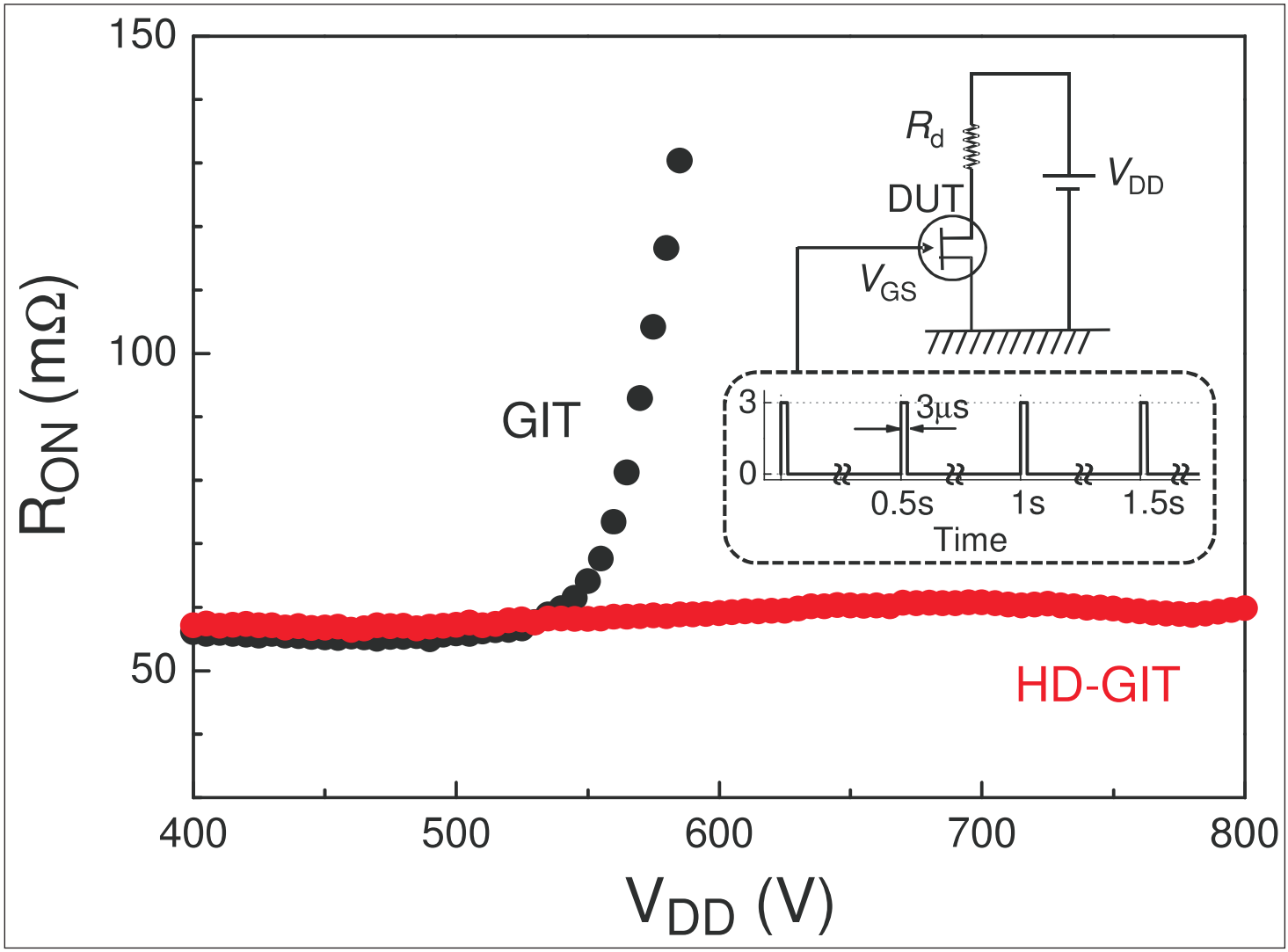

Figure 2. Dynamic ON-state resistance R_{ON} (t = 3µs) of HD-GIT and GIT as function of applied voltage V_{DD}. Inset: circuit used in switching measurement.

Current collapse in GaN transistors describes current reduction when the device is subjected to switching, compared with direct current measurements. Such effects are related to charge-trapping that affects the dynamic performance.

The p-drain in the HD-GIT helps inject holes at the OFF state and suppress the current collapse effectively

In Panasonic's GITs, current collapse has been attributed to emission of holes in the epilayer during off states. The p-drain injects holes into trapping states in the off condition so that they become inert.

The device material was grown on silicon (Figure 1). Unlike high-electron-mobility transistors (HEMTs), the structure includes a p-GaN top layer that is formed on a recessed AlGaN barrier layer. The p-GaN is used to create the gate of the GIT and the p-GaN hybrid drain. The researchers comment: "The entire structure is designed to eliminate the carrier traps and to reduce the internal electric field."

The threshold voltage for the HD-GIT was 1V. Further, the specific on-resistance was 60mΩ and breakdown occurred at 1000V with a grounded silicon substrate.

In pulsed operation, the dynamic on-resistance remained near 60mΩ up to 800V (Figure 2). A comparison GIT device, by contrast, began to show increased dynamic on-resistance above 550V.

The researchers comment: "This indicates that the introduction of the p-drain in the HD-GIT helps inject holes at the OFF state and suppress the current collapse effectively."

Simulations suggest that hole injection from the p-drain prevents the gate/p-drain access region from being negatively charged due to hot electrons, according to the researchers. They add: "At the OFF state, the hole injection from the p-drain prevents the gate/p-drain access region from being negatively charged by occupying the deep level in the epilayer. This results in the linear conduction band energy profile at the gate/p-drain access region. It also leads to flat potential right after turning ON, resulting in the complete suppression of the current collapse." ■

http://dx.doi.org/10.1063/1.4934184

Author: Mike Cooke

Increasing carrier lifetimes for high-voltage silicon carbide

Researchers looking to 10kV+ applications for electric power transmission and distribution.

Researchers in Japan have been developing ways to increase minority carrier lifetimes in lightly doped silicon carbide (SiC) with a view to insulated-gate bipolar transistors (IGBTs) [Tetsuya Miyazawa et al, J. Appl. Phys., vol118, p085702, 2015]. Such devices are being developed to handle very high voltages beyond 10kV for electric power transmission and distribution.

To handle high voltages, devices need a low resistance but relatively thick drift layer. The resistance of the drift layer is adversely affected by the short minority carrier lifetime typically achieved with SiC, particularly p-type. However, devices with n-type drift layers suffer from the high resistance of p-type substrates.

The team from Central Research Institute of Electric Power Industry (CRIEPI), Kansai Electric Power Co Inc, and National Institute of Advanced Industrial Science and Technology explored ways to create structures for both p- and n-type IGBTs to overcome these drawbacks.

A vertical hot-wall chemical vapor deposition (CVD) reactor was used for epitaxy on 3-inch 4H silicon-face n^+-SiC with 4° offcut for both devices. Silane and propane were the silicon and carbon sources, respectively. The carrier gas consisted of hydrogen and hydrogen chloride. The p- and n-type dopants were trimethyl-aluminium and nitrogen, respectively.

Particular care was needed to control the TMA delivery for low-concentration p-type doping (~10^{14}/cm^3) and the researchers developed a modified feed system that involved diluting the hydrogen containing the TMA with more hydrogen before delivering it to the CVD reactor.

A structure suitable for a p-IGBT (Figure 1) was grown first up to a 180μm p^- drift layer that was then trimmed back to 155μm by chemical mechanical polishing (CMP). Carrier lifetime enhancement was achieved for some devices (sample B) by carbon implantation to a depth of 250nm and annealing in argon. The surface was protected with a carbon cap that was later removed by ashing. The implanted region was also removed by reactive ion etch (RIE) of a 1μm layer.

PiN diodes were fabricated as test vehicles for the structure and related processing by growing and p^+ anode and p^{++} contact layers. The devices were fabricated with 4mmx4mm mesas. After contact metal deposition the devices were then singulated into chips. Sample B devices were also subjected to hydrogen annealing at 800°C for 10 minutes between contact metal deposition and singulation.

Structures for n-IGBTs (Figure 2) were achieved using an inverted growth process on an n+ substrate. The growth began on the silicon-face to create a buffer and 180μm n^- drift layer. A first carrier lifetime enhancing process consisted of thermal oxidation and annealing. Before further growth of the field stop and p-type layers, the surface was planarized with CMP.

The substrate and n-type buffer were removed by polishing, leaving a 160μm drift layer with a carbon-face on a free-standing structure. The structure suffered from significant physical distortion (increased 'SORI') due to the removal of the substrate.

Further carrier lifetime enhancement consisted of carbon implantation, annealing and removal, as for the p-IGBT structure. PiN devices were produced by growing a 5μm n^+ layer on the carbon-face drift layer and applying contacts as with the p-PiN diodes.

For the p- drift layer, the effect of the carbon implantation and annealing was to increase the minority carrier lifetime from 3.0μs to 5.6μs, according to time-resolved photoluminescence (TRPL). Even the untreated lifetime of 3.0μs is longer than typical for p^- SiC. The researchers attribute this to special measures taken to avoid carbon vacancy defects, and to the very low aluminium doping concentration.

The carbon vacancies were reduced by changing the growth temperature and C/Si ratio for the buffer (>1650°C, 0.75) and drift layer (~1600°C, 0.94–1.00) growth. The higher growth temperature and lower C/Si for the buffer avoided triangular defects indicative of 3C-polytype inclusions.

After the thermal oxidation and annealing, the 155μm drift layer had a minority carrier lifetime of 5.1μs, according to differential microwave photoconductance decay measurements.

For the n- drift layer the minority carrier lifetime was increased from 7μs to 24μs by the carbon implantation and anneal. The growth conditions for the drift layer were 1610°C and C/Si ratio of 1.00.

The p-PiN diodes had a voltage drop of more than 10V for the flow of 10A/cm^2 at room temperature. The performance improved at 200°C with a voltage drop of 3.5V with 100A/cm^2 current for sample B material (extended minority carrier lifetime). The drop for

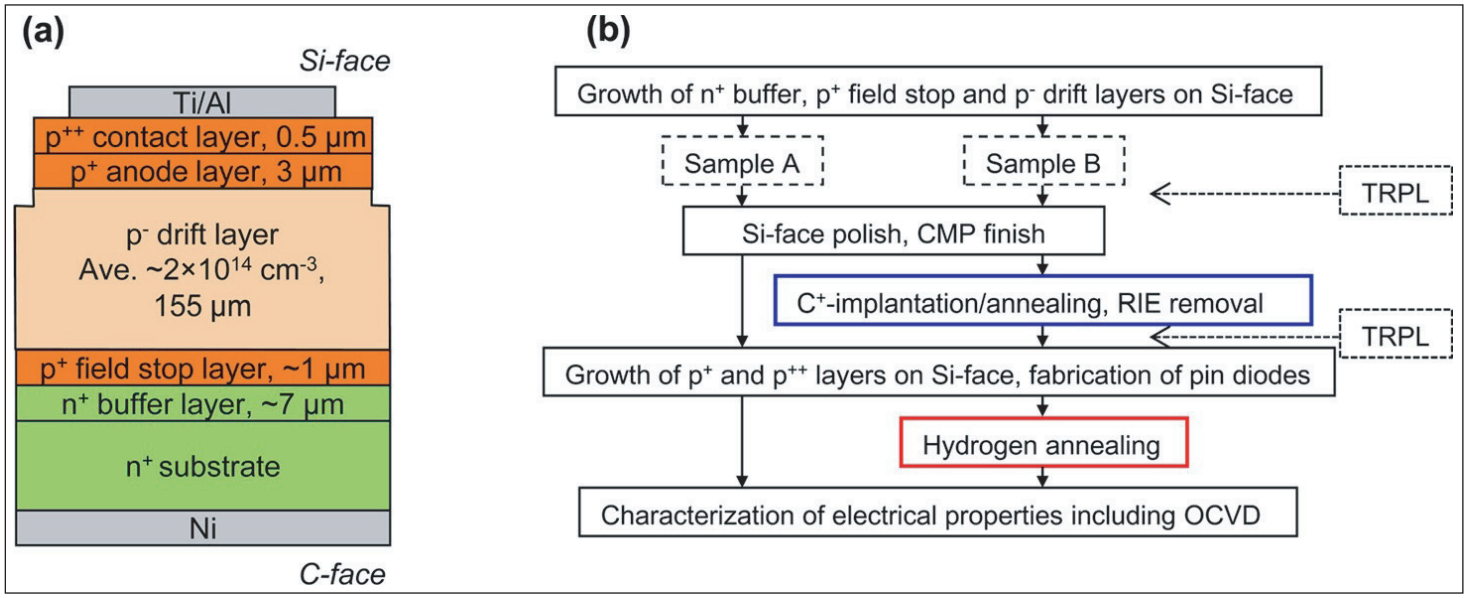

Figure 1. (a) Cross section and (b) fabrication process of simple PiN diode with Si-face p-IGBT structure (p-PiN).

