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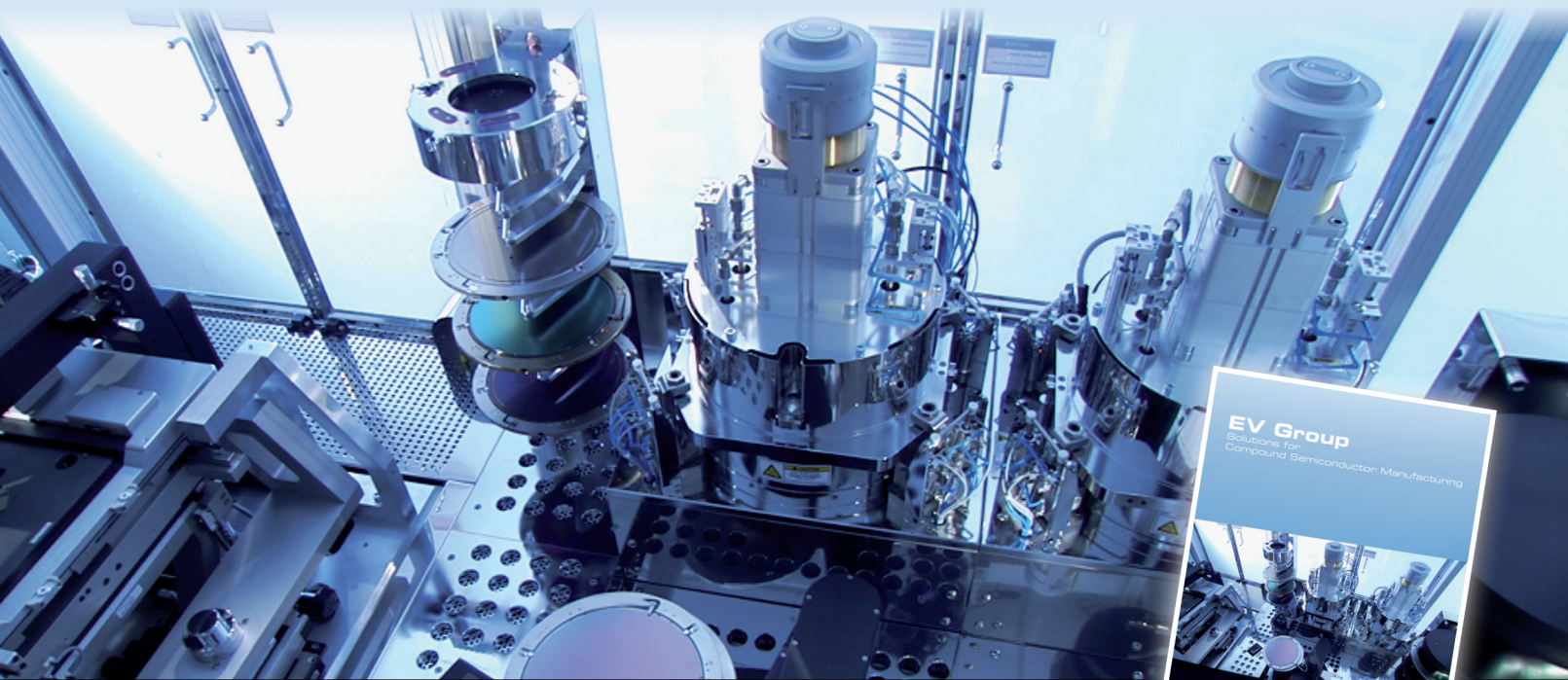

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COMPOUNDS & ADVANCED SILICON

Vol. 10 • Issue 6 • July/August 2015

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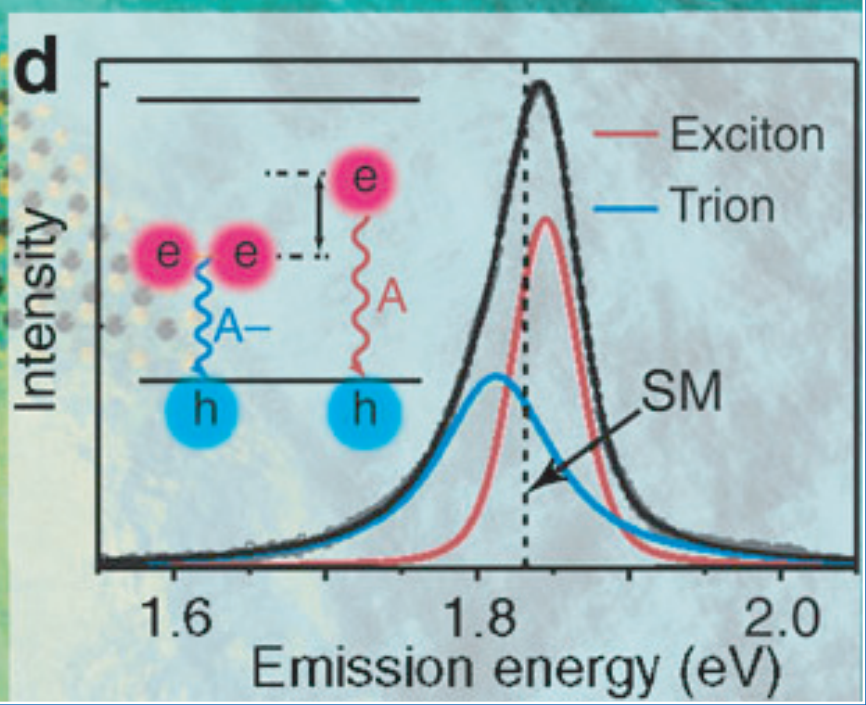
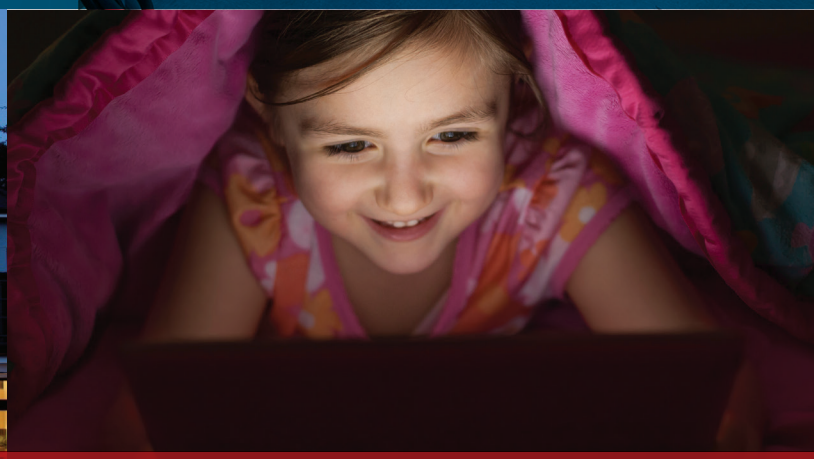
VLSI Symposium — III-V channels on silicon

Developments in 2D materials



Anadigics to make POET's VCSELs • AXT acquires Crystacomm
Seoul Viosys takes over SETi • TSMC ends CIGS PV production

Lower Cost LEDs



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Veeco's New TurboDisc EPIK700 GaN MOCVD System

contents

semiconductorTODAY
COMPOUNDS & ADVANCED SILICON

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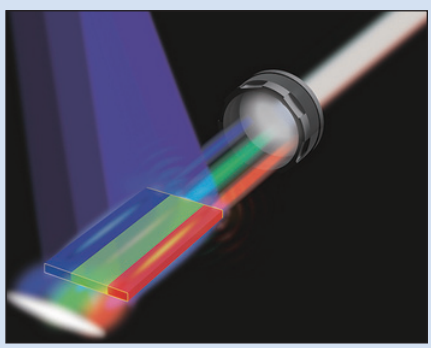
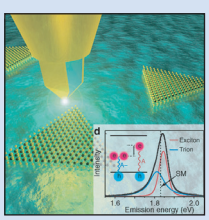
p54 A new 810nm infrared LED from Osram Opto, developed for mobile iris scanning, has been presented with the Kaiser Friedrich Research Award.

p56 University of Delaware has received a $1m grant from the W.M. Keck Foundation to explore turning low-energy colors of light (such as red) into higher-energy colors (blue or green).



p76 Arizona State University has proven that monolithic semiconductor lasers can emit over the full visible color spectrum to yield white light.



Cover: Berkeley Lab's Campanile nano-optical probe reveals effects of illumination — at the molecular level — on 2D semiconductors, specifically MoS_2, a transition-metal dichalcogenide, whose optoelectronic properties hold great promise for future nanoelectronic and photonic devices. **p84**

editorial

Mixing and matching materials

On pages 88–93 of this issue we report on the recent VLSI Symposium, highlighting presentations on developing indium gallium arsenide and other III-V compound semiconductors as high-mobility channel materials in field-effect transistors on silicon wafers for mainstream CMOS electronics.

This includes work by IBM on two ways of integrating InGaAs-on-insulator: direct wafer bonding (DWB) and confined epitaxial lateral overgrowth (CELO). The latter was used to fabricate gate-first self-aligned fin-FETs.

Also, on pages 74–75 we report how Sweden's KTH-Royal Institute of Technology has used corrugated epitaxial lateral overgrowth (CELOG) to create heterojunctions of n-type indium phosphide (n-InP) on p-type silicon, in this case to create photodiodes for low-cost, high-efficiency solar cells or for photonic integration of III-Vs on silicon.

Meanwhile, POET Technologies Inc — which has developed the planar optoelectronic technology (POET) platform for monolithic fabrication of integrated III-V-based electronic and optical devices — has entered into a manufacturing services agreement with GaAs-based manufacturer Anadigics Inc for vertical-cavity surface-emitting laser (VCSEL) process transfer and manufacturing (see page 10).

Another traditionally GaAs-based RF chip maker diversifying to emerging technologies is Qorvo, which says it is doubling its manufacturing capacity for gallium nitride (GaN)-based monolithic microwave integrated circuits after scaling from 4-inch to 6-inch silicon carbide wafers (see page 29).

A sign of the transition of GaN MMICs into the commercial sector is that Belgium-based research center Imec has extended its GaN-on-silicon R&D initiative, and is now offering industrial partners the opportunity for joint research on GaN-on-Si 200mm epitaxy and enhancement-mode device technology (see page 26).

In extension to power electronics applications, at the VLSI Symposium, Intel reported exploring "for the first time" the potential of gallium nitride transistors for low-power-consumption mobile system-on-chip (SoC) electronics (rather than the established high-voltage power switching and radio-frequency amplification applications), using normally-off enhancement-mode MOS-HEMTs (rather than normally-on depletion-mode Schottky-gate HEMTs).

Also signifying how the mainstream silicon-focused industry is increasingly responding to the overlapping of silicon and compound semiconductor technology, SEMI China (the China branch of industry association Semiconductor Equipment and Materials International) has announced the establishment of a Power and Compound Semiconductors Committee, which held its kick-off meeting in Shanghai on 28 July (page 30).

Although reflective of a year-on-year drop in its LED segment as a proportion of its equipment revenue (from 75% in first-half 2014 to just 24% in first-half 2015), MOCVD system maker Aixtron has seen rises from 5% to 19% for power electronics and 8% to 32% for silicon (page 36).

In addition, at VLSI Symposium, MIT presented papers on molybdenum disulfide (MoS_2) devices, including one with Imec and KULeuven, for 'beyond silicon' microelectronics. We also report South Korean work on fabricating transistors from fellow transition-metal dichalcogenide two-dimensional semiconductor material molybdenum ditelluride ($MoTe_2$) (page 86) and Berkeley Labs' study of MoS_2 for opto applications (page 84).

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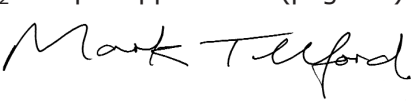

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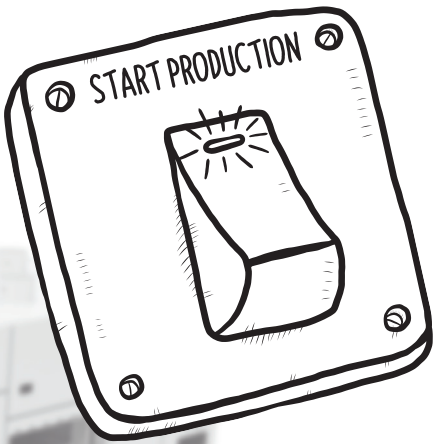

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LED prices to stabilize in Q3, before falling again in Q4

LED chip and packaging service prices fell 10-17% in first-half 2015

After prices for LED chips and packaging services fell 10–17% in first-half 2015, prices are expected to be stable in third-quarter 2015 due to peak demand, but may fall again in fourth-quarter 2015 and first-quarter 2016 due to slow demand, according to Taiwan-based LED makers, reports Digitimes.