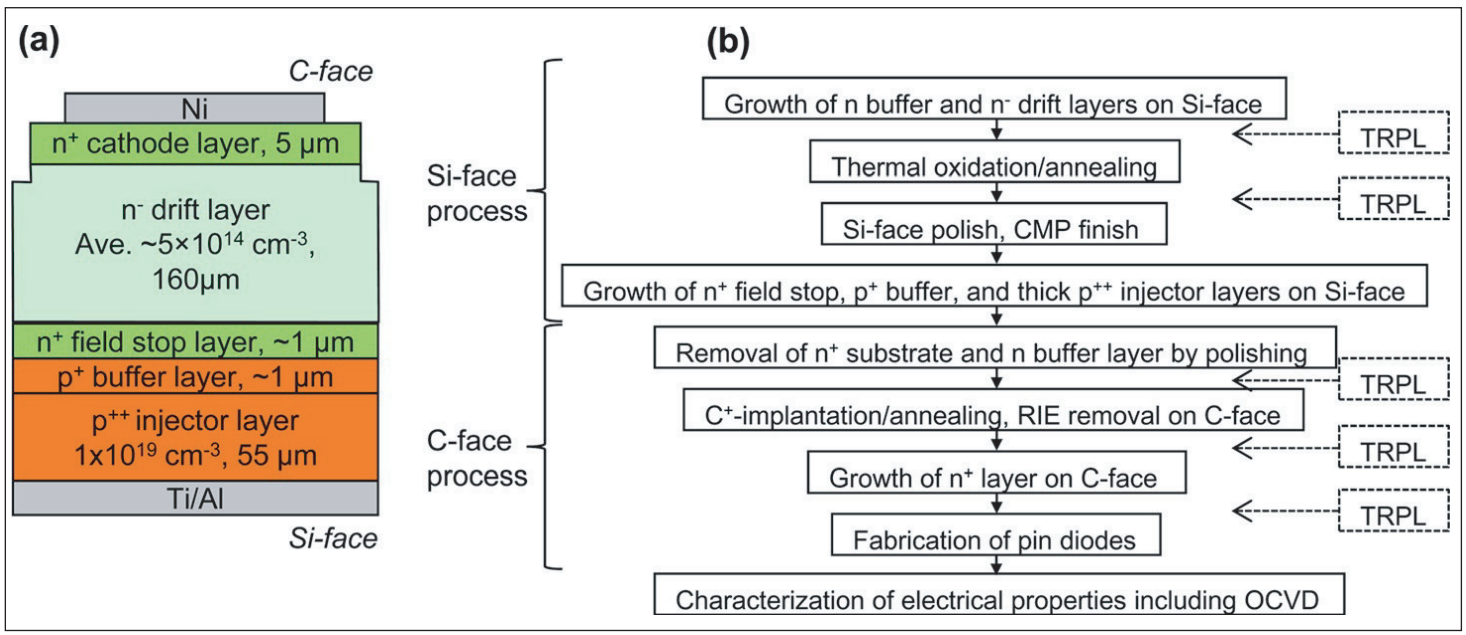

Figure 2. (a) Cross section and (b) fabrication process of simple PiN diode with C-face n-IGBT structure (n-PiN).

Table 1. TRPL minority carrier lifetimes of n⁻ thick drift layer of n-PiN.

	Minority carrier lifetime (μs)
After thick n⁻ epitaxial growth	3.2
After thermal oxidation/anneal process	10.0
After removal of n+ substrate	8.2
After C+-implantation/anneal process	10.7

sample A without carbon implant and anneal treatment was 5.7V for the same current. The differential on-resistance was 22mΩ-cm^2 and 4.2mΩ-cm^2, respectively, for samples A and B. Sample B devices without the final hydrogen anneal had a higher voltage drop of 4V.

Open-circuit voltage decay (OCVD) measurements on sample B showed an increase in minority carrier lifetime from 5μs at room temperature to 44μs at 250°C, which the researchers say is exceptionally long for a p-type epilayer.

The TRPL results for the n-PiN growth sequence (Table 1) showed the final structure as having a minority carrier lifetime of 10.7μs. The n-PiN had a much lower voltage drop at room temperature of 5.5V for 100A/cm^2 current. Increasing the temperature reduced the voltage drop to less than 3.0V at 250°C. The differential on-resistance was 17mΩ-cm^2 at room temperature and 1.9mΩ-cm^2 at 250°C.

Decreasing the device area to 1.0mmx1.0mm increased the voltage drop to the range 6.5–8.0V. The researchers attribute this to carrier recombination at the mesa periphery. Surface passivation to reduce this effect should improve performance. ■

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Author: Mike Cooke

Compound semiconductor electronics manufacturability on silicon

Mike Cooke reports on presentations at the International Electron Devices Meeting.

Indium gallium arsenide (InGaAs) and other III-V high-mobility channels continue to be developed, with many groups reporting progress on various aspects that suggest manufacturability on silicon is moving closer at December's 2015 International Electron Devices Meeting (IEDM) in Washington DC, USA. Gallium nitride devices for power and radio frequency (RF) applications formed the conference's other main strand for compound semiconductor presentations.

Future high-mobility electronics

The imec research center in Belgium has integrated high-mobility InGaAs channels into three-dimensional (3D) vertical NAND charge-trap flash memory structures [session 3.1].

Silicon-based vertical 3D NAND flash memory (Figure 1) has been in mass production at Samsung since 2013. This year, Samsung moved from a 2-bit to a 3-bit architecture. Such devices are applied in Samsung's solid-state drives (SSDs). Samsung is a key partner in imec's core complementary metal-oxide-semiconductor (CMOS) research, along with Micron–Intel, Toshiba–Sandisk, SK Hynix, TSMC, and GlobalFoundries.

imec's InGaAs NAND memory devices were formed in plugs/holes with diameters as small as 45nm. InGaAs channels improve transconductance and read current, enabling vertical NAND cost reduction by adding more layers in a stacked 3D architecture.

Planar NAND flash suffers from severe cell-to-cell interference and read noise due to aggressively scaled dimensions, reducing current levels. Present-day 3D NAND devices use polysilicon (poly-Si) channels where conductivity is affected by grain size distribution. Electrons are scattered at grain boundaries and charged defects, reducing current flow [imec also reported on modeling the impacts of such factors on poly-Si vertical NAND in session 5.6].

imec's InGaAs vertical NAND was created through a gate-first, channel-last process. The InGaAs channel was grown by metal-organic vapor phase epitaxy (MOVPE). imec says that the process demonstrated good III-V growth selectivity to silicon, allowing holes to be filled down to 45nm diameter. According to imec, the III-V channels outperformed poly-Si in terms of on-state current and transconductance (Figure 2), without degrading memory characteristics such as programming, erase and endurance.

An Steegen, senior vice president Process Technology at imec, comments: "While these results are shown on full channels, they are an important stepping stone to develop industry-compatible macaroni-type III-V channels."

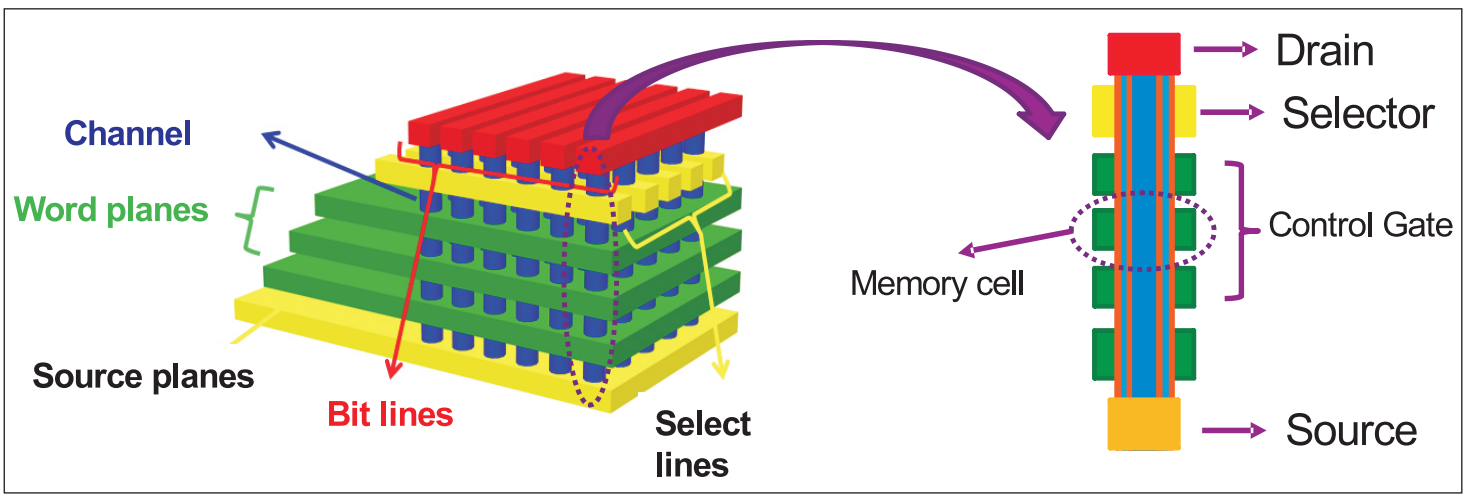


Figure 1. 3D vertical NAND memory devices bit-cost scalable (BiCS) architecture (left) and single memory string (right).

imec also claims record results for InGaAs gate-all-around (GAA) channel devices on 300mm silicon wafers [session 31.1]. This research team also included personnel from ASM, Poongsan Inc, and Belgium's KU Leuven.

The peak transconductance (g_m) for the GAA transistors was as high as 2200μS/μm for the 50nm gate-length GAA channel device, while the subthreshold swing (SS_{SAT}) was as low as 110mV/decade. The drain bias was 0.5V.

The GAA structure (Figure 3) was achieved through fin replacement and a replacement metal gate (RMG) process flow. ASM supplied a newly developed interlayer material for the gate stack, which was applied using atomic layer deposition (ALD). The researchers also added a high-pressure 400ºC annealing step to increase g_m by 22%. The team focused on improving the channel epitaxy process quality along with passivation of gate-to-channel interfaces.

The ASM interlayer material was combined with hafnium dioxide gate insulator. The researchers compared devices using the ASM material with GAA transistors that implemented a more traditional aluminium oxide layer. The novel interlayer stack achieved 2.2x higher g_m, compared with a reference aluminium oxide stack.

An imec-only team also reported on InGaAs homojunction tunnel field-effect transistors (TFETs) with claimed superior subthreshold swing (SS) reliability compared with MOSFETs [session 31.7]. The TFETs used InGaAs with the indium content increased to 70%, compared with the 53% often used in III-V devices. The increased indium content boosted the performance of 8nm-channel TFETs, giving a claimed record on-current of 4μA/μm, with an off-current of 100pA/μm, and a minimum SS of 60mV/decade at room temperature (300K). The operating voltage (V_{dd}) was 0.5V with a 0.3V drain. Reliability assessment showed that the minimum SS and g_m were more immune to positive-bias temperature instability (PBTI) stress than equivalent MOSFETs.

imec sees TFETs as a potential technology beyond present and near-future FinFETs and GAA-nanowire devices for sub-0.5V operation.

TFETs tend to have better switching properties such as SS values below the theoretical limit for traditional planar FETs of 60mV/decade at room temperature. However, TFETs struggle to provide sufficiently high on-current and low off-current, compared with the MOSFETs that dominate mainstream electronics today.

National University of Singapore and Nanyang Technological University claimed the first monolithic integration of germanium (Ge) p-FETs and InAs n-FETs on silicon substrates, as needed for CMOS logic [session 2.3].

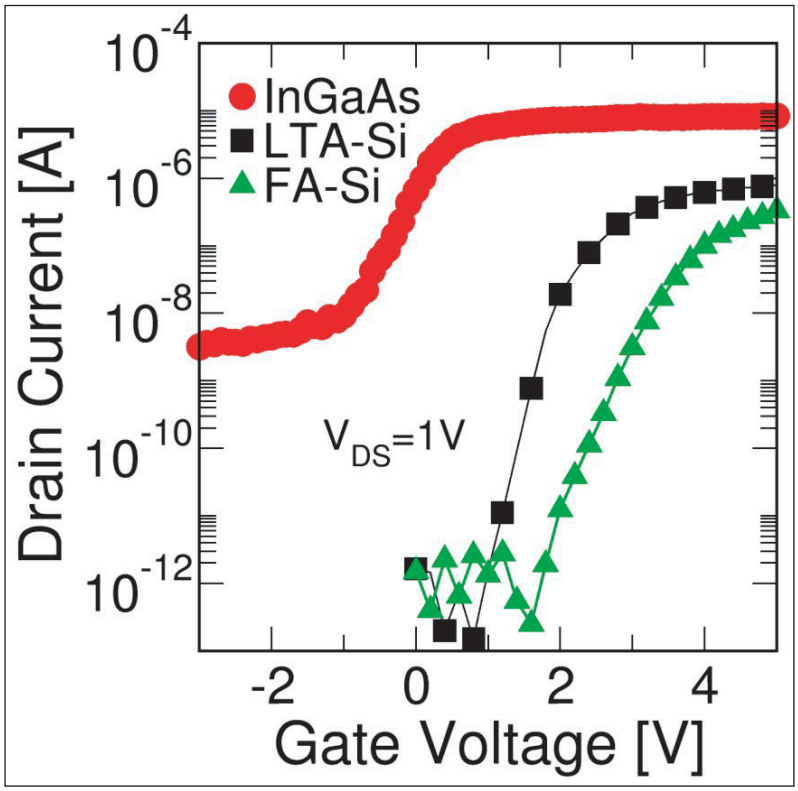


Figure 2. Drain current performance of imec InGaAs-channel vertical NAND element.

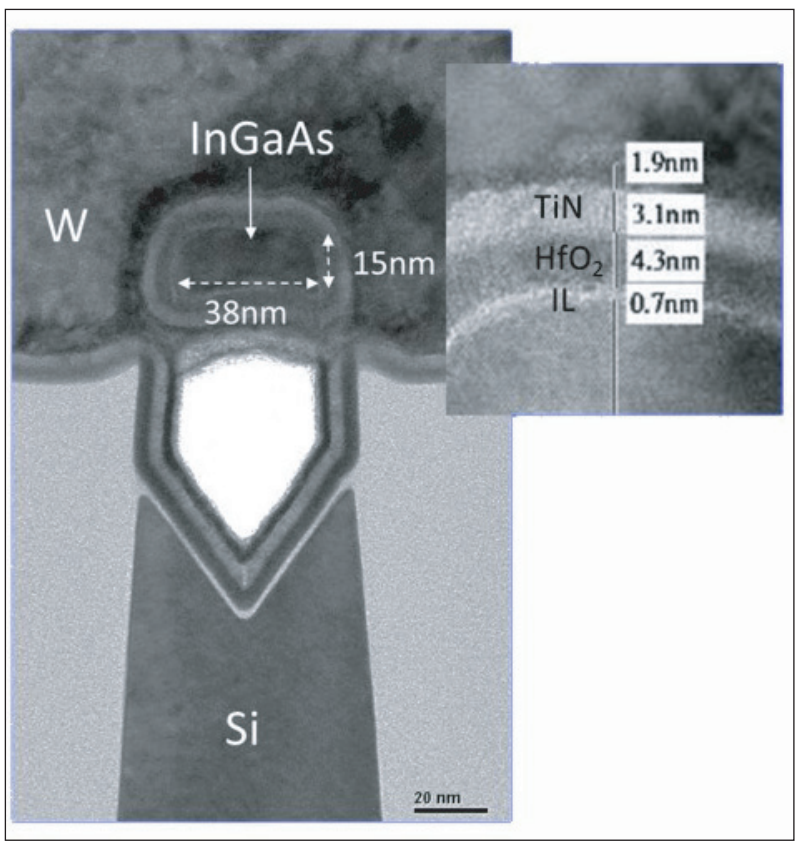


Figure 3. Transmission electron micrograph (TEM) of complete GAA InGaAs nanowire FET and high-resolution TEM (HRTEM) of gate stack.