Prices in first-half 2015 were affected by a slowdown in the industry coupled with China-based LED makers unleashing new capacity. Manufacturers consequently competed for orders through lowered price quotes, which also affected profits of various LED makers. LED 2835 products saw average price declines of 10–17%, exceeding the 10% price decline for packaging.

Heading into third-quarter 2015, these trends will balance due to a heating up in the market, but the fourth quarter is likely to see a slowing down again, it is reckoned. Going into 2016, in order to save on costs, manufacturers aim to reduce packaging sizes and the number of LEDs used in various applications, most notably for 2835 products, in an effort to reduce the effects of the price decline.

Prices in first-half 2015 were affected by a slowdown in the industry coupled with China-based LED makers unleashing new capacity. Manufacturers consequently competed for orders through lowered price quotes, which also affected profits of various LED makers

For the LED backlighting market, growth in 2015 has been slower than expected because end-market demand picked up much later and changes were made to China's LED subsidy policy. LEDs for direct-type TV applications experienced the greatest price decline in the second quarter, with 3030, 2835, 3535 and 3228 package types falling to US$0.25–0.30/unit. LED package prices for mid-range and low-end TVs has dropped by nearly 6% each quarter. In particular, 7020 packages (mainstream for edge-type TV application) are priced at US$0.085–0.095/unit, according to a recent report from market research firm LEDinside.

www.digitimes.com

LED components market in Japan to grow at compound annual growth rate of 9.3% to 2019

The LED components market in Japan is rising at a compound annual growth rate (CAGR) of 9.3% during 2014–2019, according to the report 'LED Components Market in Japan 2015-2019' from market research firm Technavio.

The Asia-Pacific region (APAC) is the major producer of LED components and is home to the four main manufacturing countries: Japan, Taiwan, China and South Korea (which account for an 83% share of the market).

Vendors are continuously enhancing lighting technology for LEDs to compete with organic light-emitting diodes (OLEDs). This advance in lighting should enable manufacturers to increase the efficiency and durability of LED components. The advance will also aid features such as voltage, consumption, and conductivity in the end-products. For example, the average luminous efficiency of high-end products is about 150lm/W. Vendors from other regions have produced more than 170lm/W, but components in Japan are slowly spanning the defined range, leading to steady growth in the market.

Since LEDs are energy saving and contain features that enhance sustainability, the Japanese government has proposed policy incentives to accelerate LED product promotion and encourage the use of LED lighting products, notes the report. The government has rolled out national policies to provide tax breaks to small- and medium-size enterprises (SMEs) on the purchase of energy-saving products, leading to growing margins for manufacturers. Also, many local governments (including Tokyo and Chiyoda) have launched subsidy programs wherein companies purchasing energy-saving products in accordance with the specified standards can apply for grants to install one-fifth of the amount.

Further, rising competition from countries such as China is one of the major challenges faced by vendors in the LED component market in Japan, says the report.

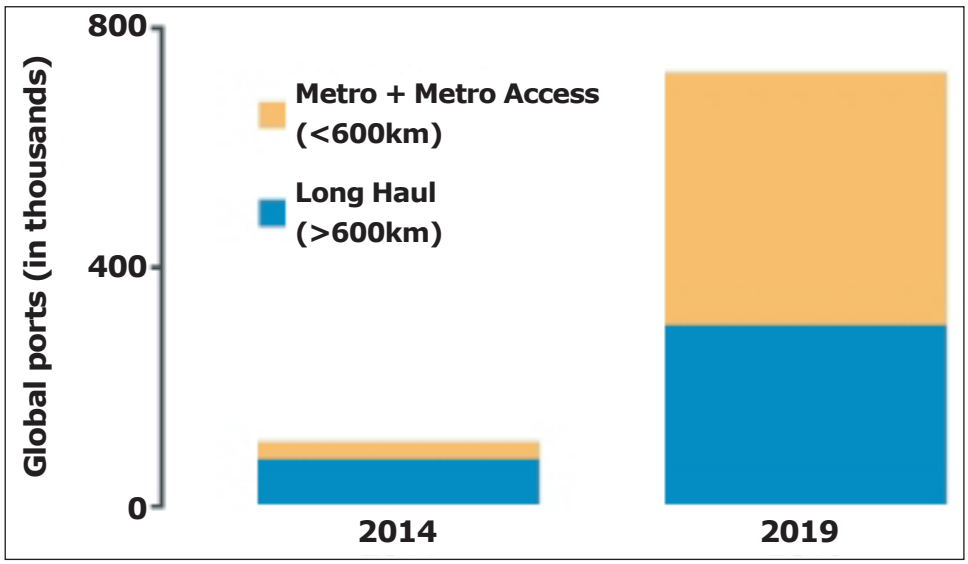
Key vendors covered include Epistar, Everlight Electronics, Huga Optotech, and Lite-On Optoelectronics. Other prominent vendors include Kingbright Electronics, Lextar Electronics, Opto Tech, Taiwan Semiconductor Manufacturing Co (TSMC), and Techcore.

www.technavio.com/report/led-components-market-in-japan-2015-2019

Coherent 100G port shipments to grow 118% in 2015 as operators increase network capacity

Shipments of coherent 100G ports for metro regional optical networks grew 145% year-on-year in 2014 and will grow another 118% in 2015, forecasts market research firm IHS.

Led by massive purchases in China from China Mobile, 2014 was a banner year for 100G port shipments. "Adoption of 100G coherent technology has surged, first in long-haul networks and now becoming a material part of metro networks," says Andrew Schmitt, research director for carrier transport networking. "The expansion of 100G into new markets was the catalyst for our '100G+ Coherent Optical Equipment Ports' report," he adds.



Long-haul versus metro and access in 100G+ coherent optical equipment ports.

Most 100G coherent technology deployed in 2014 was for long-haul applications, but metro regional (<600km) and metro access (<80km) applications will start ramping in 2016. "100G is poised to explode in 2016 as new equipment built specifically for the metro reaches the market, allowing 100G technology to economically reach new portions of the network such as metro edge and metro regional," Schmitt says.

IHS notes that 100G market share is concentrated in a small group of players: Alcatel-Lucent, Ciena, Huawei, Infinera and ZTE. The only potential catalyst for shifts will come from deployment in shorter-reach metro and data-center applications — the next growth vector for 100G, the firm believes.

Also, sometime in 2017–2018, 100G coherent will make another quantum jump, displacing 10G in the 80km or less metro-access market, IHS concludes.

www.infonetics.com

Optical network equipment spending in Europe up 8% year-on-year in Q2

Global market flat year-on-year, but up 22% on Q1

Global optical network hardware revenue (WDM and SONET/SDH) in second-quarter 2015 was up 22% on first-quarter 2015 but flat on a year ago, according to the Q2/2015 edition of the quarterly IHS Infonetics Optical Network Hardware report. Europe is the only major world region that posted positive year-on-year growth, up 8%.

"With three consecutive quarters of good results, Europe is signaling a reversal of the terrible optical spending that we've seen in the region over the last five years," says analyst Andrew Schmitt, research director for carrier transport networking at market research firm IHS. "This strength is concentrated in Alcatel-Lucent, Ciena and Infinera," he adds.

"When taking into account currency effects, the results are even stronger - adjusted for exchange rate, optical spending in Europe saw a 30% year-over-year growth rate in the second quarter when measured in euros," Schmitt notes.

In the Asia-Pacific region, spending on optical network hardware in Q2 surged 36% from last quarter, but was down 2% year-on-year.

The report examines the vendors, markets and trends related to metro and long-haul WDM and SONET/SDH equipment used to build optical networks. It also tracks Ethernet optical, SONET/SDH/POS and WDM ports. On a rolling four-quarter basis, spending on WDM equipment further extended 3 years of consecutive growth, with Q2 up 23% on last quarter and up 6% on a year ago (comprising 86% of total worldwide optical hardware revenue in Q2).

Vendors tracked by the report include Adtran, Adva, Alcatel-Lucent, Ciena, Cisco, Coriant, Cyan, ECI, Fujitsu, Huawei, Infinera, NEC, Padtec, Transmode, TE Connectivity, Tyco Telecom, and ZTE. During Q2/2015, Alcatel-Lucent (ALU) announced its intention to merge with Nokia, which IHS does not expect to have any transformative effects on ALU's optical business or the competitive landscape.

www.infonetics.com

Visible light communication market to more than double annually to $113bn in 2022

The global market for visible light communications (VLC) — an emerging technology that uses visible light (between 400 and 800THz of electromagnetic spectrum) from light-emitting diodes (LEDs) as a communication medium — will rise from $267.6m in 2014, at a compound annual growth rate (CAGR) of 109.2% from 2015, to $113,273.4m by 2022, forecasts Transparency Market Research in its report 'Visible Light Communication Market — Global Industry Analysis, Size, Share, Growth, Trends and Forecast 2015 – 2022'. North America was the largest market in 2014, accounting for 43.4% of revenue.

Swelling demand for radio frequency communication resulting in spectrum constraint is fueling demand for visible light communication as a complementary technology. Features such as safety, higher energy efficiency and minimal interference are cementing the growth of the visible light communication market, says the market research firm. In particular, the visible light communication market has lately witnessed increasing demand for VLC solutions in the retail industry, due to its use in targeted advertisements and location-based services.

The Asia Pacific region is expected to be the fastest-growing market for visible light communication in terms of revenue during the forecast period. Growth in this region is attributed primarily to increasing R&D investment in countries such as Japan, China and Korea, which are expected to pave the way for novel applications. Further, the energy efficiency of VLC networks is expected to drive demand for visible light communication in emerging regions.

The expected rise in adoption of VLC across all the regions would help to augment the growth rate in the near term with marginal steadiness reflecting the mid to long term of the forecast period. The Asia Pacific is estimated to dominate in terms of growth rate, while North America will see higher revenue contribution throughout the forecast period, the report forecasts.

Collaboration by vendors with research institutions for extensive R&D is the key trend seen in the market, says the firm. Likewise, LED OEMs in the visible light communication market are focusing on partnering with VLC solution developers and vice-versa.

Such collaborations will help to overcome existing barriers in the market such as the lack of standardization and the difficulty in upgrading existing LED lighting for VLC communication, reckons the report. Researchers are constantly testing new solutions and overcoming the existing barriers, which is further expected to boost demand for VLC solutions in the near future.

Demand for RF communication resulting in spectrum constraint is fueling demand for visible light communication as a complementary technology. Safety, higher energy efficiency and minimal interference are cementing the growth. The visible light communication market has lately witnessed increasing demand for VLC solutions in the retail industry, due to its use in targeted advertisements and location-based services

In 2014 in terms of revenue, the largest market segment by end-user application was retail indoor positioning, contributing 57.5%. By data rate and by reach, the market was dominated by the segments up to 1Mb/s and up to 10m, each accounting for about 80% of revenue.

In terms of communication type, due to challenges in uplink communication, the bi-directional visible light communication market has not been able to see as swift adoption as that of unidirectional communication. However, with technical advances negating the impact of these challenges, the bi-directional segment is expected to overtake the unidirectional visible light communication market over the forecast period.

The bi-directional VLC market should also see demand surge with growing implementation across connected devices.

Connected devices are expected to form the highest-growing segment over the forecast period as mobile companies are striving to integrate visible light communication technologies in their smartphones. So, with new opportunities emerging across the VLC market, lighting companies are also exploring their options to tap into the lucrative growth potential provided, adding to long-term VLC market growth.

Light-based Internet communication was the emerging VLC application in 2014, with major activity seen in Japan and the USA, accounting for 39.2% of global VLC market revenue. However, the penetration of visible light communication technology is currently quite low and is expected to rise with the increasing adoption of LED lighting applications.

In order to leverage the potential revenue opportunities, leading players are focusing on offering bi-directional high-speed visible light communication solutions covering large distances in various applications, notes the report.

www.transparencymarketresearch.com/visible-light-communication-market.html

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Anadigics' revenue falls 14.4% to $15.8m in Q2, as Mobile revenue drops 32.3%

Delay in DOCSIS 3.1 ramp suppresses CATV infrastructure growth

For second-quarter 2015, broadband wireless and wireline communications component maker Anadigics Inc of Warren, NJ, USA has reported revenue of $15.8m, down 14.4% on $18.4m last quarter (towards the high end of the expected 10–15% drop) and down 32% on $23.3m a year ago.

Mobile revenue was $4.3m, down 32.3% (more than the expected 20–25%) on $6.4m last quarter and down 67% on $13.1m a year ago (falling from 56% of total revenue a year ago then 35% last quarter to just 28% now). The decline from Q1 was due largely to a steeper-than-expected roll-off of non-strategic mobile cellular business.