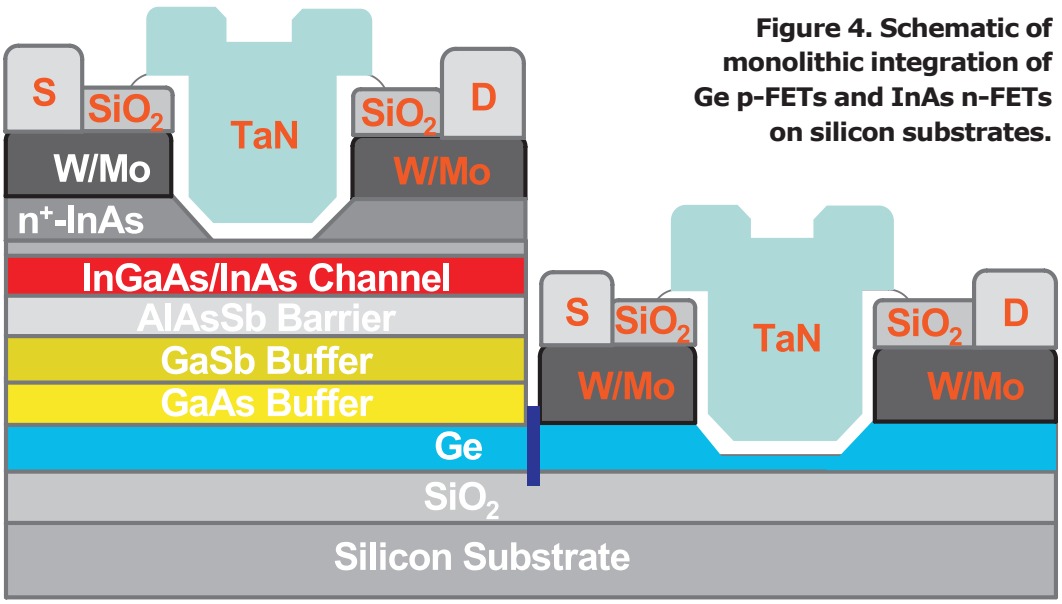


Figure 4. Schematic of monolithic integration of Ge p-FETs and InAs n-FETs on silicon substrates.

The devices featured a III-V buffer layer less than 120nm thick (Figure 4). The Ge and InAs channel bodies were less than 5nm. The raised source/drain electrodes and gate stacks for the n- and p-FETs were formed simultaneously in a common process flow. The resulting transistors achieved record drive currents, according to the researchers. The 110nm-gate n-FET drive current reached 263μA/μm with a 0.7V drain bias. The 170nm-gate p-FET on-current was 203μA/um at –1V drain.

In a separate report to IEDM, some of the same researchers presented the first demonstration of a vertically stacked structure comprising InAs nanowires and GaSb nanowires [session 15.4]. GAA CMOS devices were produced on a silicon platform, using an extremely thin buffer layer less than 150nm thick and common gate stack and contact modules. The n-FET transfer characteristics for 20nm channel length of 126mV/decade SS and 285mV/V drain-induced barrier lowering (DIBL) were described as "decent". The 500nm-channel p-FET had 188mV/decade SS and on/off ratio of 3.5 factors of 10 — both values claimed as records.

Massachusetts Institute of Technology (MIT) claimed the first fabrication of InGaAs FinFETs with sub-10nm fin widths [session 31.3]. A key step in the process was the use of precision dry etching and digital etch (reverse atomic layer deposition). The researchers report: "We find that the threshold voltage, V_T, becomes highly sensitive to the fin width, W_f, in the sub-10 nm W_f range. We attribute this to quantization effects. We also show that in the quantum regime, a sidewall slope less than 85º significantly mitigates V_T variation."

MIT also claimed, with Sandia National Laboratories, the first InGaSb p-channel FinFET [31.6]. MIT applied its dry-etch technology to give fins as narrow as

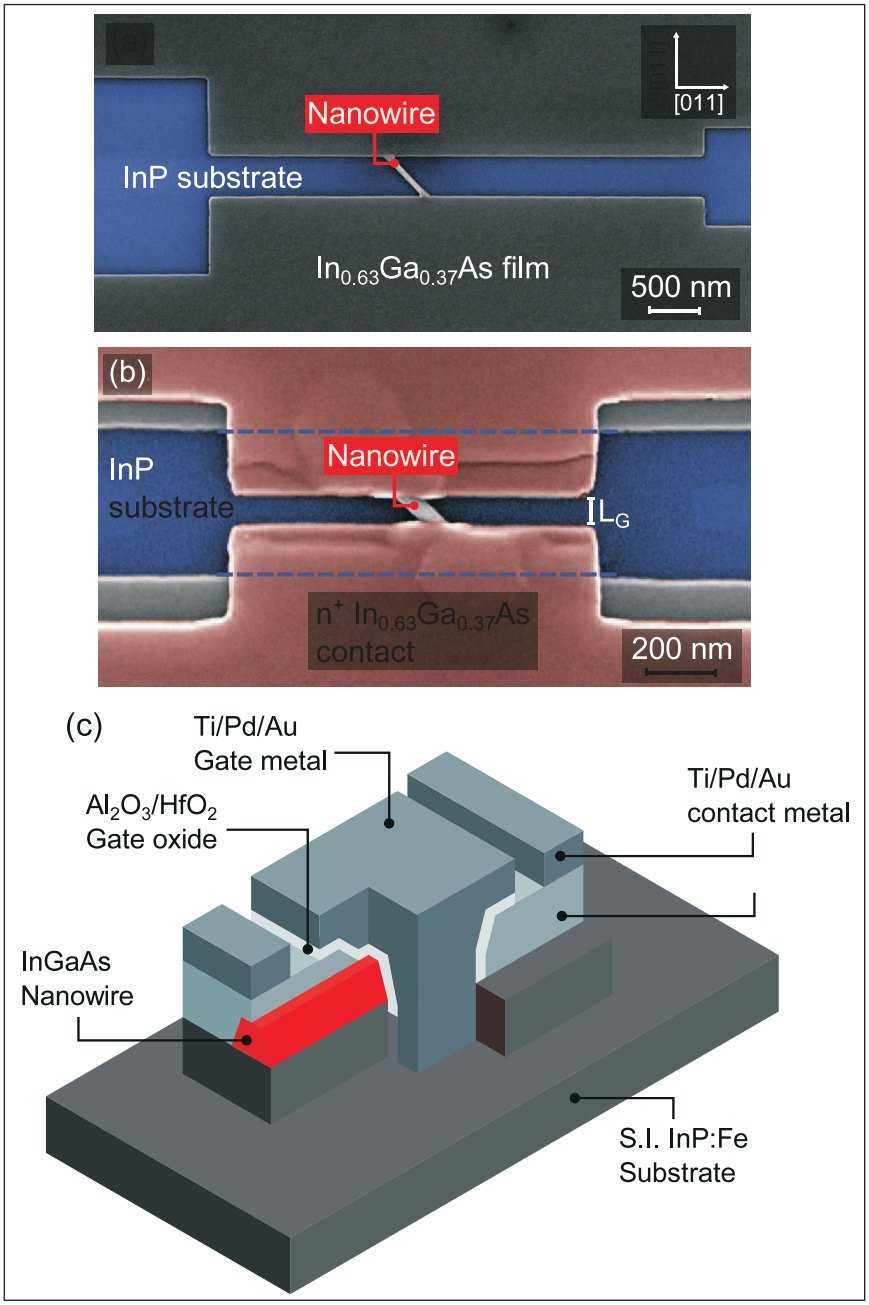


Figure 5. (a) False-color scanning electron micrograph (SEM) of single suspended InGaAs nanowire MOSFETs after nanowire regrowth. (b) False-color SEM of device after contact regrowth. (c) Schematic of final device in suspended configuration.

15nm with vertical sidewalls and low sidewall interface state density.

Lund University claimed record performance for any vertical nanowire MOSFET from a self-aligned gate-last process [session 31.2]. The process used digital etch to give thin intrinsic InAs channels and thicker doped contacts. The best peak transconductance ($g_{m,max}$) and SS were 1.29mS/μm and 90mV/decade, respectively.

The Lund team has also developed single suspended InGaAs nanowire MOSFETs with a record-high peak transconductance for any transistor [session 31.4]. The nanowires consisted of $In_{0.85}Ga_{0.15}As$ and single wires were suspended above the substrate (Figure 5). The peak g_m transconductance reached 3.3mS/μm at 0.5V drain bias. The SS value was 118mV/dec; DIBL was 40mV/V. The researchers also claim that the 'quality factor' given by g_m/SS of '28' (3.3/0.118) is the highest for non-planar III-V FETs.

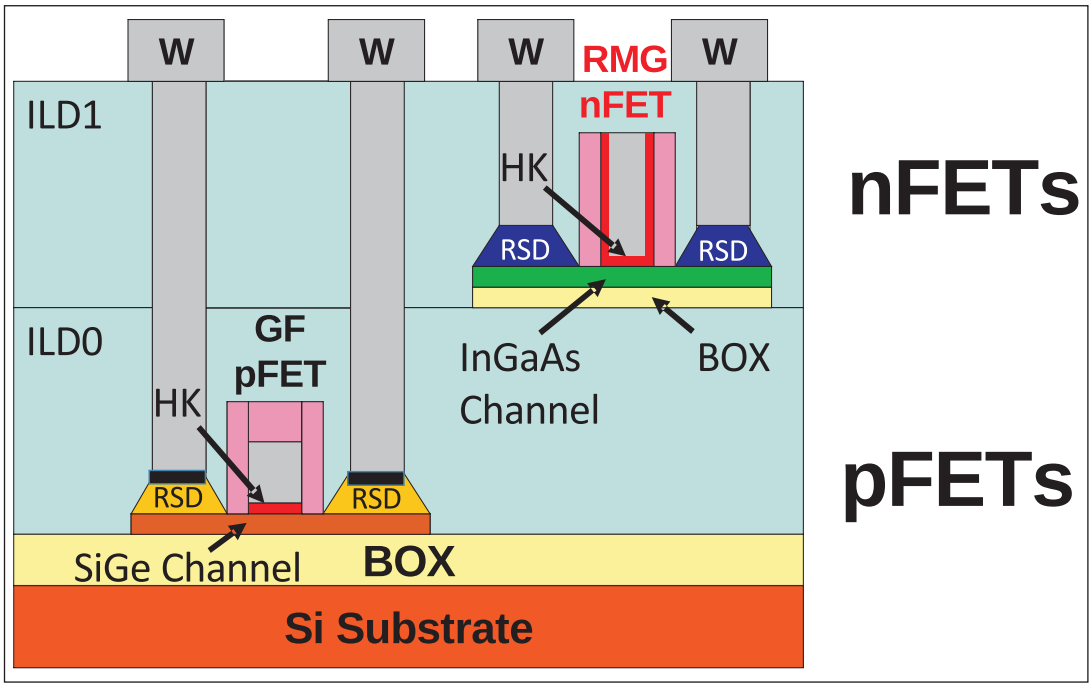


Figure 6. InGaAs-on-SiGe CMOS structure.

IBM reported on its 3D monolithic CMOS process with a short-channel replacement metal gate (RMG) InGaAs-on-insulator wide-fin/planar n-FET top layer and a SiGe-on-insulator fin p-FET bottom layer [session 8.8]. The researchers claim the first scaled hybrid inverter (NOT logic) circuits, based on state-of-the-art device integration. The operating voltage of the inverters was as low as 0.25V.

The transistors have raised source drain contacts on both levels and silicide on the bottom p-FETs (Figure 6). The bottom p-FETs were scaled down to sub-20nm gate length using a gate-first flow. The top n-FETs had sub-50nm gate length. Since high-temperature processing can degrade already constructed devices, the thermal budget for the top n-FETs was optimized to avoid impacts on the performance of the bottom p-FETs.

The IBM Zürich work is part of the EU's 7th Framework project COMPOSE^3 (Compound Semiconductors for 3D Integration) — see http://compose3.eu.

Purdue and Harvard universities reported an anisotropic wet etch process for 3D InGaAs MOSFETs [session 15.2]. Drastically different shapes can be sculpted by aligning the structures along different crystal orientations. The researchers realized FinFETs with nearly vertical sidewalls with a claimed record on/off current ratio of more than 10^8 and a minimum off-current of about 3pA/μm. These features were achieved through barrier engineering to block the off-state leakage path.

GaN power/RF

A group led by Cornell University reported on its GaN on free-standing GaN vertical p–n power diodes with a claimed record-breaking combination of breakdown (BV) and on-resistance (R_{on}) [session 9.7]. The respective values of 3.48kV and 0.95mOhm·cm^2 gave a Baliga figure-of-merit of 12.8GW/cm^2 (BV^2/R_{on}). The Cornell researchers worked with colleagues from University of Notre Dame, US Naval Research Laboratory, Signatone Corp, Quantum Spread Ltd, and Hosei University. Devices with drift layer thickness from 20μm to 32μm resulted in BV values in the range from 2.3kV to 3.5kV. Further details of Cornell/Notre Dame work with others on GaN vertical p–n diodes will be reported in a future issue.

The imec research center in Belgium claims beyond state-of-the-art performance for a p-type gallium nitride (p-GaN) high-electron-mobility transistor (HEMT) on silicon operating in enhancement-mode (normally-off) [session 16.2]. The threshold voltage was +2V. Low on-resistance of 7Ω-mm enabled high drive current of 0.4A/mm at 10V drain bias. imec claims that the p-GaN HEMT outperforms metal-insulator-semiconductor (MISHEMT) counterparts.

imec has been working of the p-GaN HEMT structure (Figure 7) for some time [www.semiconductor-today.com/news_items/2015/sep/imec_020915.shtml]. Normally-off/enhancement-mode operation is preferred for power efficiency and fail safety. Conventional GaN HEMTs, produced without special measures such as fluoride plasma treatment of the gate region, tend to be depletion-mode/normally-on. Producing GaN devices on silicon should lead to production cost savings, but device performance can be impacted by crystal

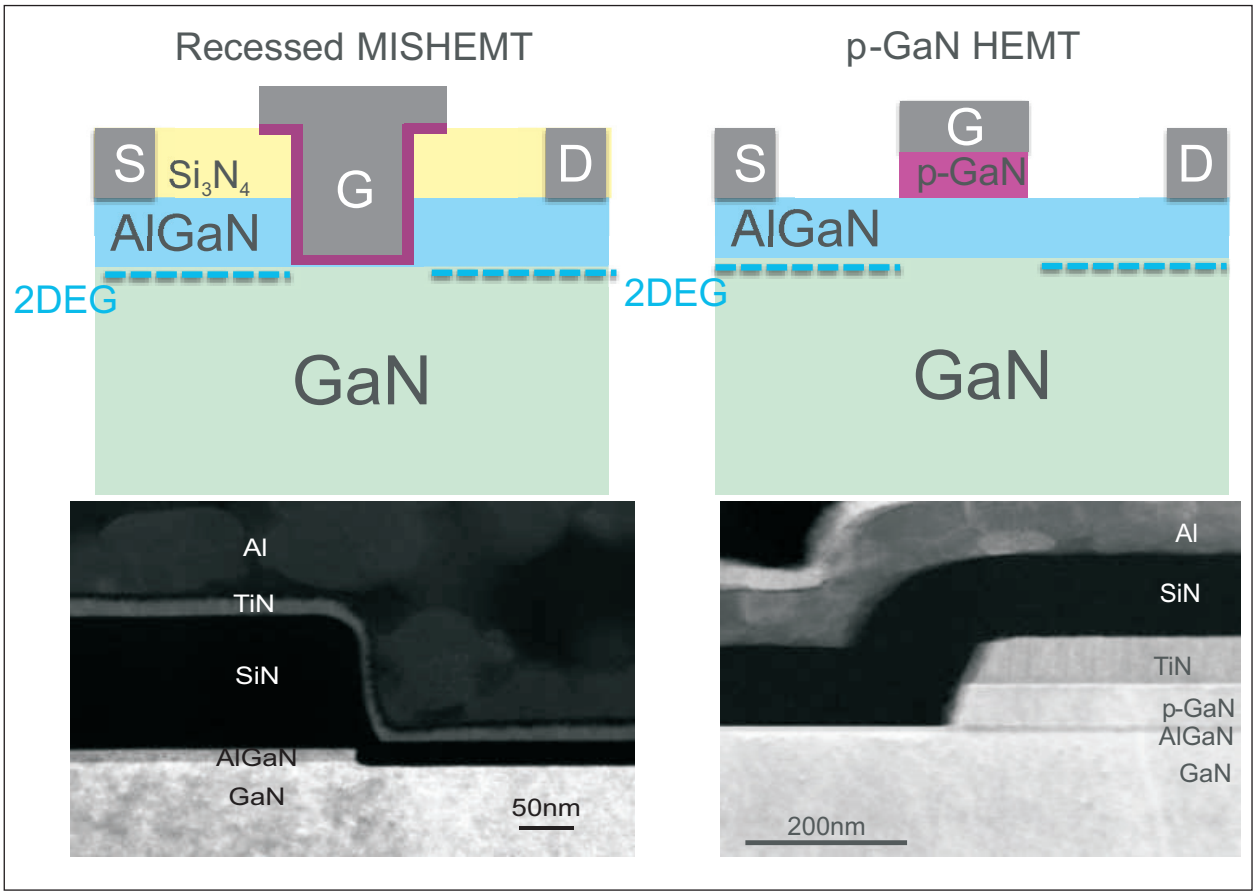


Figure 7. Schematic cross-section (upper figures) and transmission electron micrographs (TEM) of gate region (lower figures) of (a) recessed-gate MISHEMT and (b) p-GaN HEMT.

defects arising from the larger lattice mismatch, compared with silicon carbide or free-standing/bulk GaN substrates.

Another team of imec researchers focused on improving the interface between the 200mm-diameter substrate and the overlying GaN buffer with the aim of reducing dispersion/current collapse [session 35.4]. Dispersion occurs in pulse-mode/

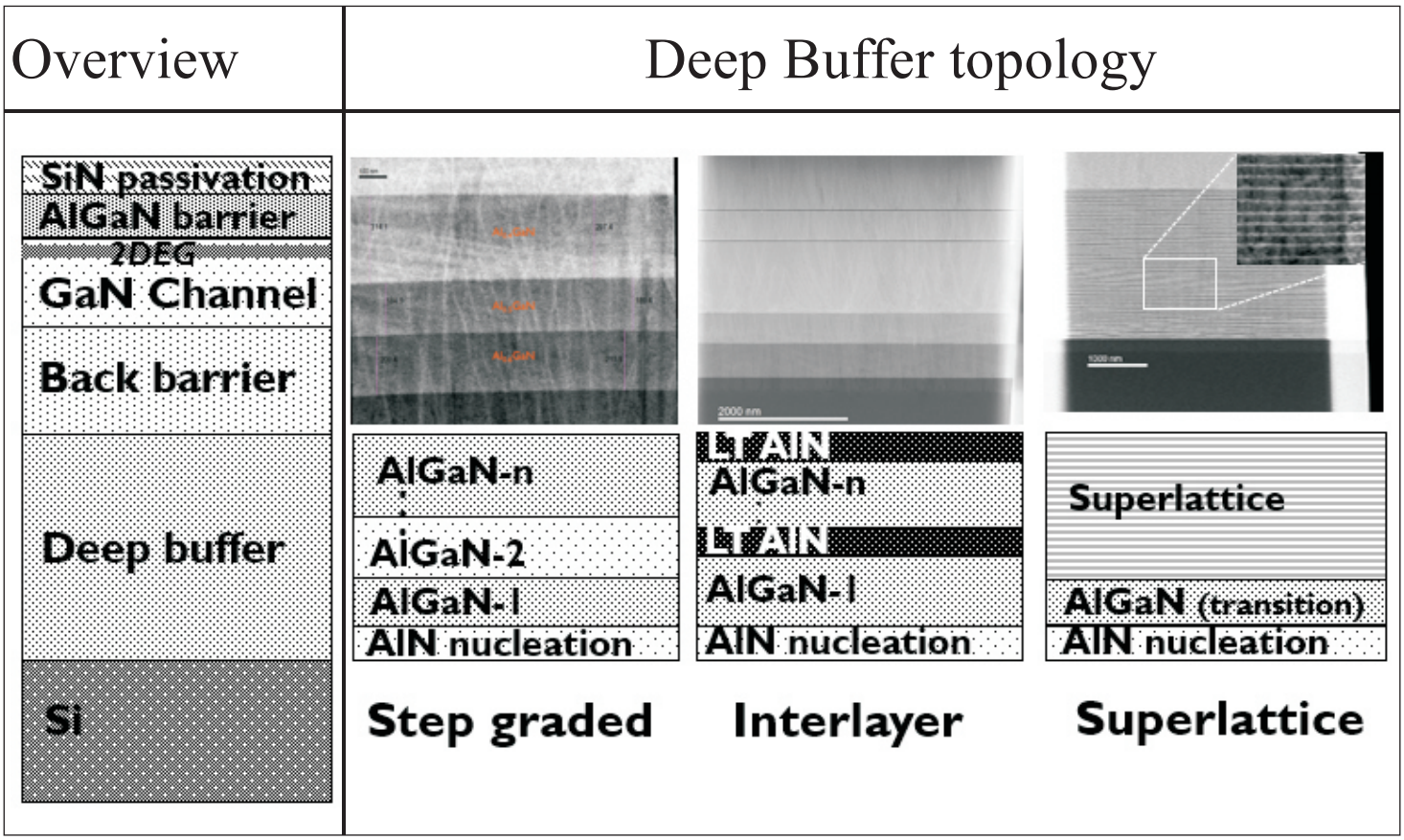


Figure 8. Schematic overview of AlGaN/GaN buffer and constituent parts. Schemes of three different deep buffer topologies are shown and illustrated with TEM cross sections of epi buffers.

switching operation. One cause of this is trap states in the buffer layer that adversely affect performance compared with DC characterization. Three types of high-voltage buffer/silicon interface were compared: step-graded, low-temperature AlN interlayer, and superlattice (Figure 8). Using a 'design of experiments' methodology, the researchers conclude that "a superlattice buffer can achieve simultaneously low dispersion and leakage under negative bulk bias".

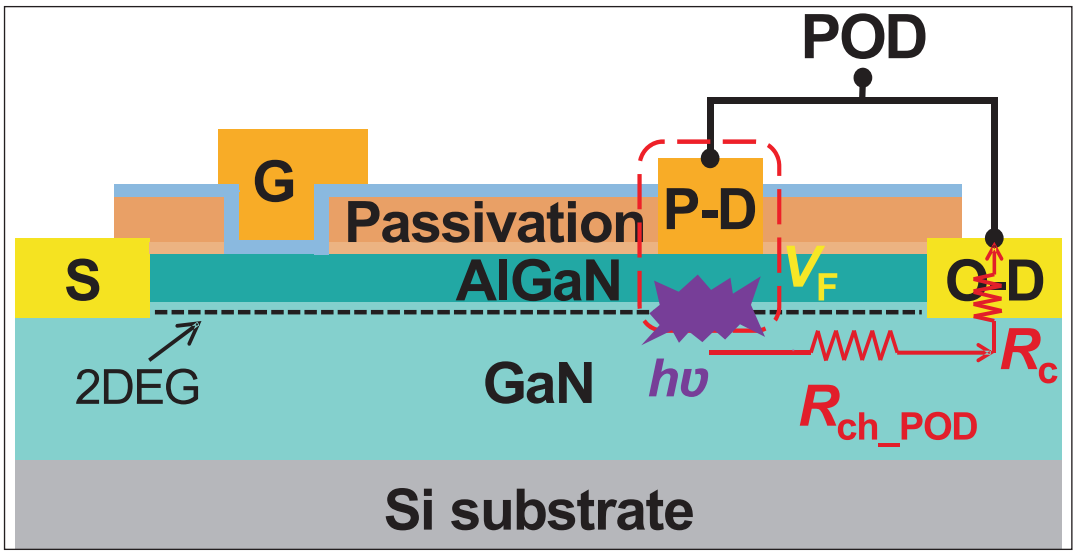


Figure 9. Schematic cross section of PODFET with MIS-gate fabricated on AlGaN/GaN-on-Si platform. The photonic-ohmic drain (POD) structure consists of photon-generation region (P-D) and ohmic region (O-D). The P-D is a Schottky-on-heterojunction light-emitting diode (SoH-LED). An AlN/SiN_x stack is employed as passivation and surface protection; 20nm SiN_x gate dielectric is grown by plasma-enhanced chemical vapor deposition (PECVD).

In their optimization efforts, the teams aimed at low dispersion/current collapse, leakage and breakdown voltage over a wide range of temperature and bias conditions. The researchers also optimized the epitaxy process for the p-GaN part of the gate stack on top of the aluminium gallium nitride (AlGaN) barrier layer.

imec says that it is working towards industrialization and is offering a complete 200mm CMOS-compatible 200V GaN process line that features excellent specs on enhancement-mode devices.

Taiwan Semiconductor Manufacturing Company (TSMC) presented low-cost GaN-on-Si enhancement-mode and depletion-mode transistors with voltage ratings up to 650V [session 9.5]. The CMOS-compatible devices are aimed at high-efficiency energy systems. The enhancement-mode devices were HEMTs, while the depletion-mode transistors were MISFETs. TSMC reports that its 100V and 650V enhancement-mode HEMTs have passed industrial reliability qualification (JEDEC), including 1000-hours high-temperature reverse bias (HTRB) testing. The company claims that the devices are ready for manufacture, with applications in energy systems needing strong robustness.

Intel has fabricated high-k gate dielectric depletion-mode and enhancement-mode GaN MOSHEMTs for power electronics and RF applications [session 16.3]. The drain-induced barrier lowering (DIBL) and off-current performance at 3.5V operation were optimized by thinning the effective oxide thickness to 23Å by removing the AlInN polarization layer from the gate stack. Intel claims that the DIBL versus gate-length characteristics are the best ever reported for a GaN transistor. A 90nm gate-length enhancement-mode high-k GaN MOSHEMT produced a high RF output power of 0.8W/mm with power-added efficiency (PAE) of 70% at 4V drain bias. At a low operating voltage of 1.5V, the output power was 0.2W/mm with 50% power-added efficiency. Intel sees applications for their devices in energy-efficient power electronics such as switching voltage regulators, and RF power amplifiers.

Hong Kong University of Science and Technology (HKUST) has demonstrated a power FET with photonic-ohmic drain (PODFET) [session 35.3]. The device was fabricated in a HEMT-compatible process on a conventional AlGaN/GaN-on-Si power electronics platform. Photons synchronously generated with a switching channel current were used to effectively pump electrons from deep surface/bulk traps (Figure 9). This overcomes delays and current collapse in pulsed/dynamic switching operations.

Research on TFETs in III-nitride and transition metal dichalcogenide (TMDC) systems were reported by a team from University of Notre Dame (UND), University of California, San Diego (UCSD), Cornell University, and University of Pittsburgh [session 35.6]. University of Notre Dame et al claim record low leakage currents in a tungsten diselenide TMDC device with a gate stack containing atomic-layer-deposited aluminium oxide. Low leakage is needed to reduce off-current. Tungsten diselenide TFETs demonstrated transfer characteristics substantially independent of temperature and consistent with tunneling transport, according to the team.