Infrastructure revenue was $11.5m, up 12.6% on $10.2m a year ago but down 4.7% (better than the expected 7–9%) on $12m last quarter (although still rising further from 44% of total revenue a year ago then 65% last quarter to 72% now). The drop in revenue from Q1 is due mostly to Wi-Fi (as the key customer digested excess inventory) and small-cell (which was expected to slow over delays at key carriers in Asia). "Despite market softness in small-cell and some temporary excess customer inventory to work through in WiFi, we experienced only a modest sequential decline in total infrastructure revenue," says chairman & CEO Ron Michels. Partly offsetting this sequential decline in both Wi-Fi infrastructure and small-cell, CATV revenue grew by over 20% sequentially. For example, in mid-May Global Technology selected Anadigics' infrastructure line amplifier for DOCSIS 3.1 equipment.

As expected since announcing its plan to shift from Mobile to Infrastructure a little over a year ago, (1) Mobile revenue has declined; (2) new Infrastructure revenue has ramped up; (3) the number of wafers needed from the fab has fallen, allowing fixed costs to be streamlined; (4) the development of Anadigics' vertical-cavity surface-emitting laser (VCSEL) manufacturing technology has expand its business and made more efficient use of the wafer fab.

Mobile revenue has declined, but faster than anticipated. Infrastructure revenue for new products has grown, but at a slower pace than anticipated

"The challenge however is that the timing has not quite aligned to our original expectations," says Michels. First, Mobile revenue has declined, but at a faster rate than anticipated. Second, Infrastructure revenue for new products has grown, but at a slower pace than anticipated. "We can attribute much of this to the delay in the DOCSIS 3.1 transition and the deployment of small-cell networks worldwide," he adds.

"We've made tremendous progress streamlining our wafer fab operations to better match our business model," says Michels. "However, with the faster Mobile decline and slower Infrastructure growth, there remains more unused fab capacity than anticipated [fab utilization fell from 32% in Q1 to just 25% in Q2]. If used wisely, the available fab capacity can create very favorable operating leverage. However, in the near-term the additional fixed cost burden weighs on the profit & loss."

On a non-GAAP basis, gross margin fell from 23.2% last quarter to 20.5%, due to the lower revenue and the sell-through of legacy mobile products from existing inventory that did not require replacement (partly offset by the reductions in fixed costs from expense reduction activities). However, this is still nearly double the 12.8% gross margin a year ago.

Operating expenses have been cut further, from $10.7m a year ago and $8.1m last quarter to $7.7m.

Net loss has risen from $3.8m ($0.04 per share) last quarter to $4.5m ($0.05 per share) but, following the prior four consecutive quarters of loss reduction, this is still less than half the $7.8m ($0.09 per share) a year ago. Likewise, earnings before interest, taxes, depreciation & amortization (EBITDA) loss has risen from $1.6m last quarter to $2.5m, but this is still much better than $6.3m a year ago.

Capital investment was about $100,000 (cut further, from $350,000 a year ago). During the quarter, net cash fell from $13m to $11.2m (excluding $4m drawn under the firm's $10m credit facility), reflecting EBITDA loss and the restructuring costs incurred, partly offset by the sell-through of non-strategic legacy mobile inventory.

For third-quarter 2015, Anadigics expects revenue to fall a further 20–24% to $12–12.6m. This reflects a continued decline in mobile revenue of 22–27% due to non-strategic legacy mobile, a decline of 20–23% in Infrastructure revenue due to broad CATV market softness, and a decline in both legacy WiMAX and Internet of Things (IoT) business, and a slow return to small-cell revenue growth due to continued delays at major carriers in Asia. Gross margin is expected to fall by 500–800 basis points. "We are hopeful that both the revenue and gross profit dollars in Q3 will represent a trough," says chief financial officer Terry Gallagher. "We continue to identify ways to operate with a leaner cost structure, especially in light of the infrastructure market softness we anticipate through the end of 2015. As a result, we expect a marginal sequential reduction in operating expenses," he adds.

"When we entered 2015 we envisioned growing our CATV revenue by 30–50%. This was based on a

forecast that US cable companies with ramp purchases of DOCSIS 3.1 equipment and then Anadigics would add a second tier-1 customer in the USA. The ramp of demand for DOCSIS 3.1 equipment has not yet materialized. Many equipment suppliers are reporting a decline in revenue from US cable companies this year," remarks Michels. "While the timing of DOCSIS 3.1 network deployment is outside of our control, our focus is to win sockets in either DOCSIS 3.0 upgrades or early DOCSIS 3.1 systems. We're doing it in the USA, Europe and Asia. We've made great strides with new products with a tier-1 US-based CATV customer, which we think is well positioned to gain significant market share… we will be well positioned to benefit from the ramp of DOCSIS 3.1 demand that is widely forecast to materialize in 2016," he believes.

"While we continue to make progress in our core infrastructure businesses by launching new products, earning new design sockets, and gaining new customers, we expect the widely reported market softness in CATV and small-cell to persist through the end of 2015," says Michels. "We believe the softness in both markets will subside in 2016 as deployments pick up steam. Most importantly, we are prepared with higher design-win penetration and broader customer diversification to meet the demand when strong market growth does, in fact, return," he adds.

"To address the impact any core market softness may have on the company's financials, we are exploring capitalization options that may provide adequate cash infusion over the next 12 months," says Gallagher. "We are already in discussions to revise certain covenants of the existing debt agreement [with Silicon Valley Bank] to maintain access to the capital that that facility provides. If such a cash infusion is secured, the company financials will be adequately strengthened to a level that mitigates any growing concerns that may arise as a result of continued infrastructure market softness," he adds.

"We believe the EBITDA breakeven is achievable at a quarterly revenue level below $19m with fab utilization of approximately only 25–30%," says Gallagher.

"Regarding VCSELs, we expect the business to increase fab utilization," says Michels. "While we were modeling VCSELs to represent only 1–2% of total revenue this year, we are seeing a steady increase in activity and anticipate a ramp in production during 2016."

www.anadigics.com

POET Technologies enters into VCSEL manufacturing services agreement with Anadigics

POET to transfer technology to Anadigics from Q4, for demonstration of integrated VCSEL prototypes in second-quarter 2016

POET Technologies Inc of Toronto, Canada — which, via subsidiary OPEL Defense Integrated Systems (ODIS Inc) of Storrs, CT, USA, has developed the proprietary planar optoelectronic technology (POET) platform for monolithic fabrication of integrated III-V-based electronic and optical devices on a single semiconductor wafer — has entered into a manufacturing services agreement with Anadigics Inc of Warren, NJ, USA for vertical-cavity surface-emitting laser (VCSEL) process transfer and manufacturing.

POET says that the agreement accelerates the transition of its technology from lab-to-fab and enables prototype demonstrations in a mature and capable manufacturing environment. "Anadigics has proven manufacturing capabilities and a long track record of innovation," says POET's CEO Dr Suresh Venkatesan. "Their recent entry into foundry manufacturing for VCSELs was timely for POET," he adds.

Anadigics' custom VCSEL foundry services leverage its proven wafer manufacturing line and toolset to provide scalability. Combined with its test capabilities, the firm's wafer foundry services support the aggressive volume and cost requirements of new VCSEL applications, POET says. Anadigics' VCSEL foundry manufacturing and test capabilities were featured at May's Compound Semiconductor Manufacturing Technology conference (CS ManTech 2015) in Scottsdale, AZ, USA.

"With the industry's first 6" VCSEL wafer fabrication line, Anadigics is able to offer manufacturing excellence and scalability, helping POET Technologies achieve its volume, quality, and reliability goals for the company's innovative optoelectronic devices," comments Anadigics' director of optical products Dr David Cheskis.

POET intends to start transferring its proprietary technology to Anadigics' manufacturing operations in fourth-quarter 2015 and anticipates demonstrating integrated VCSEL prototypes in second-quarter 2016.

"The new management team, along with founder & chief scientific advisor Dr Geoff Taylor, have assessed both internal and outsourced fabrication of POET's disruptive technology and feels that the quickest path to our commercialization goal is through outsourcing," says executive co-chairman Ajit Manocha. "The board of directors has fully endorsed the company's strategy and the prospective path for lab-to-fab-to-commercialization."

www.poet-technologies.com

Qorvo's quarterly revenue grows 6% as mobile products growth outweighs 40% drop in wireless infrastructure

Wireless infrastructure expected to bottom out in September quarter

For fiscal first-quarter 2016 (ended 27 June 2015), Qorvo Inc, a provider of core technologies and RF solutions for mobile, infrastructure and aerospace/defense applications, has reported revenue of $673.6m, up 6% on $633.9m last quarter and up 23% on $547.1m a year ago for the combined revenues for the June 2014 quarter of RF Micro Devices Inc of Greensboro, NC and TriQuint Semiconductor Inc of Hillsboro, OR, USA (following the merger of the two firms on 1 January).

There were two greater-than-10% customers (although the larger, at about 33% of revenue, represented the aggregated demand of multiple subcontractors for this end-customer). The second 10% customer was telecoms equipment maker Huawei Technologies Co Ltd of Shenzhen, China.

Growth was led by Mobile Products revenue of $551m, up 12% on last quarter and 35% on a year ago as Qorvo continues to capture a broad array of opportunities supported by long-term trends. In particular, global demand for broad-based data continues to proliferate while front-end complexity and the performance requirements for RF solutions continue to expand. Despite having seen a slowing among handset customers in China, the country still comprised Qorvo's largest customer by region. "Qorvo has secured excellent growth opportunities in China," notes president & CEO Bob Bruggeworth. For example, during the quarter, Qorvo began shipments of RF Flex integrated front-end transmit and power-amplifier modules to leading China-based smartphone makers.

The strength in Mobile Products was sufficient to offset a 13% drop in Infrastructure & Defense Products (IDP) revenue from $140m last quarter to $122m. This was driven wireless infrastructure – which had comprised about one-third of IDP revenue in the March quarter (i.e. about $45m) – falling sharply by 40% (to less than $25m), due primarily to a pause in LTE base-station deployments. Excluding wireless infrastructure, IDP revenue grew about 9% year-on-year, with sequential strength across all other markets.

Gallium nitride (GaN)-related revenue grew 30% year-on-year, led by strength in both CATV and defense & aerospace markets, where Qorvo claims to be the GaN market leader (having released over 100 GaN products during the past 18 months in both high-power and high-frequency applications, offering what it says is the industry's broadest portfolio of GaN capabilities with advanced low-cost packaging techniques). During the quarter, Qorvo sampled GaN custom macrocell power amplifiers to major base-station customers. "We continue to see GaN as a disruptive technology, displacing silicon LDMOS," says Bruggeworth.

On a non-GAAP basis, gross margin has risen from 44.8% a year ago (for RFMD and TriQuint combined) and the record 50.4% last quarter to 51.5%, reflecting favorable product mix and the realization of cost synergies.

The realization of synergies allowed Qorvo to grow investment in product and process development while making progress towards its operating expense model. Operating expenses grew from $150.2m last quarter to $158.7m. However, year-on-year, operating expenses grew at half the rate of revenue growth, as synergies realized in general & administrative (G&A) spending were balanced by investments in R&D rising by 19%.

Operating income has risen from $103.2m a year ago (for RFMD and TriQuint combined) and $169.6m (operating margin of 26.8%) last quarter to $187.8m (operating margin of 27.9% of sales, representing good progress towards the full-year goal of 30%). This dramatic improvement was led in particular by Mobile Products which, on a preliminary basis, surpassed its operating model of 30% operating margin. "That is all the more impressive when you consider our Mobile Products portfolio in June consisted entirely of legacy RFMD and TriQuint parts, and we've yet to in-source legacy TriQuint assembly, our largest cost synergy," notes Bruggeworth.

Net income was $168.5m ($1.09 per diluted share, at the high end of the $1–1.10 guidance), up from $167.2m ($1.11 per diluted share) last quarter.

Cash flow from operations was $141.4m (up on $138m last quarter). Capital expenditure was $89.4m, primarily to address continued growth in demand for premium filters. Free cash flow was hence $52m. Also during the quarter, Qorvo repurchased about 602,000 shares of its common stock at an average price of $83.10 per share (a total cost of $50m). Overall, total cash and investments rose from $544.6m to $558m.

For fiscal second-quarter 2016 (ending 3 October 2015), Qorvo expects revenue to rise by 4% sequentially to $690–710m, driven by growth in Mobile Products since IDP revenue will be flat as a result of wireless infrastructure falling further due to the soft LTE base-station market (although it is bottoming out, feels IDP Group president James Klein). Also, some customers in China have a few weeks of excess inventory to digest. Gross margin should fall back slightly to 50–51%. Diluted earnings per share (EPS) is expected to be $1.05–1.15.

"The wireless infrastructure market remains a great market where

Qorvo can do extremely well," says Bruggeworth. "We are looking forward to the return of the wireless infrastructure market, and we're bringing out new GaN and SOI products to support this market and the continued global roll-out of 4G networks," he adds. In GaN, Qorvo is transitioning to 6-inch wafers in its Texas fab this year.