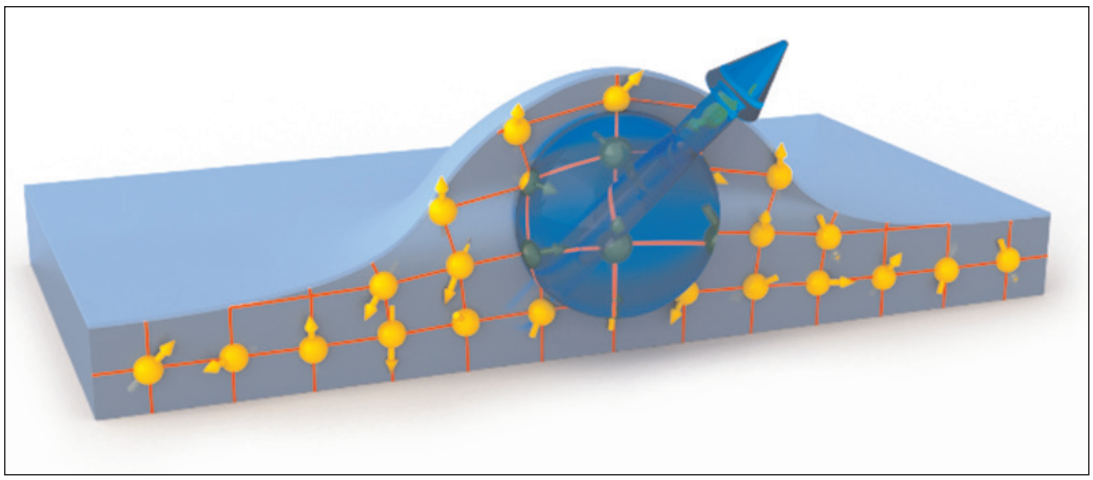
TMDC devices are in a very early stage of development, with potential applications in very thin few-atomic-layer formations for ultimate device scaling. ■

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

Electron trapped in InGaAs quantum dots on GaAs reveals qubit information loss mechanisms

Quantum computer loss channels switched off by 1.5T magnetic field.

Physicists at the Technical University of Munich (TUM) in Germany and the Los Alamos National Laboratory and Stanford University in the USA have tracked down semiconductor nanostructure mechanisms that can result in the loss of stored information — and halted the 'amnesia' using an external magnetic field ('Three-stage decoherence dynamics of an electron spin qubit in an optically active quantum dot', Alexander Bechtold et al; Nature Physics, 11, 1005–1008 (2015)). The new nanostructures comprise common semiconductor materials compatible with standard manufacturing processes.



An electron in a quantum dot, influenced by the nuclear spins of its environment.

Quantum bits (qubits) are the basic logical elements of quantum information processing (QIP) that may represent the future of computer technology. Since they process problems in a quantum-mechanical manner, such quantum computers might be able to solve complex problems much more quickly than currently possible.

In principle, there are various possibilities for implementing qubits: photons are an option equally as viable as confined ions or atoms whose states can be altered in a targeted manner using lasers. The key questions regarding their potential use as memory units are how long information can be stored in the system and which mechanisms might lead to a loss of information.

A team of physicists headed by Alexander Bechtold and professor Jonathan Finley at the Walter Schottky Institute of the Technical University of Munich and the Cluster of Excellence Nanosystems Initiative Munich (NIM) have now presented a system comprising a single electron trapped in a semiconductor nanostructure, where the electron's spin serves as the information carrier.

The researchers were able to precisely demonstrate the existence of different data loss mechanisms and also showed that stored information can nonetheless be retained using an external magnetic field.

Electrons trapped in a quantum dot

To form the nanostructure, the physicists at Technical University of Munich evaporated indium gallium arsenide (InGaAs) onto a gallium arsenide (GaAs) substrate. Due to the different lattice spacing of the two semiconductor materials, strain is produced at the interface between the crystal grids. The system thus forms nanometer-scale 'hills' (quantum dots).

When the quantum dots are cooled down to liquid helium temperatures and optically excited, a single electron can be trapped in each of the quantum dots. The spin states of the electrons can then be used as information stores. Laser pulses can read and alter the states optically from outside. This makes the system ideal as a building block for future quantum computers.

Spin up or spin down correspond to the standard logical information units 0 and 1. But, on top of this come additional intermediate states of quantum mechanical up and down superpositions.

Hitherto unknown memory loss mechanisms

However, there is one problem. "We found out that the strain in the semiconductor material leads to a new and until recently unknown mechanism that results in the loss of quantum information," says Bechtold. The strain creates tiny electric fields in the semiconductor that influence the nuclear spin orientation of the atomic nuclei.

"It's a kind of piezoelectric effect," says Bechthold. "It results in uncontrolled fluctuations in the nuclear spins." These can, in turn, modify the spin of the electrons, i.e. the stored information. The information is lost within a few hundred nanoseconds.

In addition, Bechthold's team was able to provide concrete evidence for further information loss mechanisms, for example that electron spins are generally influenced by the spins of the surrounding 100,000 atomic nuclei.

Preventing quantum mechanical amnesia

"However, both loss channels can be switched off when a magnetic field of around 1.5 tesla is applied," says Bechtold. "This corresponds to the magnetic field strength of a strong permanent magnet. It stabilizes the nuclear spins and the encoded information remains intact," he adds.

"Overall, the system is extremely promising," according to Jonathan Finley, head of the research group. "The semiconductor quantum dots have the advantage that they harmonize perfectly with existing computer technology since they are made of similar semiconductor material." They could even be equipped with electrical contacts, allowing them to be controlled not only optically using a laser but also using voltage pulses.

The research was funded by the European Union (S3 Nano and BaCaTeC), the US Department of Energy, the US Army Research Office (ARO), the German Research Foundation DFG (Cluster of Excellence Nanosystems Munich (NIM) and SFB 631), the Alexander von Humboldt Foundation as well as the TUM Institute for Advanced Study (Focus Group Nanophotonics and Quantum Optics). ■

www.nature.com/nphys/journal/vaop/ncurrent/full/nphys3470.html

www.wsi.tum.de

Metal deposition of acoustic wave devices for mobile & Internet of Things

Kuohsiung Li PhD of Raisin Technologies and John Hubschmann discuss the applications of SAW and BAW devices in wireless communication and IoT.

The Internet platform and mobile devices have ushered in a new phase in human productivity and social life. This profound transition is manifested by 2.8 billion Internet users and 5.2 billion mobile phone users in 2014 (www.kpcb.com/internet-trends). The next leap in connectivity is anticipated with the evolution in the Internet of Things (IoT). As many as 50 billion connected devices are envisioned for 2020 and consequently an increasingly high premium will be put on the maximization of spectrum utilization. To ensure high-quality communication within each of the booming number of frequency bands, engineers deploy filters to reduce the interference among bands. With high performance, small size and low cost, bulk acoustic wave (BAW) and surface acoustic wave (SAW) filters win over the market from the traditional ceramic and LC filters.

The number of acoustic wave devices utilized in a cellular phone has increased from 2 in a feature phone to about 5 in a low-end smart-phone and more than 15 in a high-end smart-phone. The market size of acoustic wave devices is projected to grow from $1.9bn in 2011 to $4.9bn in 2016, with BAW growing more than twice as fast as SAW (www.bccresearch.com). Although the lower insertion loss, steeper filter skirts and better out-of-band rejection of BAW enable it to perform better at high frequency and for communication bands of close proximity, recent innovation in temperature compensation and circuit design have expanded SAW into previous BAW territory, especially in China's latest-generation TD-LTE (time-division long-term evolution) communication market due to the Asian market's sensitivity to cost. The battle between SAW and BAW manufacturers remains fierce.

In light of the increasing competition from both the well established (i. e. Qualcomm) and a number of startup CMOS companies in the mobile power amplifier (PA) marketplace, which is currently dominated by compound semiconductor (CS) IC companies, the compound semiconductor industry is seeking opportunities to grow their top line (revenue) meaningfully. Acoustic wave devices become the most natural business opportunity for the expansion of compound semiconductor IC companies for the following reasons:

- The total component price of acoustic wave devices for a high-end mobile device now far surpasses that of PA devices. Acoustic wave devices therefore enable a high growth rate in future revenue.
- The similarity in processing technology between the acoustic wave and PA devices is such that the technical barrier of entry into the SAW/BAW business is not high for compound semiconductor RF IC companies.
- Much of the processing equipment used in the compound semiconductor RF IC fab could be used just as well for SAW/BAW processing. This enables flexibility to maximize equipment and facility utilization.

Nonetheless, in order to profitably serve the acoustic devices market, compound semiconductor RF IC companies must still address the problem of many patents being owned by other companies. After a few years of intense consolidation (through merger, acquisition, partnership and alliance), many leading compound semiconductor companies (i.e. Avago, Qorvo, Skyworks etc.) are now in a good position to grow their acoustic wave business aggressively. Since SAW and BAW are fabricated on different substrate materials than compound semiconductor RF IC, the SAW/BAWs are not integrated into the same chip with the PAs. However, acoustic wave devices are incorporated into the same module as PA devices in order to minimize the size and to reduce the cost of mobile devices.

This paper presents the many considerations involved in the metal evaporation process for high-yield acoustic wave devices and the benefit of Ferrotec's UEFC-5700/4900 evaporators for the production of SAW and BAW devices (see Figure 1).

Device characteristics of acoustic wave filters

FBAR (film bulk acoustic resonator) and BAW-SMR (solidly mounted resonator) are popular implementations of BAW devices. FBAR confines the acoustic energy via the large difference in acoustic impedances between the FBAR structure and air on both the top and bottom sides. On the other hand, BAW-SMR has an acoustic reflector at the bottom. There should be a large mismatch in acoustic impedance between the electrode and the

reflector to ensure the confinement of acoustic wave. The superior confinement of acoustic energy by FBAR and BAW-SMR makes these filters ideal for communication at higher frequency compared with SAW filters. Consequently they are widely deployed in the new generation (4G) of smart-phones and 5GHz Wi-Fi. AlN is the piezoelectric material of choice for BAW filters due to its higher acoustic velocity (10,400m/s) compared with ZnO (6330m/s) and less acoustic loss (5dB/us versus 8.3dB/us @1GHz). As a rule, the piezoelectric mono-crystal should also have a high degree of crystal orientation and be very smooth (~5Å rms) for the production of filters with high-Q (quality factor).

Molybdenum (Mo) is a popular electrode material for FBAR with high acoustic impedance and high power handling capability. W, Au, Ti, Al, Pt, V and Cu could also be used as electrodes. BAW is inherently less sensitive to temperature drift than SAW over the typical operating range of –20°C to 85°C experienced by the end users. With boron (B)-doped SiO_2 juxtaposed with one of the electrodes, the temperature coefficient of frequency (TCF) could further be reduced to nearly zero (Avago, 2009, US Patent 7561009). The improvement in TCF enables the deployment of BAW for communication bands of very close proximity (for example, LTE Band 40 has only 1MHz of transition guard band with 2.4GHz Wi-Fi). Furthermore, FBAR and SAW-SMR have the advantage of decreasing size with increasing frequency.

Al (Aluminum) is a popular electrode material for SAW with very low electrical resistance and low density (2.7g/cm^3) which minimizes the mass loading effect. Quartz, $LiTaO_3$ and $LiNbO_3$ are common piezoelectric materials. Typically, 2% Cu (by weight) is added to the Al to serve as 'glue' among Al grains, and hence to inhibit Al electromigration that moves grain boundaries at high temperature or at high power for better device reliability. Although the addition of Cu improves the power handling capability of SAW devices by minimizing hillock and void formation, too much Cu will increase the electrical resistance (see Figure 2). On the other hand, Cu concentration of less than 1% renders the Cu ineffective. There is an optimal range of Cu concentrations that reduces electromigration without unduly increasing electrical resistance.

Although SAW devices typically have a higher TCF of about –45ppm/°C, over-coating of IDT (inter-digital transducer) structures with a dielectric layer (i.e. SiO_2) that increases the acoustic stiffness at high temperature can reduce the TCF to nearly zero. Furthermore, the insertion loss in the pass-band could be reduced as well (TriQuint, 2011, US Patent 8044553).

Fig. 1: Ferrotec UF-5700 electron-beam evaporator for the manufacturing of SAW and BAW devices.

Considerations in metal evaporation process for acoustic wave devices

The most critical processing step for the manufacturing of SAW/BAW devices is the deposition of IDT (inter-digital transducer) metallization, which determines the device performance and reliability under high tempera-

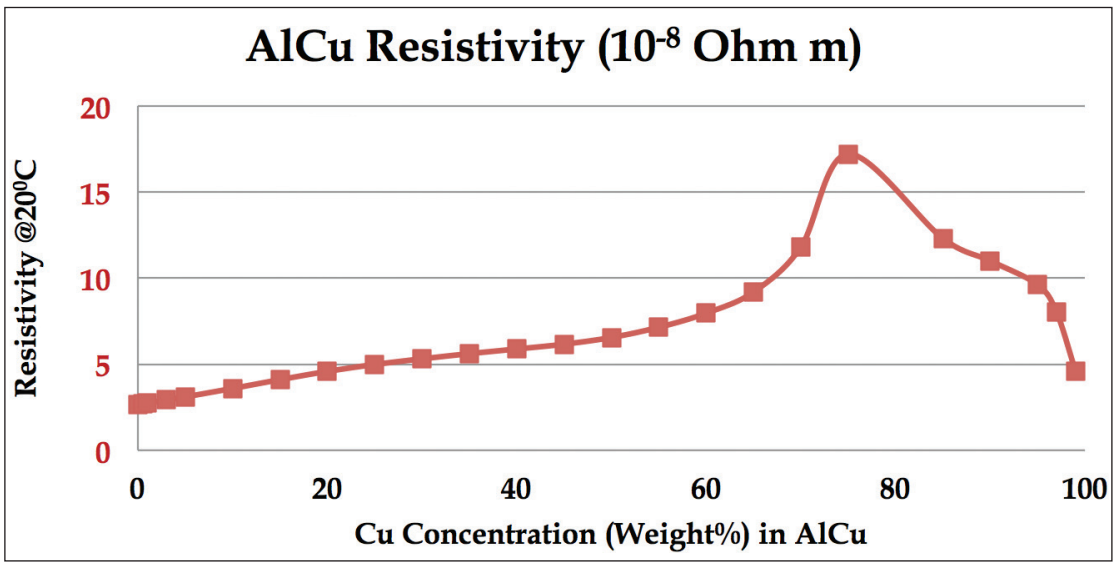


Fig. 2: The resistivity of AlCu as a function of Cu (weight %) concentration (www.nist.gov/data/PDFfiles/jpcrd221.pdf).

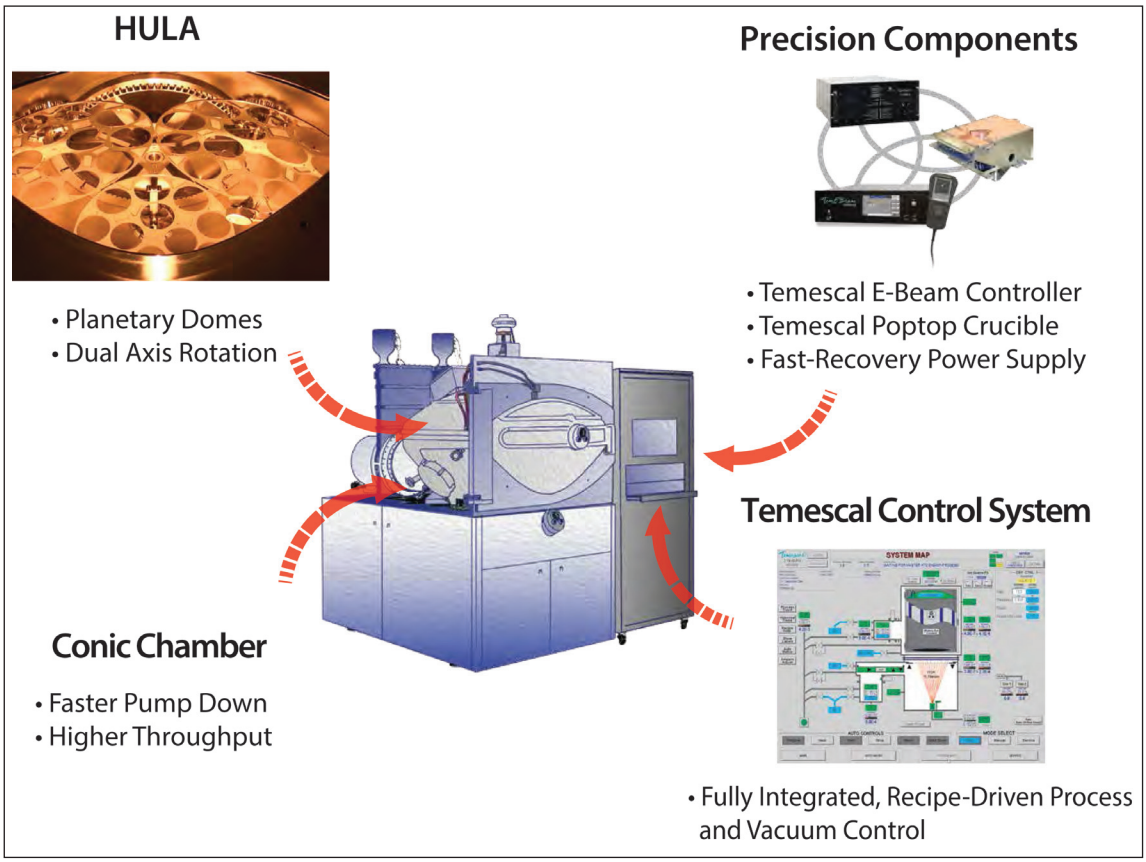


Fig. 3: Ferrotec UF-5700/4900 system control hardware.

ture and high power. Electron-beam evaporation has many advantages for the production of IDT fingers. Chief among them is that the directionality of evaporation facilitates the lift-off process and consequently eliminates the need to selectively etch the blanket metal for the formation of IDT fingers. Additionally, the large batch process reduces the cost of ownership (CoO) and the gentle deposition of evaporants drastically reduces the surface damage on the wafers that would impact acoustic coupling.

For SAW devices, the deposition of alloys such as AlCu presents a challenge in the control of Cu concentration (typically 2% by weight) within the wafer, wafer-to-wafer and run-to-run. When the Cu concentration errs on the low side, the Al migration at subsequent high-temperature process is not arrested and thus results in catastrophic failure. When the Cu concentration errs on the high side, the resistivity of AlCu film and the insertion loss of SAW devices increase. This challenge is due to the difference in vaporization temperature between Al and Cu (2327°C and 2595°C, respectively) which results in a higher evaporation rate of Al than that of Cu. Ferrotec has developed a proprietary procedure that efficiently prepares the AlCu source in the crucible to ensure 2% Cu concentration in the deposited film reliably. This recipe will be provided to Ferrotec's customers to quickly bring the production process on line.

Tight control of the electron-beam evaporation process is required to produce an alloy of precise stoichiometry and thickness. Control of beam sweep and evaporation rate are the most critical. Ferrotec's electron-beam sweep controller allows users virtually infinite control over sweep patterns and beam dwell (sweep speed) time. This — along with the deposition rate controller, featuring programmable temperature ramp rates and dwell (soak) steps — gives users total control over the melt and evaporation conditions (see Figure 3). Patented planetary domes are also incorporated into Ferrotec's UEFC-5700/4900 evaporators to further improve the uniformity control on both the Cu concentration and film thickness.

It is essential to eliminate all surface contamination prior to the evaporation of IDT metal to ensure effective acoustic coupling. A robust multi-stage cleaning process is widely adopted throughout the acoustic wave industry. For example, in a first-stage process to remove chemical residues from the CMP (chemical mechanical planarization) polishing process used by the substrate suppliers, NH_4OH/H_2O_2 solution is heated to 50–60°C to clean the substrates and then followed by a cascade rinse in deionized (DI) water until the DI water reaches 14–16MΩ-cm resistivity.

The second stage of surface cleaning removes hydrocarbon contamination from either the substrate suppliers' process or other natural sources. This requires two heated (50–60°C) ultrasonic tanks. The first tank is filled with acetone to completely immerse the substrates for 10 minutes of ultrasonic agitation. Substrates are then transferred to the second tank for isopropanol alcohol (IPA) immersion with 10 minutes of ultrasonic agitation. The substrates are then immediately dried in a heated 'N_2 only' spin dryer.

The last stage is oxygen plasma cleaning to remove stubborn hydrocarbon residue. The oxygen plasma must be energetic enough to exhibit a glow discharge from the ionization process. Oxygen should also have a high flow rate to maintain a partial pressure of 1 Torr for approximately 10 minutes. In addition, some device manufacturers also use ultraviolet ozone cleaner (UVOC) for 10 minutes to deplete the surface of very aggressive,

chemically bonded OH molecules which can cause issues with subsequent processes that are sensitive to OH contamination.

The cleanliness of the surface will need to be verified to ensure the efficacy of the cleaning process. A simple method is commonly employed to measure changes in the surface energy with a goniometer to measure the contact angle. Small angle θ indicates high surface energy exhibits from a clean surface (see Figure 4). Prior to the above-mentioned rigorous surface cleaning procedure, quartz substrates typically have contact angles ranging between 20° to 40°, and 2° to 3° after a multi-stage cleaning.

In SAW/BAW processing, the application of photoresist is necessary to define various layers. Photoresist is a hydrocarbon contaminant and must be completely removed before subsequent processes and before final encapsulation of the acoustic wave devices. The contact angle test can also be used to verify that no photoresist residue (scum) remains; otherwise contact angles of ≥20° are often observed. The presence of any contamination dampens the wave velocity and adversely impacts the coupling of RF electrical energy with the piezoelectric surface and results in an output frequency higher than originally designed. Furthermore, the insertion loss will also be higher. Process engineers may be tempted to increase the IDT metal thickness to bring the frequency back to specification, only to see the next batch of wafers out of specification due to the unpredictability of the photoresist contamination. Therefore emphasis has to be placed on substrate surface cleaning from the start. Proper cleaning ensures any subsequent process steps will only need a short pre-clean via an O_2 plasma de-scum to return the surface to a clean baseline. The UEFC-5700/4900 evaporators also have an option to provide in-situ cleaning with an ion gun. This allows for removal of several atomic surface layers to ensure efficient acoustic coupling to the piezoelectric substrate.

Care should further be taken on the accuracy of thickness measurement. The conventional method used for thickness measurements of thin-film metals has been the surface profilometer. This tool has several inherent draw backs for measurement on films below 800Å. First of all, the signal-to-noise ratio is insufficient for ±1% accuracy. Secondly, the stylus contacts the surface and has a downward force as it moves across the measured features and may damage them. The solution is to incorporate numerous design verification structures across each wafer in sacrificial areas for non-contact thickness measurement via white light interferometer (WLI).

In addition, the accurate measurement of the thin-film resistivity of IDT fingers is critically important as a key indicator of film quality and Cu concentration in AlCu.

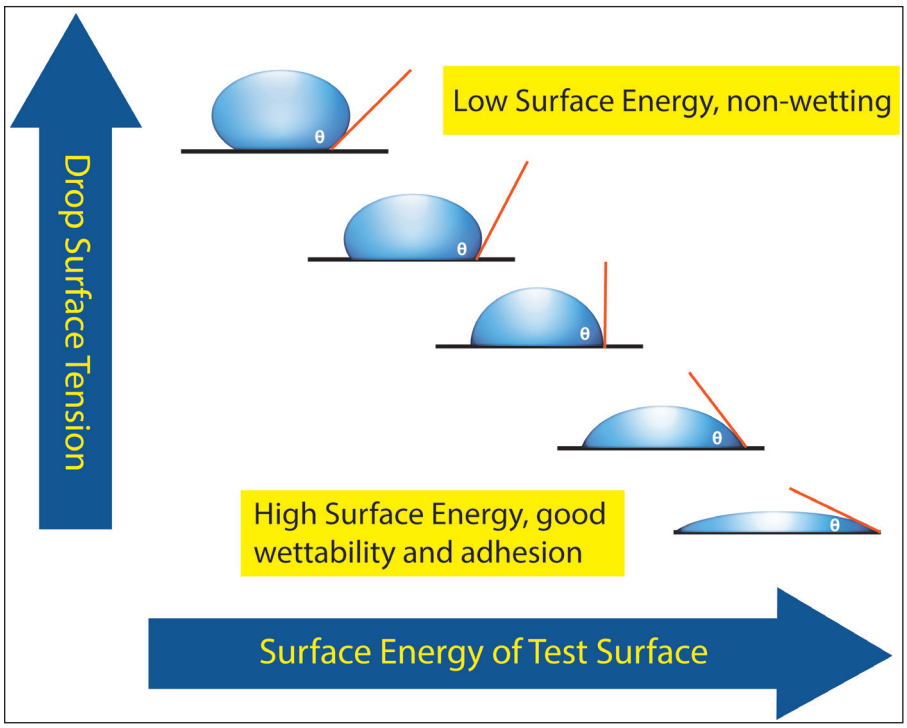


Fig. 4: Deionized water droplets showing contact angle as a function of surface energy.

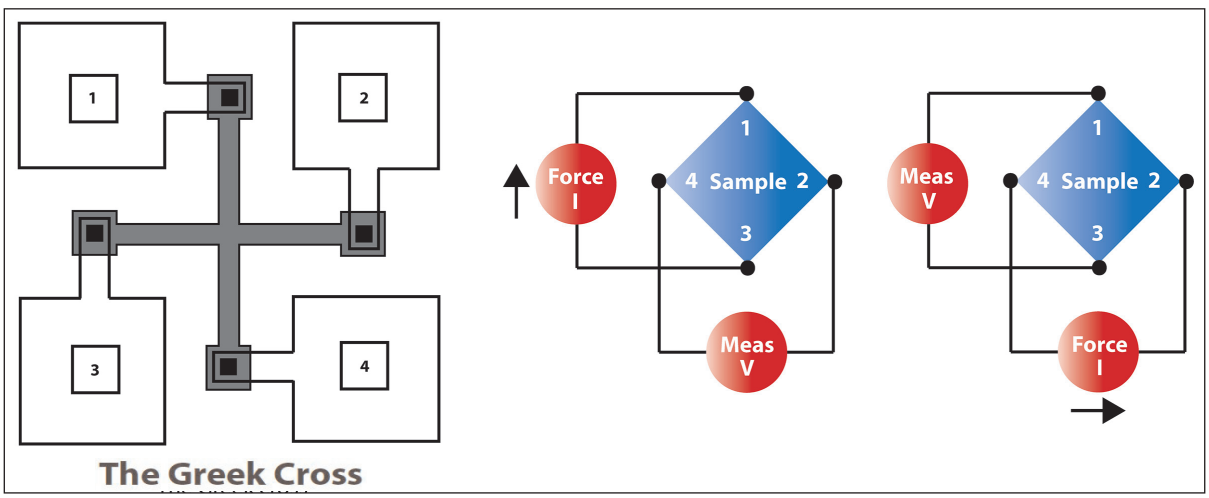


Fig. 5: A Van der Pauw structure, known as a 'Greek cross' for voltage measurement with applied current to extract the sheet resistance.