"We are designing and developing an increasing number of differentiated system-level RF solutions that integrate our legacy capabilities," says Bruggeworth. "These new Qorvo solutions, which include receive diversity modules, Wi-Fi integrated front-end modules, and silicon-on-insulator (SOI) infrastructure switches, are expected to contribute meaningfully to revenue next calendar year," he adds. Some early examples during the June quarter include the BAW-based high-band RF Fusion, which secured multiple design wins in flagship smartphones and with leading LTE reference designs, and the recently introduced BAW-based RF Fusion mobile Wi-Fi iFEM (integrated front-end module) for a flagship Android smartphone, which was announced last quarter and has now already received production orders. Qorvo has also received the first production orders for high-performance low-noise amplifiers (LNAs) from a leading smartphone maker.

"Add in the substantial synergies yet to come, and we feel confident we can hit our model while making substantial investments in the process technologies and great products that sustain and enhance our competitive advantage," says Bruggeworth. "We expect to finish the calendar year very strong, and we believe calendar 2016 will be an even stronger year."

www.qorvo.com

Qorvo completes $200m share repurchase program; board approves additional $400m program

Qorvo has completed its $200m share repurchase program (authorized by its board of directors in February), under which the firm repurchased about 3.1 million shares of common stock at an average price of $63.80 per share.

Qorvo also announced that its board has authorized a new share repurchase program to repurchase up to $400m of its common stock.

"Qorvo has excellent long-term growth prospects, a healthy balance sheet and the ability to generate increasing free cash flow," says president & CEO Bob Bruggeworth. "The Qorvo board of directors and management team believe the repurchase of our common stock is an excellent use of capital that creates additional value for our stockholders."

Under the new program, share repurchases will be made in accordance with applicable securities laws either on the open market or in privately negotiated transactions. The extent to which Qorvo repurchases its shares, the number of shares, and the timing of any repurchases will depend on general market conditions, regulatory requirements, alternative investment opportunities and other considerations. The program does not require Qorvo to repurchase a minimum number of shares, and it may be modified, suspended or terminated any time without notice.

Qorvo's Richardson location wins Corporate Innovation Award from Metroplex Technology Business Council

On 21 August at the Tech Titans 15th Anniversary Gala, Qorvo Inc (a provider of core technologies and RF solutions for mobile, infrastructure and aerospace/defense applications) received the Corporate Innovation award for its development of RF solutions and investment in the city of Richardson, Texas.

Organized by the Metroplex Technology Business Council (MTBC, the largest technology trade association in Texas), the Tech Titans Awards celebrate the achievements of leaders from over 4000 tech firms.

The Corporate Innovation award recognizes technology companies for outstanding innovation and unique accomplishments for breakthrough technology within the industry. MTBC's Tech Titan event recognizes key influencers in North Texas that are impacting the technology and community through achievements that give their organization a competitive edge.

"Qorvo is driving RF innovation for mobile applications with our industry-leading bulk acoustic wave (BAW) technology," says Howard Witham, VP of Texas Operations at Qorvo.

Due to the demand for BAW filter technology, Qorvo is expanding its manufacturing facility in Richardson. The expansion will result in a major investment in the community, creating over 200 manufacturing and equipment technician jobs.

Qorvo's Richardson, Texas location is the headquarters for the firm's Infrastructure and Defense Products group, and manufactures the building blocks of RF components including gallium nitride (GaN), gallium arsenide (GaAs), surface acoustic wave (SAW) and bulk acoustic wave (BAW), all of which help solve many of the challenges for defense and aerospace applications as well as wired and wireless connectivity.

www.techtitans.org
www.qorvo.com

Skyworks expands filter operations in Japan

Osaka facility to house design, development and manufacturing, complementing front-end solutions and assembly, test & packaging

Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) is expanding production capacity in Japan to meet growing demand for its filter technology.

Skyworks is facilitizing a two-storey 405,000ft^2 facility in Osaka that will house the design, development and manufacture of filter devices to complement its front-end solutions and assembly, test & packaging capabilities. The facility will be fully operational by September.

Skyworks reckons that, with the additional capacity, it is well positioned to offer differentiated architectures for the most demanding customer applications where high-performance filter technology is required — addressing the stringent technical challenges associated with tighter band spacing and coexistence across low-, mid- and high-band LTE frequencies.

High-performance filter technology is required — addressing the stringent technical challenges associated with tighter band spacing and coexistence across low-, mid- and high-band LTE frequencies

"Skyworks' investment in filter capacity reflects our commitment to delivering the world's most highly integrated, cost-efficient and shortest cycle-time front-end solutions," says chairman & CEO David J. Aldrich. "Given the increasing importance of filters to our target markets and customers, we are expanding our internal capability to meet current and future demand in a world-class environment," he adds. "At a higher level, our enhanced capability aligns with our unique business model of combining above-market top-line growth with the best-in-class financial returns of a diversified analog semiconductor company," he adds.

www.skyworksinc.com

Skyworks providing RF content for D-Link's Wave 2 Wi-Fi routers

Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) says that it will be the exclusive provider of RF content powering D-Links' next-generation 802.11ac Wave 2 devices.

The AC5300 (DIR-895L/R) and AC3150 (DIR-885L/R) ultra Wi-Fi routers support tri-band 2.4 and 5GHz technology, multiple-user multiple input multiple output (MIMO) and deliver wireless speeds up to 5.3Gbps and 3.2Gbps, respectively. The DIR-895L/R is said to be the world's fastest router, facilitating uninterrupted, high-definition multimedia streaming in the home.

"As new technologies emerge and more devices become connected within the home, consumers are demanding reliable, high-speed wide-area network connections to carry data, voice, video and multimedia content simultaneously," says D-Link's chief technology officer AJ Wang. "By leveraging Skyworks' leading-edge Wave 2 connectivity solutions, we are able to offer customers the world's fastest networking speeds and Wi-Fi connections for every type of mobile device," he adds.

According to a Cisco Visual Networking Index Forecast in May, by 2019 fixed networking devices such as routers will handle about 82% of all consumer Internet traffic, with total Internet traffic increasing at a compounded annual growth rate (CAGR) of 33% from 2015 to 2019. By leveraging networking technology from Skyworks and D-Link, users can support applications and devices with ever increasing bandwidth demands, says Skyworks.

Skyworks' networking solutions include the following devices:

- SKY85201-11 and SKY85605-11 are integrated single-pole double-throw (SPDT) switches with a low-noise amplifier (LNA), operating at 2.4–2.5GHz and 4.9–5.9GHz respectively, for wireless applications. The devices have a low noise figure, offer the ability to add custom filtering between the switch and LNA blocks and operate at 3.3V, drawing low current with what is claimed to be class-leading IIP3. The small footprint provides the industry's smallest PCB area needed to implement an integrated broadband SPDT switch with LNA functionality, it is claimed.
- SKY85405 is a high-power 802.11ac WLAN power amplifier with integrated power detector. The device features an internal bandgap regulator that eliminates the need for an external reference supply. Its packaging offers a highly manufacturable, low-cost solution.
- SE2623L-R is a 2.4GHz power amplifier designed for industrial, scientific & medical (ISM) bands for WLAN applications. The device incorporates a power detector for closed-loop monitoring of the output power and includes a digital enable control for device on/off control.

www.skyworksinc.com

MACOM completes divestiture of Automotive business

M/A-COM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) has completed the divestiture of its Automotive business (announced in mid-July) to Autoliv ASP Inc for about $100m in cash, plus the opportunity to receive up to an additional $30m in cash based on the achievement of revenue-and customer-order-based earn-out targets through 2019.

The Automotive business represented about 18% of MACOM's total revenue of $125m in its fiscal second-quarter 2015 (ended 3 April).

In conjunction, excluding the Automotive business (now classified as discontinued operations), for its fiscal fourth-quarter 2015 (ending October) MACOM now expects revenue of $110–114m (up 1–4.5% on fiscal Q3/2015 without Automotive), non-GAAP gross margin of 56–59%, and earnings per diluted share of $0.32–0.34.

Divesting the Automotive business is "a key step towards realizing our full potential as a pure-play high-performance analog semiconductor company

Divesting the Automotive business represents "a key step towards realizing our full potential as a pure-play high-performance analog semiconductor company," says president & CEO John Croteau. "Since announcing the transaction, we have become increasingly confident in the accelerated growth of our business, which we now expect to replace the pre-divestiture earnings contribution from the Auto business within a few quarters," he adds. "With our remaining business well aligned with our high-growth, high-margin model, we expect to achieve our target of 60% non-GAAP gross margin in the first half of fiscal 2016 and 30% non-GAAP operating margin as we exit fiscal 2016. This exceptional financial profile will position MACOM in the highest-performing segment of our industry."

www.autoliv.com
www.macom.com

MACOM showcasing fourth-generation GaN technology for RF energy applications at European Microwave Week

At European Microwave Week (EuMW 2015) in Paris, France (6–11 September), MACOM is showcasing its gallium nitride (GaN) RF product and technology portfolio, including its Gen 4 GaN-on-silicon RF product solutions optimized for commercial, industrial, scientific & medical applications.

At volume production levels, Gen 4 GaN technology is expected to yield devices that achieve breakthrough performance and higher efficiency below the semiconductor cost per watt of comparable LDMOS silicon products, and at significantly lower cost than comparably performing GaN-on-SiC (silicon carbide) wafers.

As a member of the RF Energy Alliance, MACOM is bringing GaN RF technology into mainstream applications, including RF ignition systems, solid-state cooking and high-lumen plasma lighting.

At EuMW, MACOM's booth features a suite of new products aimed at applications spanning industrial, scientific, medical, E-band point-to-point wireless and X-band radar. In particular, the GaN portfolio and live demonstrations on show include:

- Gen4 GaN-on-silicon process, enabling GaN-on-SiC performance below LDMOS cost structures;
- RF energy applications, achieving higher efficiency and excellent gain at a lower cost structure; and
- Multifunction Phased Array (MPAR) panel, supporting challenging civil and military radar applications.

On 9 September, guest speaker Klaus Werner is talking about the future of RF Energy.

In addition, MACOM staff are presenting the following papers on RF & microwave technology:

7 September

- Session EuMIC02-02 — 'Reduced-Size E-Band GaAs Power Amplifier MMIC' by Alex Bessemoulin, Jabra Tarazi, Melissa Rodriguez, M.G. McCulloch, A.E. Parker, Simon Mahon;
- Session EuMIC01-05 — 'Miniaturized Broadband Up-Converter MMIC' by Alex Bessemoulin, Emmanuelle Convert, Simon Mahon, A.E. Parker.

8 September

- Session EuMIC10-03 — 'A Broadband Receiver Protection Limiter for FET Based Integrated Circuits' by Alan Noll, Wayne Struble;
- Session EuMC13-01 — 'A Linearized, High Efficiency 2.6GHz Wideband Doherty Power Amplifier With Class-J Based Performance Enhancement' by Neal Tuffy, Lyndon Pattison.

9 September

- Session EuMIC Poster02-04 — 'GaN Schottky Diodes for RF Wireless Power Detection and Conversion' by Tim Boles, Gary Lopes;
- Session EuMC34-02 — 'Improving upon Pulse-to-Pulse Stability in GaN RADAR Amplifiers Compromised by the Presence of GaN Trapping Effects' by Damian McCann.

10 September

- Session EuMC43-05 — 'Plastic Packaged E-mode Transistors to 50GHz with Integrated ESD Protection and Bias Control' by Alex Bessemoulin.

www.macom.com/EuMW2015
www.eumweek.com

ST's SiGe BiCMOS chosen by European E3NETWORK R&D initiative for integrated E-band transceiver

STMicroelectronics of Geneva, Switzerland says that its BiCMOS55 55nm bipolar complementary metal–oxide–semiconductor silicon germanium (SiGe) technology has been selected by the European R&D initiative E3NETWORK ('Energy-efficient E-band transceiver for backhaul of the future networks') for developing energy-efficient, high-capacity transmission systems in next-generation mobile networks.

Rapidly rising mobile-data usage requires networks to support greater capacity and higher data rates, says the firm. This places new challenges on the backhaul infrastructure, accelerating the transition to advanced network architectures, such as Heterogeneous Network and Cloud RAN (radio access network), and higher frequency bands (such as the E-band, at 71–76 and 81–86GHz), where more spectrum is available to support faster data-rate channels.

To build these super-efficient mobile networks, equipment manufacturers need high-performance electronic components that combine large-scale chip integration, reduced power consumption, and optimized cost, says ST. The E3NETWORK project leverages the integration and power advantages of ST's BiCMOS55 SiGe technology, which delivers heterojunction bipolar transistors (HBT) with a threshold frequency (f_T) up to 320GHz in 55nm lithography. This technology allows the integration of a high-frequency analog section with high-performance, dense digital blocks such as logic, AD/DA converters, and memories.