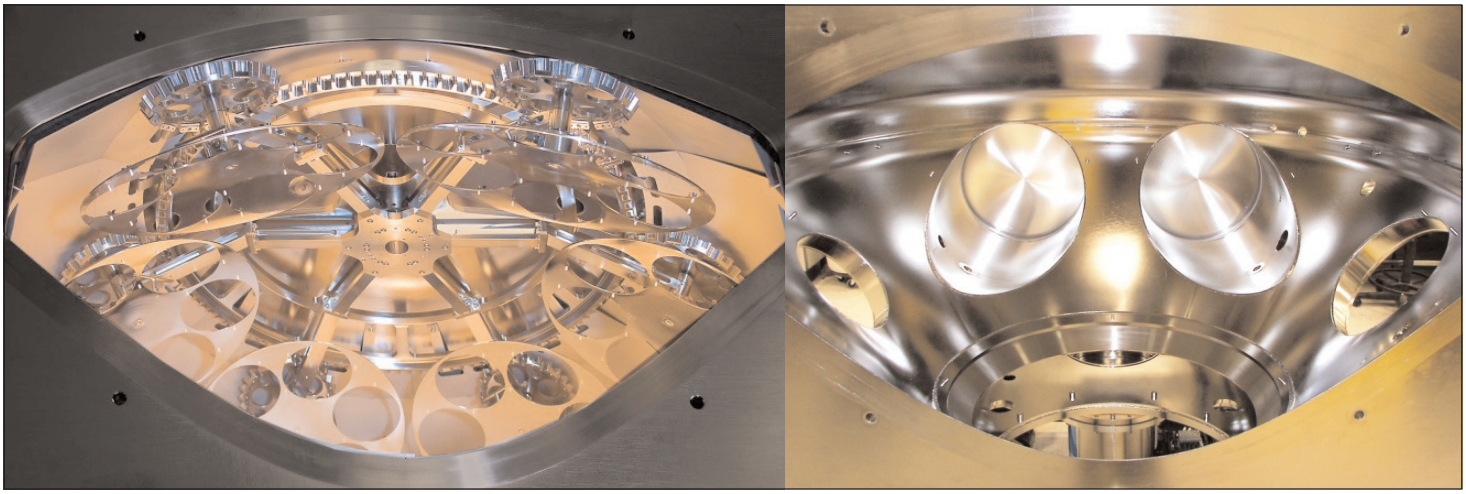


Fig. 6: Ferrotec's HULA Planetary rotating domes (left) and conic chamber (right).

The resistivity measurement must be sensitive enough to detect minute changes that reflect the variation in copper concentration. A Van der Pauw structure, known as a 'Greek cross' in the semiconductor industry, is commonly used (see Figure 5). Automatic test on the product wafers could thus be performed 'in process' (before bond pad metal). This sensitive 'in process' test allows for early screening of bad wafers to save manufacturing cost.

Advantages of Ferrotec UEFC-5700/4900 for SAW, FBAR & BAW-SMR

Ferrotec's UEFC-5700 and UEFC-4900 incorporate two main features to minimize the CoO of an electron-beam (E-beam) evaporator. The first is the patented magnetic drive HULA (High Uniformity Liftoff Assembly), which is a set of planetary rotating wafer carrier domes that change the location of each wafer relative to the evaporants in the source crucible continuously via a contactless magnetic drive. Each wafer remains orthogonal to the direction of evaporation. This directionality is critical to a high-yield lift-off process. The second is the patented conic shape chamber design that minimizes both the volume and surface area of the product chamber. This leads to much reduced pump-down time and hence better throughput (see Figure 6). The magnetic HULA drive is contactless and therefore generates no particles and thus results in better yield. The planetary domes rotate around the central axis of the product chamber and each dome is also self-rotating to facilitate uniform depositions for all wafers. Furthermore, the design of UEFC-5700 is footprint efficient, such that the batch size is increased by 40% for the same footprint (as Ferrotec's more traditional 'box coater' FC-4400) to allow for better utilization of cleanroom space.

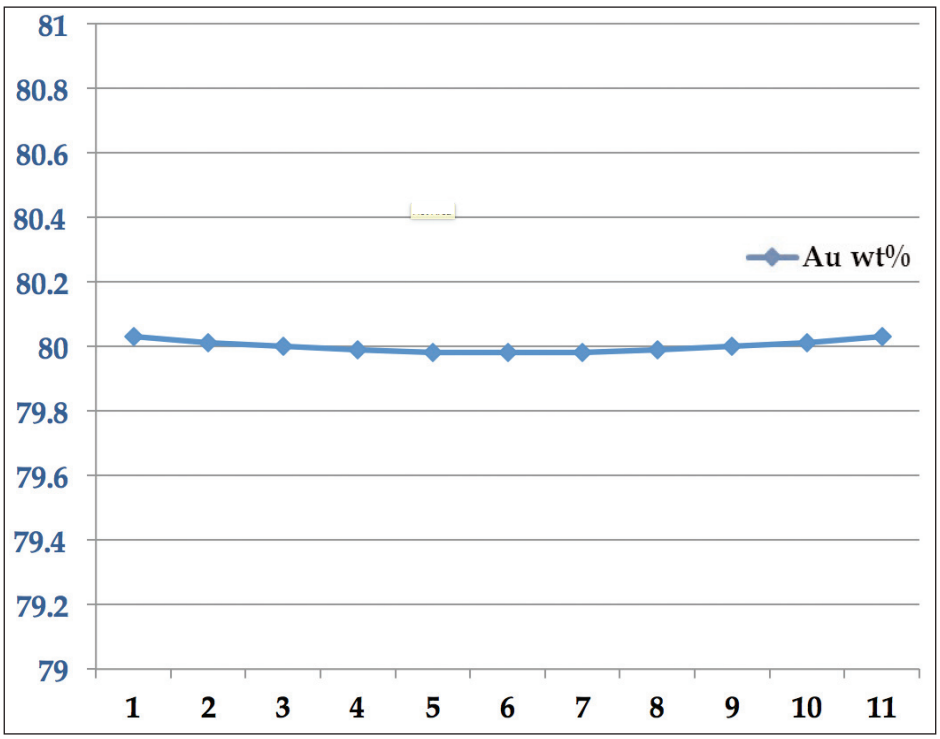


Fig. 7: Precise control of Au/Sn eutectic composition to 0.02% standard deviation within-wafer in a Ferrotec HULA system, without mask.

Ferrotec has previously demonstrated the ability of UEFC-5700 and UEFC-4900 for the precise control of eutectic composition (Amirani I., 2015. The Resurgence of Electron Beam Evaporation. Compound Semiconductor magazine). This allows for the control of eutectic melting temperature within a narrow range to ensure the bonding quality. Even without the utilization of a uniformity mask, UEFC-5700/4900 could control the 80%Au/20%Sn eutectic composition to 0.02% standard deviation (see Figure 7) within-wafer, and about 0.3% standard deviation from wafer to wafer. Care should be taken to control the batch-to-batch thickness repeatability as well.

Ferrotec's UEFC systems have good repeatability on AlCu evaporated from a

single-source crucible as well, for the manufacturing of SAW devices. As discussed in the previous section, 2% Cu (by weight) in Al inhibits the electromigration of Al at high temperature and/or at high power. The within-wafer thickness uniformity of AlCu (98%/2% by weight) is about 1% standard deviation and the run-to-run uniformity is also about 1% standard deviation even with a refill of AlCu at the source crucible for run number 8 (see Figure 8). This test is conducted at a relatively high evaporation rate of 10Å/s to simulate high-throughput production.

The control of Cu concentration from run to run is also evaluated in a Ferrotec UEFC-4900 system. The AlCu was evaporated repeatedly from a single-source crucible and a source refill was performed at the 11th run. The Cu concentration could be tightly controlled to 0.2% standard deviation for run-to-run repeatability (see Figure 9).

In addition to electrodes of acoustic wave devices, Ferrotec's evaporators are also ideal for the metal deposition of bond pads, such as NiCr/Au where NiCr serves as a diffusion barrier for Au, or Cr/Al where a very thin layer (<100A) of Cr strengthens the bond pad attachment.

In summary, the applications of acoustic wave devices have exploded with the current wide adoption of mobile devices and the future expansion of IoT. The battles between SAW, FBAR and BAW-SMR are fierce, fueled by innovation in device and circuit design. Mo, AlCu and other electrode materials can be uniformly evaporated by Ferrotec's UEFC-5700 and UEFC-4900 at low cost of ownership. Ferrotec provides customers with guidance on the cleaning of piezoelectric materials, preparation of AlCu source crucible and the high-yield lift-off process of the evaporated metals from a single crucible with precision control on thickness and composition. This is accomplished via the patented HULA planetary domes and conic product chamber. ■

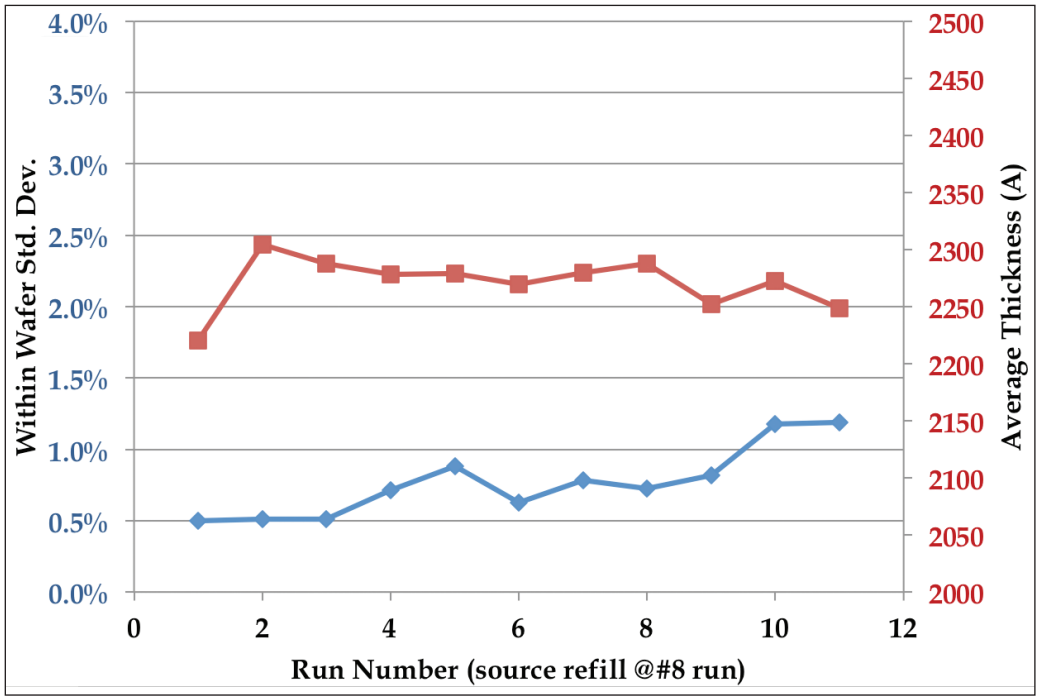


Fig. 8: Within-wafer and run-to-run thickness uniformity of AlCu (98%/2% by weight) evaporated at 10Å/s in a Ferrotec UF-4900 with source refill at run #8.

Authors:
Kuohsiung Li PhD, Raisin Technologies, and
John Hubschmann
J. Hubschmann was with Raytheon for 13 years and is a SAW process specialist.

For more information about the Ferrotec products cited, visit **www.temescal.net**

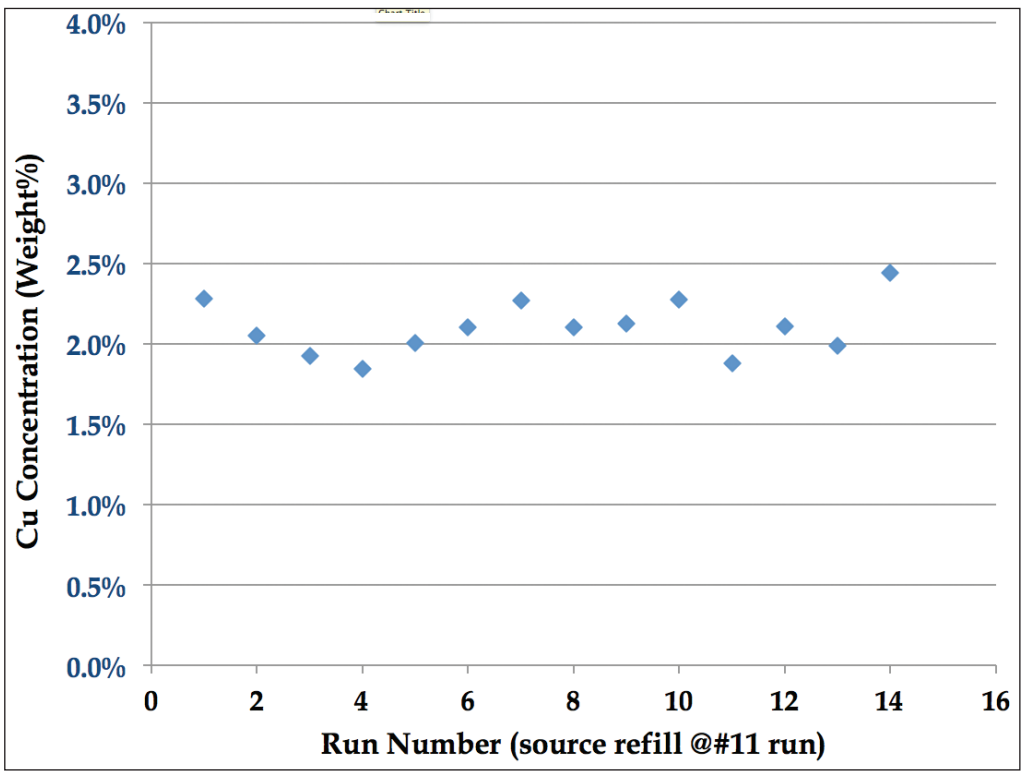


Fig. 9: Run-to-run repeatability of Cu concentration in AlCu targeting 2% Cu with source refill at run #11 in a Ferrotec UF-4900 evaporator.

'Dialing-in' wet processing parameters for compound semiconductor manufacturing

Companies engaged in compound semiconductor wafer processing experience benefits from using wet processing equipment designed to handle a variety of application parameters.

With the growing range of microelectronic devices that utilize compound semiconductors, increased attention is being paid to the design and selection of the wet processing equipment used for etching, photoresist wet stripping, photolithography, metal lift-off, and related polymer removal processes.