E3NETWORK is designing an integrated E-band transceiver… for front-haul and back-haul infrastructure, which enables digital multi-level modulations, highly focused 'pencil-beam' transmissions, and data rates above 10Gbps

E3NETWORK is designing an integrated E-band transceiver using ST's BiCMOS55 technology for front-haul and back-haul infrastructure, which enables digital multi-level modulations, highly focused 'pencil-beam' transmissions, and data rates above 10Gbps. The pencil-beam property facilitates a high degree of frequency reuse in the deployment of back-haul and front-haul links, while preserving the spectrum efficiency over the millimeter-wave interval.

An EU project within the Seventh Framework program, E3NETWORK brings together a consortium of companies including CEIT (Spain), Fraunhofer (Germany), Alcatel-Lucent (Italy), CEA (France), INXYS (Spain), OTE (Greece), SiR (Germany), Sivers IMA (Sweden), and STMicroelectronics (Italy).

www.st.com

Guerrilla RF ramping production of ten Ultra-LNA devices; to reach 20 devices by Q4

Guerrilla RF Inc of Greensboro, NC, USA, which provides monolithic microwave integrated circuits (MMICs) to wireless network infrastructure original equipment manufacturers, has received volume production orders for its ultra-low-noise amplifier (Ultra-LNA) devices.

The GRF2051, along with the higher-gain GRF2052, support a wide range of high-performance LNA applications including macro base-stations, small cells, distributed antenna systems (DAS) and other high-performance applications requiring the lowest possible NF along with the highest possible input-referenced linearity.

"These devices showcase our technical capability and allow our customer's systems to achieve maximum receiver sensitivity and dynamic range," says VP of applications & technical marketing Alan Ake. "Their flexible application circuits result in a simple and low-cost implementations that allow for optimal efficiency and re-use," he adds.

According to Research and Markets, the overall wireless network infrastructure market will see tremendous growth over the coming years. Rising at a compound annual growth rate (CAGR) of over 5%, the market will account for more than $104bn in annual spending by the end of 2020.

The GRF2051 is claimed to set the standard for ultra-low noise figure and input-referenced linearity over the 1.7–3.8GHz bands, while the GRF2052 provides a higher-gain, ultra-low-noise-figure alternative over the 2.3–4.5GHz bands. Whether used as first-stage LNAs, linear drivers or cascaded gain blocks, their simple external matching, adjustable current and flexible Vdd allow these devices to be used in multiple locations within a single design or across platforms, says the firm. Offered in 2.0mm x 2.0mm x 0.55mm QFN-12 packages, the GRF2051 and GRF2052 operate at temperatures up to +105C.

Full production is underway. Pricing is $1.37 each in 10,000-unit quantities.

http://guerrilla-rf.com

RFaxis collaborates with Silicon Labs to support Internet of Things and smart home market initiatives

RFAxis's reference designs support Silicon Labs' IP-based Thread wireless mesh networking solution

Fabless semiconductor firm RFaxis Inc of Irvine, CA, USA, which designs RF semiconductors and embedded antenna solutions for wireless connectivity and cellular mobility, is collaborating with Silicon Labs Inc of Austin, TX, USA (which provides analog-intensive, mixed-signal ICs) on chipset reference designs to address the high-growth Internet of Things (IoT) and smart home markets.

Specifically, RFaxis has developed RF front-end reference designs that extend the reach and capabilities of Silicon Labs' ZigBee and Thread EM35x mesh networking products. Silicon Labs is a founding member of the Thread Group that is helping product developers and consumers to easily and securely connect more than 250 devices into a low-power, wireless mesh network that supports seamless Internet and cloud access.

"The RFaxis chipset reference designs provide our mutual customers with fully integrated and cost-effective RF front-ends to meet the needs of a wide variety of products in the connected home," says Greg Fyke, director of marketing for IoT Wireless Products at Silicon Labs.

"The integrated and cost-effective CMOS RF front-end integrated circuit (RFeIC) technology that RFaxis provides combined with Silicon Labs' chips, ZigBee or Thread software and development tools will help spur development of innovative and low-cost IoT products by device makers," says Raymond Biagan, RFaxis' VP of worldwide sales.

RFaxis initially will provide its RFX2401C reference design, followed by its RFX2411 and future products with antenna diversity. The RFX2401C and RFX2411 are fully integrated, single-chip, single-die RFeICs that incorporate all the RF functionality needed for IEEE 802.15.4/ZigBee, wireless sensor networks, the IP-based Thread mesh networking protocol and other wireless systems in the 2.4GHz ISM band.

The RFX2401C and RFX2411 architectures integrate the power amplifier (PA), low-noise amplifier (LNA), transmit and receive switching circuitry, the associated matching network and a harmonic filter in a single-chip CMOS device. The RFX2411 includes an additional antenna diversity switch, as well as a bypass mode to provide maximum flexibility for system implementations. RFaxis says that, suitable for high-power applications like home automation, smart house/smart living and smart power environments, the RFX2401C and RFX2411 combine superior performance, high sensitivity and efficiency, low noise, small form factor and low cost. Both provide a solution for applications requiring extended range, receive sensitivity and bandwidth, the firm adds.

www.silabs.com
www.rfaxis.com

Pasternack receives 4-Star Supplier Excellence Award from Raytheon Integrated Defense Systems

Pasternack Enterprises Inc of Irvine, CA, USA (which makes both passive and active RF, microwave and millimeter-wave products) has been awarded the 4-Star Supplier Excellence Award by Raytheon's Integrated Defense Systems (IDS) business. This is the third consecutive year that Pasternack has been honored with a Supplier Excellence Award from Raytheon IDS.

Raytheon's Integrated Defense Systems business instituted its annual Supplier Excellence Awards program to recognize suppliers that have provided outstanding service and partnership in exceeding customer requirements. Candidates are judged on certain criteria, including overall quality, on-time delivery and demonstrated commitment to continuous improvement. Pasternack was one of 99 firms recognized by Raytheon IDS for 4-Star honors.

The 4-Star Supplier Excellence Award from Raytheon IDS.

"Our commitment and contributions to the overall success of Raytheon's programs over the past 30+ years have been mutually beneficial and we look forward to years of success to come," says Pasternack's CEO Terry Jarnigan.

www.pasternack.com

Peregrine expands into third building at San Diego HQ

High-performance analog and mobile wireless solutions business units expanding following acquisition by Murata

Peregrine Semiconductor Corp of San Diego, CA, USA — a fabless provider of radio-frequency integrated circuits (RFICs) based on silicon-on-insulator (SOI) — has added a third building to its Sorrento Valley headquarters.

The new office building (9339 Carroll Park Drive, Suite 150) covers 18,000ft^2 in area and will accommodate a growing workforce. The other two office buildings are at 9369 and 9380 Carroll Park Drive.

"On the heels of our acquisition by Murata last December, we've been tasked with growing our two business units — high-performance analog (HPA) and mobile wireless solutions (MWS)," says director of human resources Sarah Canfield. "We currently have over 350 employees, but that number is rapidly growing," she adds. "This new building enables us to have space for our new San Diego hires."

Peregrine's new third building in San Diego.

As well as its San Diego headquarters, Peregrine has offices in Arlington Heights, Illinois; Reading, UK; Seongnam-si, South Korea; and Shanghai, China, and is hiring in all locations.

Peregrine certified as MIL-PRF-38535-qualified manufacturers list supplier for aerospace and defense

Peregrine has gained QML (qualified manufacturers list) certification, class Q (military) and V (space).

After a thorough evaluation, Peregrine demonstrated to the US Defense Logistics Agency (DLA) Land and Maritime that it fully complies with MIL-PRF-38535, the performance specification used by the US Department of Defense for monolithic integrated circuits that operate in severe environments.

"This is a giant step forward for Peregrine's high-reliability products and demonstrates our continued commitment to serving the aerospace and defense market — an industry we have served for over 15 years," says Duncan Pilgrim, VP & general manager of Peregrine's high-performance analog (HPA) business unit. "We are actively taking the next steps to qualify and release Peregrine's space and military product portfolio as standard microcircuit drawings (SMDs)."

Peregrine offers high-reliability products for aerospace & defense applications including RF switches, digital step attenuators (DSAs), pre-scalers, phase-locked loops (PLLs) and DC–DC converters, based on its own technologies. Built on its UltraCMOS technology on a sapphire substrate, the high-reliability products offer proven RF performance and unique integration capabilities, it is claimed.

www.psemi.com

Analog Devices' RF design tools now support Hittite Microwave products

Analog Devices Inc (ADI) of Norwood, MA, USA (which provides ICs for analog and digital signal processing applications) has announced new releases of its RF design tools, which now provide support for the products of Hittite Microwave Corp (acquired in July 2014).

The ADIsimRF design tool enables engineers to model RF and microwave signal chains using devices from across ADI's RF IC portfolio. ADIsimRF Version 1.9 adds 190 mixers, amplifiers, switches and attenuators, which are primarily from the Hittite portfolio.

The ADIsimPLL design tool is a comprehensive and easy-to-use PLL (phased-locked loop) synthesizer design and simulation tool. ADIsimPLL Version 4 has been upgraded to include device models for the HMC703 and HMC704 PLLs and the HMC830, HMC832, ADF4355, ADF4355-2 and ADF5355 integrated PLLs and VCOs (voltage-controlled oscillators).

Since acquiring Hittite Microwave, Analog Devices claims that it now offers the broadest portfolio of RF and microwave products covering the entire signal chain, from antenna to bits and back, across the entire frequency spectrum beyond 100GHz. Complemented by data converters, ADI's RF, microwave and millimeter-wave portfolio includes more than 2000 products, from functional blocks to highly integrated solutions, development platforms and modules.

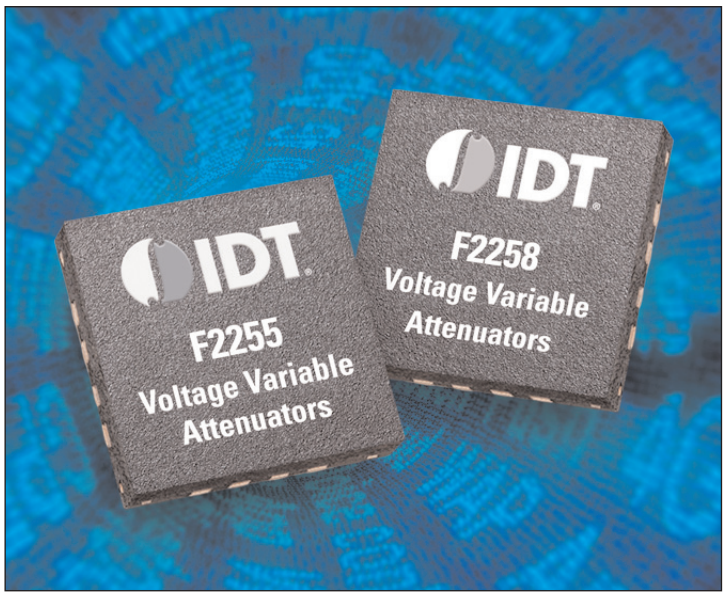
www.analog.com/hittite

IDT extends RF voltage variable attenuator range to 6GHz, claiming 1000-fold linearity improvement over GaAs

Integrated Device Technology Inc (IDT) of San Jose, CA, USA has added two new members to its growing family of silicon-based RF voltage variable attenuators (VVA) – which deliver analog control for applications that require precise attenuation – expanding the firm's frequency coverage to a range of 1MHz to 6GHz.

Like the other members of the family, the F2255 and F2258 devices offer what is claimed to be industry-leading low insertion loss and high linearity. Coming in a compact 3mm x 3mm, 16-pin TQFN package, the new devices offer about half the insertion loss of competitive solutions, IP3 (third-order intercept point) linearity performance 1000x (30dB) better than the competing gallium arsenide device, it is reckoned, and exhibit a linear-in-dB attenuation characteristic across the voltage control range. Their low insertion loss reduces RF chain path loss, while their high linearity improves system data rates.

The new devices match popular footprints and are suitable for base-stations (2G, 3G and 4G), microwave infrastructure, public safety, portable wireless communication/data equipment, test/ATE equipment, military systems, JTRS radios, and HF, VHF and UHF radios.



"IDT's silicon-based RF products deliver exceptional performance compared to GaAs solutions, in this case up to a 30dB linearity improvement," said Chris Stephens, general manager of IDT's RF division. "These devices are the lowest insertion loss VVAs on the market, and have the most linear attenuation control characteristic."

IDT claims that, by using silicon-based RF semiconductor technology, its attenuators offer a robust alternative to older GaAs-based technology. Silicon offers more robust electrostatic discharge (ESD) protections, better moisture sensitivity levels (MSL), improved thermal performance, lower current consumption, and proven reliability, the firm adds.

Comparing the F2258 to its pin-compatible GaAs competitor, the device has an input IP3 of up to 65dBm versus 35dBm, a maximum attenuation slope of 33dB/V versus 53dB/V, minimum return loss up to 6000MHz of 12.5dB versus 7dB, and a maximum operating temperature range of 105°C versus 85°C. The F2255 supports a frequency range down to 1MHz and has a maximum attenuation slope of 33dB/V.

Both devices have bi-directional RF ports, support a single positive supply voltage of either 3V or 5V, and have an operating temperature range of –40°C to 105°C.

www.idt.com

MwT launches pre-amplifiers for MRI coil applications

MicroWave Technology Inc (MwT) of Fremont, CA, USA (a division of IXYS Corp that makes RF and microwave discrete devices, MMICs, hybrid modules and connecterized amplifiers for wireless communication infrastructure, military/aerospace, industrial and medical applications) has introduced two new pre-amplifiers for MRI (magnetic resonance imaging) coil applications, fabricated using low-noise gallium arsenide (GaAs) devices and components with very low magnetism (which is a critical requirement for MRI coils).

The MSM series pre-amp has a 0.45dB noise figure and 28dB gain at 1.5T (64MHz), 3T (123–128MHz) and 7T (298MHz) frequencies. It has linearity of 20dBm IP3. The MSM pre-amp is in a miniature package of 0.43-inches x 0.36-inches. The MPE series pre-amp is targeted for 3T (123-128MHz) applications and it has a noise figure as low as 0.4dB with 27dB gain and 20dBm IP3. It also has input power protection as high as 30dBm.

"The MSM series pre-amp is housed in a miniature package of 0.43-inch x 0.36-inch and will be an ideal choice for MRI coils with a large number of channels," says MwT general manager Dr Greg Zhou. "The MPE pre-amp is targeted at the low-cost MRI coil market while still maintaining excellent RF performance," he adds. "These two pre-amplifiers are the newest additions to our pre-amp product family. As a major pre-amplifier supplier to major MRI equipment manufacturers in the past 15 years, we are committed to support our medical equipment customers so they can meet their latest requirements."

www.mwtinc.com

NASA awards Ozark $245,000 in phase 1 SBIR grants to design SiC-based ICs for Venus Rover

The US National Aeronautics and Space Administration (NASA) has awarded two grants totaling $245,000 to Ozark Integrated Circuits Inc of Fayetteville, AK, USA (a firm affiliated with the University of Arkansas that develops ICs for remote sensing and actuation under extreme environmental conditions).

The firm, which designs semiconductors at the Arkansas Research and Technology Park, will use the grants to design ICs that can operate on the surface of Venus, where the temperature can reach 500°C (932°F). The two silicon carbide-based circuits could be incorporated into the overall design of the space agency's proposed Venus Landsailing Rover, says Ozark IC's president & CEO Matt Francis.

The firm will collaborate with electrical engineering students at the University of Arkansas on one of the projects. It will also utilize the IC packaging expertise and facilities of the university's High Density Electronics Research Center at the research park.

"Silicon carbide is a semiconductor that is ideally suited for the extreme environments found on Venus," says Francis. "We have many years of experience working with this semiconductor fabrication process, developing models and process-design kits specifically for this process." Francis and chief technology officer Jim Holmes have developed design procedures, tools, characterization and modeling approaches that have enabled them, in conjunction with researchers at the university, to design high-voltage electronics capable of operating at conditions beyond 600°F. "We will demonstrate the feasibility of creating these needed ICs," says Francis. "We will also generate a commercial feasibility analysis based on projections of the manufacturing costs for each of these integrated circuits."

In the first NASA award, Ozark IC will address NASA's Earth and planetary science missions through the development of a reliable ultraviolet imager suited to planetary composition experiments and Earth observation in space. The imager will allow monitoring of UV signals to understand the environment on Venus as well as for UV astronomy by observing and analyzing other planets and stars.

In the second award, Ozark IC will address NASA's need for a microcontroller to provide real-time programmability for the proposed mobile lander for Venus. Alan Mantooth, Distinguished Professor of electrical engineering at the University of Arkansas, will supervise student research on this project.

The Phase I grants came via the Small Business Innovation Research (SBIR) program, which allows federal agencies to stimulate technological innovation in the private sector by strengthening small businesses that meet federal R&D needs. The program also aims to increase the commercial application of federally supported research results.

www.ozarkic.com
www.nasa.gov/directorates/spacetech/niac/2012_phase_I_fellows_landis.html

University of Arkansas receives $200,000 NSF grant to study GaN device modeling

The University of Arkansas' GRid-connected Advanced Power Electronic Systems Center (GRAPES) has received a $200,000 grant to study modeling of gallium nitride devices. Alan Mantooth, Distinguished Professor of electrical engineering and executive director of the center, will lead the effort.

Researchers at the center work to accelerate the adoption and insertion of power electronics into the electric power grid. Improvements in these devices should ultimately lead to lower costs for consumers and a substantial reduction in carbon emissions.

As a hard-compound, mechanically stable semiconductor material that has high heat capacity and thermal conductivity, GaN can be used to develop devices that can operate at higher voltages, temperatures and switching frequencies than those currently using silicon.

One of the barriers to the acceptance of such new devices is a lack of high-quality models for circuit simulation that allow designers to evaluate them against the entrenched silicon technology. Since the vast majority of all circuit design and simulation is performed in computer programs, the lack of these models makes it very difficult for circuit designers to accurately portray how GaN devices will behave, says University of Arkansas.

The grant will allow the researchers at GRAPES to develop and evaluate a high-performance compact model for GaN power devices. Compact models are used by circuit designers to simulate the performance and behavior of their designs before committing them to manufacture. These models are especially important in power electronic applications where many real-world scenarios can be analyzed safely. Further, statistical and failure mode analyses, which are practically impossible through experimentation, can be easily performed, concludes the University of Arkansas.

https://grapes.uark.edu

GE and SUNY Poly developing SiC power electronics packaging facility at QUAD C

GE to be anchor tenant of Computer Chip Commercialization Center in next phase of New York governor's $1.5bn Nano Utica initiative

New York State governor Andrew Cuomo has announced that GE Global Research Center of Niskayuna, NY, USA will expand its New York global operations to the Mohawk Valley, serving as the anchor tenant of the Computer Chip Commercialization Center (QUAD C) on the campus of the State University of New York (SUNY) Polytechnic Institute's Colleges of Nanoscale Science and Engineering (CNSE) in Utica. Between SUNY Poly, GE and affiliated corporations, nearly 500 jobs are expected to be created in the Mohawk Valley in the next five years, plus another 350 in the subsequent five years.

Cuomo also announced that Austria-based analog IC and sensor manufacturer ams AG plans to generate more than 1000 new jobs and initially invest over $2bn in construction of a 360,000ft^2 wafer fabrication plant at the Nano Utica site in Marcy.

Nano Utica is governor Cuomo's $1.5bn economic development plan to revitalize the Mohawk Valley by establishing a nanotechnology-driven ecosystem, including QUAD C and the Marcy Nanocenter.

These two new public–private partnerships represent the launch of the next phase of the Nano Utica initiative, which now exceeds more than 4000 projected jobs over the next ten years. Designed to replicate the success of SUNY Poly's Nanotech Megaplex in Albany, Nano Utica aims to boost New York's role as a hub for 21st century nanotechnology innovation, education, and economic development.

"Today's announcement by Governor Andrew Cuomo represents a major expansion for Quad-C and the Nano Utica initiative," comments SUNY Poly's president & CEO Dr Alain Kaloyeros. "Governor Cuomo's pioneering economic development model, coupled with SUNY Poly CNSE's world-class expertise and resources, continues to generate historic investment and job creation throughout the state."

The packaging facility is a critical component of the New York Power Electronics Manufacturing Consortium at SUNY Poly

GE's SiC power electronics packaging facility

GE Global Research and SUNY Poly will develop a power electronics packaging facility at QUAD C that aims to advance New York's role in next-generation semiconductor research, development, and commercial fabrication to meet global demand for smaller, faster and more efficient devices. This will expand the scope of the Nano Utica initiative from computer chip commercialization into power electronics applications for industrial products such as wind turbines, utility-scale solar inverters, data centers and hybrid cars. GE's silicon carbide (SiC) technology provides a material platform upon which the next generation of power devices can be built, enabling higher power in smaller, more efficient packages.

"Together with New York State and SUNY Polytechnic Institute in Albany, and now Utica, we are creating a Silicon Carbide Corridor that will be the epicenter of the next revolution in power," says GE's senior VP & chief technology officer Mark Little. "In Utica, it will expand the focus from computer chip commercialization to creating the first US-based Power Electronics Manufacturing Center with GE's silicon carbide technology," he adds.

Advanced packaging technologies are vital in the development of faster and more powerful computer chips, as well as silicon carbide chips for power electronics applications. The packaging facility at QUAD C targets commercial breakthroughs in an array of applications ranging from defense, super-computing, tablets, cell phones, and a myriad of power electronics applications.

The packaging facility is a critical component of the New York Power Electronics Manufacturing Consortium, the governor's $500m public–private semiconductor research partnership that involves over 100 companies. Based at the SUNY Poly Megaplex in Albany with lead partners including GE and IBM, the consortium is driving coordinated materials research and job creation across the Upstate corridor.

QUAD C and Nano Utica

The expansion of QUAD C includes cleanrooms, laboratories, hands-on education and workforce training facilities, and integrated offices encompassing 253,000ft^2. It is reckoned that the cleanroom will be the first of its kind in the USA: 56,000ft^2 stacked on two levels and five times larger than initial plans.

In accordance with the governor Cuomo's innovation-driven economic development model, no public funds will be given to private companies. New York will invest $250m at QUAD C and the Marcy Nanocenter to support critical equipment and infrastructure improvements at both locations. The state will own and manage these facilities through SUNY Poly, and such state investment will catalyze the Mohawk Valley's high-tech economic ecosystem, aiming to attract additional nanotechnology jobs and supply-chain companies to support and contribute to the Nano Utica initiative.

www.sunycnse.com
www.geglobalresearch.com

Rohm adopts latest model of Lasertec's silicon carbide wafer inspection and review system

Metrology and inspection equipment maker Lasertec Corp of Yokohama, Japan says that Japan-based power semiconductor device manufacturer Rohm Co Ltd has selected the latest model of its SICA silicon carbide (SiC) wafer inspection and review system as part of efforts to further enhance its SiC device quality and production infrastructure.

Silicon carbide's properties are suitable for power semiconductors and hence it is viewed as a vitally important option for power device manufacturing. For mass production of SiC wafers and devices, further quality enhancement is expected.

Among various challenges, a key factor in the mass production of high-quality SiC devices is to reduce defects that are commonly generated during grinding and epitaxial processes. In this respect, it is extremely important to be able to accurately and quickly detect and categorize defects that affect device performance.

Defects of interest (DOI) include not only scratches and epi-defects on the wafer surface but also crystal-related defects such as basal plane dislocations (BPD) and stacking faults (SF) inside epilayers. Eliminating these killer defects early in the process ensures high device yield in mass production, says Lasertec.

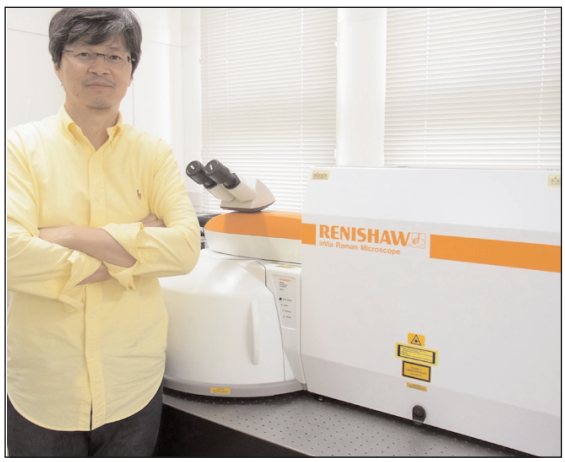
The latest model of SICA incorporates a photoluminescence (PL)-based technology that enables the simultaneous detection of both surface defects and crystal defects at significantly higher throughput. Lasertec says that it will continue to pursue the development of defect inspection technologies in order to facilitate the further enhancement of power device quality and productivity.

www.lasertec.co.jp
www.rohm.com

Kwansei Gakuin University uses Renishaw Raman microscope to study defects in silicon carbide

Professor Noboru Ohtani and colleagues in the Department of Nanotechnology for Sustainable Energy of the School of Science and Technology at Japan's Kwansei Gakuin University (who researches wide-bandgap semiconductors and crystallographic defects) have reported on using Renishaw's inVia confocal Raman microscope for micro-Raman imaging to help show the influence of heavily doped nitrogen donors on the defect formation in silicon carbide (T Takahashi et al, 'Structural and electrical characterization of the initial stage of physical vapour transport growth of 4H-SiC crystals', Materials Science Forum vols 821–823 (2015) p90).