By doing so, compound semiconductor manufacturers of LED chips, non-silicon-based photovoltaics, power electronics, optoelectronics, sensors and other micro- and nano-technologies can increase product quality and throughput, while reducing downtime and chemical costs and disposal.

Although there are similarities in the wet processing techniques used to create a broad variety of compound semiconductors, each process might not be identical in concentration, time, temperature and chemical used in wafer processing.

As a result, there is a wide variety of equipment designs available that include process modules for solvents, acid, bases, deionized water rinse and drying. Mechanical, ultrasonic or megasonic agitation as well as high-pressure spraying and other processes may also be incorporated, if needed.

Another consideration is safety, and there are many mandated requirements for items such as ventilation, fire suppression, chemical handling and explosion prevention.

Dialing-in equipment design

Although manual wet benches are available, with the growth of the compound semiconductor market many manufacturers are turning to automated equipment to increase throughput and ensure process repeatability.

Fully automated process equipment often includes multiple stations or modules as well as robotics, sophisticated control, data logging and monitoring systems.

Since the design of many wet processing systems is proprietary, specifications are protected by the equipment manufacturer and user alike. Therefore, considering all of the possible design variables, it may be advisable to visit an equipment manufacturer with design capabilities and an application laboratory.

One of the prominent designers and builders of wet processing equipment, JST Manufacturing Inc of Boise, ID, USA has an on-site applications laboratory where end-users can develop their process with various chemistries and do tests on real equipment, ranging from immersion and spray tools to dryers. The laboratory includes sophisticated metrology equipment including a scanning electron microscope and a Tencor particle counter.

By visiting applications labs such as those provided by JST Manufacturing, end-users can 'dial-in' and optimize their processes, and can minimize the amount of chemicals required and/or determine the tool features they need for their applications. This can save the customer money by eliminating features they do not need.

"Even though a manufacturer arrives with a good idea how they want to handle the wet processing, we are often able to recommend modifications after we have a chance to review the project," says JST's president Louise Bertagnolli, adding that a majority of JST Manufacturing's customers are in the compound semiconductor market. "Sometimes design variations will perform the cleaning or etching work in the manner required, but will also save money, reduce the floor space requirement, simplify maintenance or provide other benefits," she adds.

Dialing-in parameters

To facilitate the economical design and building of a wet processing equipment solution, many users insist on a standardized approach with customizable features that will best handle their applications parameters.

For example, JST utilizes standard products and standard methodologies to design and manufacture equipment. Using SOLIDWORKS 3D modeling software, the company can make minor changes and customizations to meet the needs of each application. Also, the equipment is modular by design, allowing for easy changing and reconfiguration should process or product requirements change.

Another powerful feature: each unit is designed with software that is capable of performing all tool functions, including those that are not required. With this, end-users can create their own process, or recipes, with all sub-routines at their disposal.

JST Manufacturing has an on-site applications laboratory where end-users can develop their process with various chemistries and conduct tests on real equipment ranging from immersion and spray tools to dryers.

"We like to give customers added flexibility by programming their equipment to do everything that the equipment is capable of doing," explains Bertagnolli. "This enables them to dial in applications, such as chemical concentrations. They can also turn various features on or off, depending on your process requirements," she adds. "Even though they may not need some of the features today, they may want to turn them on in the future, which can be both economical and powerful."

Optimizing manual applications

According to Dennis M. Schweiger, senior director of Infrastructure at the University of Michigan's Lurie Nanofabrication Facility (LNF), soliciting the opinion of equipment manufacturers regarding equipment design can be highly beneficial.

The LNF is a world-class facility in all areas of semiconductor device and circuit fabrication, integrated microsystems and MEMS technologies, nanotechnology, nanoelectronics, nanophotonics and nanobiotechnology. The LNF is an open-use facility with hundreds of users from various UM departments, as well as many other universities and businesses.

"Since we essentially rent lab space and equipment to our diverse users, it is important that we provide them with wet processing equipment that suits their purposes well, from those that are processing wafers to those who may be doing very advanced research or testing on non-wafer components," says Schweiger.

The original equipment design for the new lab area's wet processing benches was very specific, and determined by the LNF staff.

"We had looked at it in terms of process flow, from start to finish, not really taking into account the variety, and variation, of process samples that our user community might be working with, how we'd accommodate non-standard sample sizes, or what the impact might be in total cost of ownership with respect to chemical usage," adds Schweiger.

In addition, some of the new equipment had its decks reconfigured once the tools were installed. Several of the earlier wet benches, some of which were purchased over 20 years ago, were also modified to allow for more flexibility in meeting the process needs of the user community.

"In retrospect, our initial plan for the deck space, and processing capability of the benches, wasn't adaptable or flexible enough, and we worked with JST to implement modifications so that the bench decks were simpler, and could provide more working space," Schweiger concluded. ■

For further information contact:
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Tel: +1 925 245 5817
Fax: +1 925 449-4096
www.temescal.net

Temescal, the expert in metallization systems for the processing of compound semiconductor-based substrates, provides the finest evaporation systems available. Multi-layer coatings of materials such as Ti, Pt, Au, Pd, Ag, NiCr, Al, Cr, Cu, Mo, Nb, SiO_2, with high uniformity are guaranteed. Today the world's most sophisticated handsets, optical, wireless and telecom systems rely on millions of devices that are made using Temescal deposition systems and components.

Oxford Instruments Plasma Technology
North End, Yatton,
Bristol, Avon BS49 4AP, UK
Tel: +44 1934 837 000
Fax: +44 1934 837 001
www.oxford-instruments.co.uk

We provide flexible tools and processes for precise materials deposition, etching and controlled nanostructure growth. Core technologies include plasma and ion-beam deposition and etch and ALD.

Plasma-Therm LLC
10050 16th Street North,
St. Petersburg, FL 33716, USA
Tel: +1 727 577 4999
Fax: +1 727 577 7035
www.plasmatherm.com

Plasma-Therm, LLC is an established leading provider of advanced plasma processing equipment for the semiconductor industry and related specialty markets.

Riber
31 rue Casimir Périer, BP 70083,
95873 Bezons Cedex, France
Tel: +33 (0) 1 39 96 65 00
Fax: +33 (0) 1 39 47 45 62
www.riber.com

SVT Associates Inc
7620 Executive Drive,
Eden Prairie, MN 55344, USA
Tel: +1 952 934 2100
Fax: +1 952 934 2737
www.svta.com

Veeco Instruments Inc
100 Sunnyside Blvd.,
Woodbury, NY 11797,
USA
Tel: +1 516 677 0200
Fax: +1 516 714 1231
www.veeco.com

Veeco is a world-leading supplier of compound semiconductor equipment, and the only company offering both MOCVD and MBE solutions. With complementary AFM technology and the industry's most advanced Process Integration Center, Veeco tools help grow and measure nanoscale devices in worldwide LED/wireless, data storage, semiconductor and scientific research markets—offering important choices, delivering ideal solutions.

7 Wafer processing materials

Air Products and Chemicals Inc
7201 Hamilton Blvd.,
Allentown, PA 18195, USA
Tel: +1 610 481 4911
www.airproducts.com/compound

MicroChem Corp
1254 Chestnut St. Newton,
MA 02464, USA
Tel: +1 617 965 5511
Fax: +1 617 965 5818
www.microchem.com

Praxair Electronics
(see section 5 for full contact details)

8 Wafer processing equipment

EV Group
DI Erich Thallner Strasse 1,
St. Florian/Inn, 4782,
Austria
Tel: +43 7712 5311 0
Fax: +43 7712 5311 4600
www.EVGroup.com
Technology and market leader for wafer processing equipment. Worldwide industry standards for aligned wafer bonding, resist processing for the MEMS, nano and semiconductor industry.

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

Oxford Instruments Plasma Technology
(see section 6 for full contact details)

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

SAMCO International Inc
532 Weddell Drive,
Sunnyvale,
CA,
USA
Tel: +1 408 734 0459
Fax: +1 408 734 0961
www.samcointl.com

SPTS Technology Ltd
Ringland Way,
Newport NP18 2TA,
UK
Tel: +44 (0)1633 414000
Fax: +44 (0)1633 414141
www.spts.com

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

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

9 Materials & metals

Goodfellow Cambridge Ltd
Ermine Business Park,
Huntingdon,
Cambridgeshire
PE29 6WR,
UK
Tel: +44 (0) 1480 424800
Fax: +44 (0) 1480 424900
www.goodfellow.com
Goodfellow supplies small quantities of metals and materials for research, development, prototyping and specialised manufacturing operations.

10 Gas and liquid handling equipment

Air Products and Chemicals Inc
(see section 7 for full contact details)

Cambridge Fluid Systems
12 Trafalgar Way, Bar Hill,
Cambridge CB3 8SQ,
UK
Tel: +44 (0)1954 786800
Fax: +44 (0)1954 786818
www.cambridge-fluid.com

CS CLEAN SYSTEMS AG
Fraunhoferstrasse 4,
Ismaning, 85737,
Germany
Tel: +49 89 96 24 00 0
Fax: +49 89 96 24 00 122
www.cscleansystems.com

SAES Pure Gas Inc
4175 Santa Fe Road,
San Luis Obispo,
CA 93401,
USA
Tel: +1 805 541 9299
Fax: +1 805 541 9399
www.saesgetters.com

11 Process monitoring and control

k-Space Associates Inc
2182 Bishop Circle
East, Dexter,
MI 48130,
USA
Tel: +1 734 426 7977
Fax: +1 734 426 7955
www.k-space.com
k-Space Associates Inc specializes in in-situ, real-time thin-film process monitoring tools for MBE, MOCVD, PVD, and thermal evaporation. Applications and materials include the research and production line monitoring of compound semiconductor-based electronic, optoelectronic, and photovoltaic devices.

KLA-Tencor
One Technology Dr,
1-2221I, Milpitas, CA 95035, USA
Tel: +1 408 875 3000
Fax: +1 408 875 4144
www.kla-tencor.com

LayTec AG
Seesener Str. 10–13,
10709 Berlin,
Germany
Tel: +49 30 89 00 55 0
Fax: +49 30 89 00 180
www.laytec.de
LayTec develops and manufactures optical in-situ and in-line metrology systems for thin-film processes with particular focus on compound semiconductor and photovoltaic applications. Its know-how is based on optical techniques: reflectometry, emissivity corrected pyrometry, curvature measurements and reflectance anisotropy spectroscopy.

WEP (Ingenieurbüro Wolff für Elektronik- und Programmentwicklungen)
Bregstrasse 90, D-78120
Furtwangen im Schwarzwald,
Germany
Tel: +49 7723 9197 0
Fax: +49 7723 9197 22
www.wepcontrol.com

12 Inspection equipment

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

13 Characterization equipment

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

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

14 Chip test equipment

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

15 Assembly/packaging materials

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

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

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

Materion Advanced Materials Group
2978 Main Street,
Buffalo, NY 14214,
USA
Tel: +1 716 837 1000
Fax: +1 716 833 2926
www.williams-adv.com

16 Assembly/packaging equipment

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

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

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

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

17 Assembly/packaging foundry

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

18 Chip foundry

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

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

19 Facility equipment

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

20 Facility consumables

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

21 Computer hardware & software

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

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

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

22 Used equipment

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

23 Services

Henry Butcher International
Brownlow House, 50–51
High Holborn, London WC1V 6EG,
UK
Tel: +44 (0)20 7405 8411
Fax: +44 (0)20 7405 9772
www.henrybutcher.com

M+W Zander Holding AG
Lotterbergstrasse 30,
Stuttgart,
Germany
Tel: +49 711 8804 1141
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
1346 The Alameda,
7140 San Jose, CA 95126, USA
Tel: +1 408 289 9555
www.alshuktz.com

SEMI Global Headquarters
3081 Zanker Road,
San Jose, CA 95134, USA
Tel: +1 408 943 6900
Fax: +1 408 428 9600
www.semi.org

Yole Développement
45 rue Sainte Geneviève,
69006 Lyon, France
Tel: +33 472 83 01 86
www.yole.fr

event calendar

If you would like your event listed in *Semiconductor Today*'s Event Calendar, then please e-mail all details to the Editor at mark@semiconductor-today.com

27–29 January 2016
SEMICON Korea 2016
COEX, Seoul, South Korea
E-mail: semiconkorea@semi.org
www.semiconkorea.org/en

2–4 February 2016
13th annual Solid-State Lighting (SSL) R&D Workshop
Raleigh, NC, USA
E-mail: SSLRandD2016@yesevents.com
http://energy.gov/eere/ssl/2016-ssl-rd-workshop

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

20-24 March 2016
Optical Fiber Communication Conference and Exposition (OFC 2016)
Anaheim Convention Center, CA, USA
E-mail: OFC@compusystems.com
www.ofcconference.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:

advertisers' index

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 & Circuits
Hilton Hawaiian Village, Honolulu, HI, USA
E-mail: vlsi@vlsisymposium.org
www.vlsisymposium.org

22–24 June 2016
Intersolar Europe
Messe München, Germany
E-mail: info@intersolar.de
www.intersolar.de

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
E-mail: secretary2016@csw-jpn.org
www.csw-jpn.org

11–14 July 2016
Intersolar North America (co-located with ees North America and SEMICON West)
San Francisco, CA, USA
E-mail: info@intersolar.us
www.intersolar.us

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

6–7 September 2016
2nd International Forum on Sapphire Market & Technologies
Shenzhen, China
E-mail: veyrier@yole.fr
www.i-micronews.com/events/yole-events/eventdetail/142/-/2nd-int-forum-on-sapphire-market-technologies.html
alongside:
6–9 September 2016
18th China International Optoelectronic Exposition (CIOE 2016)
Shenzhen Convention & Exhibition Center (SZCEC), China
E-mail: cioe@cioe.cn
www.cioe.cn/en

7–9 September 2016
SEMICON Taiwan 2016
Taipei Nangang Exhibition Center, Taiwan
E-mail: semicontaiwan@semi.org
www.semicontaiwan.org

2–6 October 2016
29th IEEE Photonics Conference (IPC 2016)
Waikoloa, Hawaii, USA
E-mail: c.c.scott@ieee.org
www.ipc-ieee.org

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