Crystallographic defects in 4H-SiC epitaxial wafers (such as dislocations and stacking faults) limit the commercialization of SiC devices and must therefore be eliminated or reduced to levels lower than some critical density. The department's research goal is to establish SiC crystal growth processes that can produce large, ultra-high-quality SiC epitaxial wafers. To achieve this, they try to clarify the cause and formation mechanism of crystallographic defects in SiC bulk crystal and epitaxial film.



Professor Noboru Ohtani, with Renishaw inVia Raman microscope.

Crystallographic defects give rise to residual stresses in the crystals. The stresses can occur through a variety of mechanisms in 4H-SiC crystals. For example, temperature gradients in the grown crystals, which are a primary driving force for crystal growth, lead to plastic deformation of the crystals during the growth and/or cooling process. This deformation results in residual stresses when the crystals are cooled to room temperature. The spatial variation of stresses in the crystals can be measured using Renishaw's inVia confocal Raman microscope. These measurements provide information about the formation of defects during physical vapour transport (PVT) growth and chemical vapour deposition (CVD) processes. This information can be used to improve the crystal growth process.

Ohtani's laboratory also uses high-resolution x-ray diffraction (HR-XRD) to characterize stress distribution. Raman microscopy provides complementary information to the HR-XRD data but with much higher spatial resolution. "The key benefit is the ultra-high speed data acquisition system, which results in a higher sensitivity to measuring stresses in the materials compared to other Raman systems," commented Ohtani regarding the inVia system.

www.renishaw.com/invia
www.scientific.net/MSF.821-823.90

Japan's AIST adopts Silvaco's TCAD products for silicon carbide power semiconductor research

Yokohama-based Silvaco Japan Co Ltd — a branch of Silvaco Inc of Santa Clara, CA, USA, a provider of technology computer-aided design (TCAD), circuit simulation and electronic design automation (EDA) software tools — says that the Advanced Power Electronics Research Center of Japan's National Institute of Advanced Industrial Science and Technology (AIST) has adopted Silvaco's TCAD tool for its silicon carbide (SiC) power semiconductor research.

AIST began research on wide-bandgap semiconductor materials such as silicon carbide and gallium nitride (GaN) during the second half of the 1970s in the era of the Industrial Science and Technology Agency of the former Ministry of International Trade and Industry, and from the second half of the 1990s AIST assumed a leading role in national projects aimed at establishing fundamental technologies for these new semiconductors.

"TCAD simulations are essential to the research on wide-gap semiconductors such as SiC and GaN," says Advanced Power Electronics Research Center deputy director Kunihiro Sakamoto. "By doing simulations with varied parameters, such as the types of materials and device structures and doping of implanted impurities, device characteristics can be estimated before doing trials. This makes it possible to shorten turnaround time by reducing the number of manufacturing iterations and to improve the robustness of the device design. We look forward to even greater acceleration of our research by utilizing Silvaco's TCAD products," he adds.

"Compound semiconductor simulation is a field in which Silvaco has a long track record, with many years of development experience including 3D TCAD enhancements such as high-performance meshing and powerful parallelized solver technology," notes Silvaco's general manager Yoshiharu Furui. "Our increased focus on the power electronics market has been rewarded by strong customer acceptance of the accuracy and convergence properties of our TCAD simulation products," he adds. "Going forward, we will continue to extend our products to meet our customers' requirements as they push forward their technology innovations."

www.silvaco.co.jp
www.aist.go.jp

GaN Systems signs Shenzhen-based SZ APL as distribution partner in China and Taiwan

GaN Systems Inc of Ottawa, Ontario, Canada — a fabless producer of gallium nitride (GaN)-based power switching transistors based on its proprietary Island Technology for power conversion and control applications — has appointed Shenzhen APL to distribute its Island Technology high-power gallium nitride devices in China and Taiwan. With headquarters in Shenzhen and additional offices in Shanghai, Beijing and Taipei, SZ APL has extensive experience in power electronics components distribution to major tier-1 customers in the automotive, industrial and enterprise segments.

SZ APL has "both significant knowledge of power electronics and strong relationships with tier-1 Chinese and Taiwanese customers," comments GaN Systems' president Girvan Patterson. "Demand for our GaN power switching transistors is growing very rapidly as manufacturers seek to design smaller, lighter and more power-efficient products in order to gain competitive edge. We are expecting multiple consumer and enterprise products designed with our GaN devices to be launched in the region in early 2016, with other applications from our industrial and automotive customers to follow later next year," he adds.

"Prior to signing our distribution agreement with GaN Systems, discussions with our tier-1 customers confirmed GaN Systems as their first-choice manufacturer of GaN E-HEMTs [enhancement-mode high-electron-mobility transistor]," comments SZ APL's president Henry Ruan.

"SZ APL has many key relationships with major tier-1 customers in China and Taiwan, as well as a strong focus and understanding of power electronics and power ICs," says Charles Bailley, GaN Systems' senior director, sales & marketing, Asia. "During 2015, we have significantly increased our customer penetration in China and Taiwan and look forward to working with SZ APL to continuously add further major design wins."

GaN Systems claims to be the first firm to have developed and productized a comprehensive portfolio of GaN E-HEMT power devices with current ratings from 7A to 250A, in both 650V and 100V ranges. The firm's Island Technology die design — combined with the extremely low inductance and thermal efficiency of GaNPX packaging and DriveAssist technology — provides its GaN E-HEMTs with what is reckoned to be a 45x improvement in switching and conduction performance over silicon MOSFETs and IGBTs.

www.szapl.com

GaN Systems adds director, product line management as part of strategic growth

GaN Systems Inc has appointed Peter Di Maso as director, product line management.

The newly created position is part of the firm's strategic growth and headcount increase at all levels as it ramps up production of its Island Technology GaN devices to supply global demand from design engineers.

Di Maso will be responsible for creating and executing a sustainable product and market strategy to achieve GaN Systems' business growth objectives. Working with customers, sales teams and development teams, he will lead and execute the development of new product ideas.

"Peter joins us with more than 20 years' experience in the power electronics industry," comments president Girvan Patterson. "Peter's background includes strategic product marketing at Texas Instruments, expertise in automotive ICs gained at Allegro Microsystems and an early career as a power supply design engineer at Bell-Northern Research," he adds. "This is an extremely relevant portfolio of experience and skills, and places him in a perfect position to lead teams dovetailing our innovative GaN technology with creative customer solutions."

Peter di Maso, GaN Systems' new director, product line management.

Di Maso has a Bachelor of Engineering degree (Electrical) from Concordia University in Montreal and is currently completing an MBA at Southern New Hampshire University in Manchester, NH, USA.

GaN Systems claims to be the first company to have developed and productized a comprehensive portfolio of GaN E-HEMT power devices with current ratings from 7A to 250A, in both 650V and 100V ranges. Its Island Technology die design, combined with its extremely low inductance and thermally efficient GaNPX packaging and Drive Assist technology, provides a 40-fold improvement in switching and conduction performance over traditional silicon MOSFETs and IGBTs.

www.gansystems.com

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Imec extends GaN-on-silicon R&D initiative for joint research on 200mm epi and E-mode device

Nano-electronics research center Imec of Leuven, Belgium is extending its gallium nitride-on-silicon R&D program, and is now offering joint research on GaN-on-Si 200mm epitaxy and enhancement-mode device technology.

The extended R&D initiative includes exploration of novel substrates to improve the quality of the epitaxial layers, new isolation modules to increase the level of integration, and the development of advanced vertical devices. Imec says that it welcomes new partners interested in next-generation GaN technologies and companies looking for low-volume manufacturing of GaN-on-Si devices to enable the next generation of more efficient and compact power converters.

GaN technology offers faster-switching power devices with higher breakdown voltage and lower on-resistance than silicon, making it an outstanding material for advanced power electronic components. Imec's R&D program on GaN-on-Si was launched to develop a GaN-on-Si process and bring GaN technology towards industrialization.

"Since the program's launch in July 2009, we have benefited from strong industry engagement, including participation from integrated device manufacturers (IDMs), epi-vendors and equipment and material suppliers. This underscores the industrial relevance of our offering," says Rudi Cartuyvels, executive VP of smart systems at Imec.

Building on its track record in GaN epilayer growth, new device concepts and CMOS device integration, Imec has developed a complete 200mm CMOS-compatible GaN process line. Its GaN-on-Si technology is reaching maturity, and companies can gain access to the platform by joining its GaN-on-Si industrial affiliation program (IIAP). The process line is also open to fabless companies interested in low-volume production of GaN-on-Si devices tailored to their specific needs, through dedicated development projects.

Imec's portfolio includes three types of buffers optimized for breakdown voltage and low trap-related phenomena (i.e. current dispersion): a step-graded aluminium gallium nitride (AlGaN) buffer, a superlattice buffer, and a buffer with low-temperature AlN interlayers. Imec explored side-by-side enhancement-mode power devices of the MISHEMT and p-GaN HEMT type, as well as a gate-edge-terminated Schottky power diode featuring low reverse leakage and low turn-on voltage.

The latest generation of Imec enhancement-mode power devices shows a threshold voltage beyond +2V, an on-resistance below 10Ωmm and output current over 450mA/mm. These devices represents the state-of-the-art of enhancement-mode power devices, Imec claims.

In this next phase of the GaN program, Imec is focusing on further improving the performance and reliability of its existing power devices, while in parallel pushing the boundaries of the technology through innovation in substrate technology, higher levels of integration and exploration of novel device architectures.

"Interested companies are invited to become a partner and actively participate in our program," says Cartuyvels. "Imec's open innovation model allows companies to have early access to next-generation devices and power electronics processes, equipment and technologies and speed up innovation at shared cost."

www.imec.be

EPC launches low-cost, high-power-density eGaN FET for high-frequency power conversion including wireless power transfer

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA, which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications, has launched the EPC2039 high-power-density eGaN power transistor.

The EPC2039 is an extremely small 1.35mm x 1.35mm (1.82mm^2) 80V_{DS}, 6.8A power transistor with a maximum $R_{DS(on)}$ of 22mΩ with 5V applied to the gate. EPC says that the GaN power transistor delivers high performance in power conversion systems due to its high switching capabilities in a very small package. "It enables designers to increase the output power of their designs without increasing the space needed to do it," says Steve Colino, VP global sales & marketing.

The EPC2039 is designed primarily for high-frequency power conversion applications, such as synchronous rectification, Class-D audio, high-voltage buck converters, wireless charging, and pulsed power (LiDAR) applications. Emerging LiDAR applications include driverless vehicles and augmented reality.

Pricing for the EPC2039 power transistor is $0.78 each in 1000-unit quantities.

http://digikey.com/Suppliers/us/Efficient-Power-Conversion.page
http://epc-co.com/epc/Products/eGaNFETs/EPC2039.aspx

Cambridge Electronics launches GaN transistors and power electronic circuits

Cambridge Electronics Inc (CEI) — spun off from Massachusetts Institute of Technology (MIT) in 2012 — has launched a range of gallium nitride transistors and power electronic circuits targeted at cutting energy usage in data centers, electric cars, and consumer devices by 10–20%.

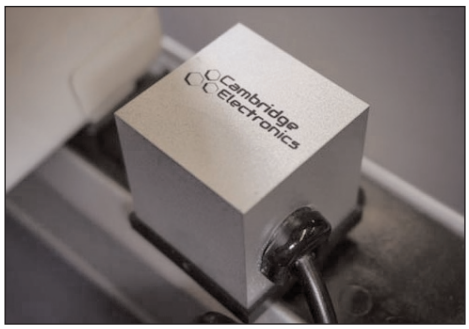
As a ubiquitous technology used to convert electricity to higher or lower voltages and different currents (such as in a laptop's power adapter or in electric substations that convert voltages and distribute electricity to consumers) most power electronics systems rely on silicon transistors that switch on and off to regulate voltage. However, due to speed and resistance constraints, they waste energy as heat.

CEI says its GaN transistors have at least one-tenth the resistance of silicon-based transistors, allowing much higher energy efficiency and orders-of-magnitude faster switching frequency, so power electronics systems made with the components can be much smaller. CEI is using its transistors to enable power electronics that will make data centers less energy-intensive, electric cars cheaper and more powerful, and laptop power adapters one-third the size — or even small enough to fit inside the computer itself.

CEI's co-founders and co-inventors of the technology include Tomás Palacios (an MIT associate professor of electrical engineering and computer science); technical advisory board chair Anantha Chandrakasan (the Joseph F. and Nancy P. Keithley Professor in Electrical Engineering); VP for device development Dr Bin Lu; director of operations Dr Ling Xia; director of epitaxy Dr Mohamed Azize; and director of product reliability Dr Omair Saadat.

Making GaN feasible

While GaN transistors have several benefits over silicon, safety drawbacks and costly manufacturing have largely kept them off the market. But Palacios, Lu, Saadat and other



MIT researchers managed to overcome these issues through design innovations made in the late 2000s.

Power transistors are designed to flow high currents when on, and to block high voltages when off. Should the circuit break or fail, the transistors must default to 'off' to cut the current to avoid short circuits etc (an important feature of silicon power transistors). However, GaN transistors are typically 'normally-on' (by default, always allowing a flow of current), which has historically been difficult to correct. Using MIT's Microsystems Technology Laboratory, the researchers — supported by US Department of Defense (DoD) and Department of Energy (DoE) grants — developed GaN transistors that were 'normally off' by modifying the structure of the material.

Rather than growing a thin layer of GaN on the substrate (as in traditional GaN transistors), the MIT team used layers of different material compositions to yield GaN transistors that are normally-off.

Also, GaN and other non-silicon semiconductors are manufactured in expensive processes. To cut costs, the researchers — at MIT and, later, with the company — developed new fabrication technologies, Lu says. This involved, among other things, replacing gold metals (used in manufacturing GaN devices) with metals that were compatible with silicon fabrication, and developing ways to deposit GaN on large wafers used by silicon foundries.

"We are fabricating our advanced GaN transistors and circuits in conventional silicon foundries, at the cost of silicon," Lu says. "The cost is the same, but the performance of the new devices is 100 times better."

Major applications

CEI is currently using its transistors to develop laptop power adaptors about 1.5 cubic inches in volume (the smallest ever made, it claims).

Other applications include better power electronics for data centers to power the cloud. Currently, these consume about 2% of electricity in the USA. But GaN-based power electronics could save a very significant fraction of that, Palacios says.

Another major application is replacing the silicon-based power electronics in battery chargers and in inverters that convert the battery power to drive electric motors in electric vehicles. Existing silicon transistors have a constrained power capability that limits how much power the car can handle (one of the main reasons why there are few large electric vehicles).

GaN-based power electronics could boost power output for electric cars, while making them more energy-efficient and lighter — and hence cheaper and longer range. "Electric vehicles are popular, but still a niche product. GaN power electronics will be key to make them mainstream," Palacios says.

Innovative ideas

In launching CEI, the founders turned to MIT's entrepreneurial programs. "MIT's innovation and entrepreneurial ecosystem has been key," Palacios comments.

Palacios first earned a grant from the Deshpande Center for Technological Innovation to launch CEI. He then took his idea for GaN-based power electronics to Innovation Teams (i-Teams), which brings together MIT students from across disciplines to evaluate the commercial feasibility of new technologies. That program showed him the huge market pull for GaN power electronics, and helped CEI settle on its first products.

www.gantechnology.com

Qorvo to double GaN capacity after scaling from 4-inch to 6-inch wafers

GaN-on-SiC using 6-inch wafers enables higher-volume, lower-cost GaN applications

Qorvo Inc, a provider of core technologies and RF solutions for mobile, infrastructure and aerospace/defense applications, says that it has scaled its proprietary QGaN25 gallium nitride (GaN) on silicon carbide (SiC) process to produce monolithic microwave integrated circuits (MMICs) on 6" wafers. The transition from 4" to 6" wafers is expected to approximately double Qorvo's GaN-on-SiC manufacturing capacity and favorably impact manufacturing costs — significantly accelerating the affordable manufacture of RF devices, Qorvo reckons.

"The successful demonstration of GaN-on-SiC MMICs on 6" wafers paves the way for significantly increased production capacity and cost efficiencies," says James Klein, president of Qorvo's Infrastructure and Defense Products Group (IDP). "This is a significant milestone that extends Qorvo's leadership position, providing best-in-class processes and GaN products to the commercial and defense markets," he adds.

Qorvo says that scaling its QGaN25 production process — on high-yielding, X-band power amplifier (PA) MMICs — from 4" to 6" GaN-on-SiC wafers paves the way for the conversion to 6" wafers of all of its GaN-on-SiC production processes, with gate lengths ranging from 0.15μm to 0.50μm, covering the full range of microwave to millimeter-wave (mmW) applications. Full-rate production is anticipated in 2016.

The 12-watt X-band point-to-point MMIC PAs met greater than 80% DC and RF yields. This process feasibility sets the stage for high-rate production for the commercial base-transceiver station (BTS) and point-to-point radio, CATV and defense markets, says Qorvo.

Qorvo reckons that the scale-up in wafer size consolidates its position as a Defense Manufacturing Electronics Agency accredited 1A Trusted Source. The firm completed the Defense Production Act Title III GaN-on-SiC program in 2014, and is the first firm to have achieved Manufacturing Readiness Level (MRL) 9, demonstrating that its high manufacturing processes are ready for full-rate production.

The US Department of Defense's Manufacturing Readiness Assessment (MRA) ensures that manufacturing, production and quality assurance can meet operational mission needs. This process ensures that the product or system transitions successfully from the factory to the field, providing the best value for the customer, and meeting full performance, cost and capacity goals.

www.qorvo.com

HexaTech wins continued DoE funding

Demonstrated results lead to $1.2m one-year extension of $2.8m two-year ARPA-E contract

HexaTech Inc of Morrisville, NC, USA, which manufactures aluminium nitride (AlN) substrates and is developing long-life UV-C LEDs and high-voltage power devices, has received a continuation of funding under the US Department of Energy's Advanced Research Projects Agency (ARPA-E) development program (a collaborative government agency that catalyzes transformational energy technologies through funding, technical assistance, and market readiness to accelerate the pace of energy innovation). The cost-share extension is valued at $1.2m over one year, and follows $2.8m over two years when the contract was initiated in 2012.

HexaTech's contract focuses on developing high-power semiconductor switching devices based on AlN to more efficiently control the flow of electricity across high-voltage electrical lines. AlN-based devices should exceed the capabilities of existing materials, enabling smaller, more reliable components. Further implementation of these components could decrease the cost of electricity transmission while increasing overall grid security and reliability, it is reckoned.

"This contract extension will allow us to further expand our market leadership in high-power AlN device development," says CEO John Goehrke. "Combined with ARPA-E's unique Tech-To-Market concept, we anticipate not only raising the bar in device performance, but also raising awareness for AlN in general, which will in turn be a significant growth opportunity for our core substrate business," he adds.

"This continued support from ARPA-E will allow us to demonstrate the potential of AlN for high-voltage devices by optimizing MOCVD [metal-organic chemical vapor deposition] growth parameters, as well as fabricating and testing commercially oriented components," says Dr Baxter Moody, principal investigator for the program at HexaTech.

www.hexatechinc.com

Power and Compound Semiconductors Committee established by SEMI China

SEMI China (the China branch of industry association Semiconductor Equipment and Materials International) has announced the establishment of a Power and Compound Semiconductors Committee, which held its kick-off meeting in Shanghai on 28 July.

At the meeting, SEMI China's president Dr Lu Haoan introduced the SEMI China team to concepts around the promotion of industrial cooperation and exchange platform constructed of industrial development. At the meeting, the group adopted the 'SEMI Chinese Power and Compound Semiconductor Committee Charter' and selected Dr Zhang Naiqian of News Energy Ltd Suzhou as co-chair.

The committee is composed of global power and compound semiconductor companies (including Infineon Technologies and NXP), three safety optoelectronics firms, the Chinese Academy of Sciences, telecoms energy semiconductor firms (PlayNitride Inc, Cham Crystal Semiconductor, Silicon Cenda, CSR Electric, Silver Mao Microelectronics, Huahong Hong force, Tower Jazz CNR), as well as electricity companies.

At the meeting, Dr Zhang Naiqian discussed the characteristics and advantages of gallium nitride (GaN) RF devices and power electronic devices, as important core devices as GaN power electronics play an increasingly important role in the potential future development of computers, mobile communications, networking, automotive electronics, power transmission, modern transportation and other industries. Also, Dr Zhuang Weidong, general manager of Nanjing Silver Mau Microelectronics Co Ltd, discussed 'Chinese IGBT technology and market development', and shared the latest advances in the silicon insulated-gate bipolar transistor (IGBT) industry and market forecasts for the future.

At the meeting, the members of the Power and Compound Semiconductors Committee worked on SEMI's future direction, and discussed how to work together to build the community. Members concluded that the development of industry standards and a thematic meeting on technology and the market, together with industrial policy advocacy, can help to build a bridge between domestic and foreign enterprises.

www.semi.org/en/node/57446

EU's ASCENT project offers researchers access to European nanoelectronics infrastructure

Tyndall National Institute of Cork, Ireland, Grenoble-based CEA-Leti (the French government's Laboratory for Electronics & Information Technology) and nanoelectronics R&D center Imec in Leuven, Belgium have entered into the collaborative open-access project ASCENT (Access to European Nanoelectronics Network) to mobilize European research capabilities.

Funded by the European Union via Horizon 2020 (the EU's framework program for Research and Innovation for 2014–2020) under Grant Agreement No. 654384, the €4.7m project will make the unique research infrastructure of the three European R&D centers available to the nanoelectronics modeling and characterization research community.

ASCENT aims to share best scientific and technological practices, form a knowledge-innovation hub, train new researchers in advanced methodologies, and establish a research network of advanced technology designers, modellers and manufacturers in Europe. The aim is to boost Europe's knowledge in the integral area of nanoelectronics research.

The three partners will provide researchers access to advanced device data, test chips and characterization equipment. Their respective facilities represent over €2bn of combined research infrastructure with what are reckoned to be unique credentials in advanced semiconductor processing, nanofabrication, heterogeneous and 3D integration, electrical characterization, and atomistic and TCAD modelling. This is the first time that access to these devices and test structures will become available anywhere in the world, it is claimed.

The project will engage industry directly through an 'Industry Innovation Committee' and will feed back the results of the open research to device manufacturers, giving them crucial information to improve the next generation of electronic devices.

"In the frame of the ASCENT project, three of Europe's leading research institutes — Tyndall, Imec and Leti — join forces in supporting the EU research and academic community, SMEs and industry by providing access to test structures and electrical data of state-of-the-art semiconductor technologies," comments Imec's Luc Van den hove. "This will enable them to explore exciting new opportunities in the 'More Moore' as well as the 'More than Moore' domains, and will allow them to participate and compete effectively on the global stage for the development of advanced nano-electronics."

www.tyndall.ie

AXT's revenue grows 4.5% in Q2

InP revenue grows 50% year-on-year in first-half 2015, offsetting GaAs weakness and low gallium pricing

For second-quarter 2015, AXT Inc of Fremont, CA, USA, which makes gallium arsenide (GaAs, indium phosphide (InP) and germanium (Ge) substrates and raw materials, has reported revenue of $21m, down 2% on $21.4m a year ago but up 4.5% on $20.1m last quarter.

Of total revenue, 14% came from North America, 59% from Asia Pacific, and 27% from Europe. The top five customers generated about 36% of total revenue (with none over 10% individually), reflecting AXT's diversification of both customers and products.

In particular, in first-half 2015 InP revenue grew by well over 50% year-on-year. "Indium phosphide continues to be a strong contributor to our business for both new and existing applications, including optoelectronic devices for fiber-optic communications, passive optical networks, and data-center connectivity, as well as solar cells and next-generation wireless amplifiers," says CEO Morris Young.

As expected, germanium substrate saw a modest improvement in revenue in Q2/2015, with growth coming largely from traditional aerospace applications.

Following several quarters of healthy growth, revenue from raw material joint ventures was down in Q2. "Gallium pricing has continued to drift lower and we do not expect any major changes in the pricing environment in the near term," says Young. "However, these joint ventures provided us with profitable revenue and additional benefit to our vertically integrated business model."

Even in Q2, AXT posted sequential revenue growth in semi-insulating GaAs substrates, despite the in-roads made by silicon-on-insulator (SOI) hitting the GaAs wireless industry. Wireless business as a proportion of total revenue contribution is currently relatively small. "We continue to expand our engagement with customers in both mobile and non-mobile applications," says Young. "The market has stabilized at this current level, having evolved significantly in the past several years," he believes. "Though we are conservative in the way that we forecast this area of our business, we continue to look for opportunities to increase market share and identify new applications for our products."

Semiconducting GaAs revenue also grew in Q2, despite the fierce competitive landscape in LEDs and excess capacity continuing to present business challenges. "For applications such as backlighting, signage and automotive, with specifications now more stringent, we had better success in maintaining a more reasonable margin profile," says Young. "However, we are consciously stepping away from searching for highly competitive low-end opportunities for which pricing pressure would damage our consolidated gross margin performance, and devalue our product at the high end," he adds. "As such, we are not expecting to see meaningful progress in this area in the near future."

We are consciously stepping away from searching for highly competitive low-end opportunities for which pricing pressure would damage our consolidated gross margin

Although still up on 19.4% a year ago, gross margin has fallen from 23.7% last quarter to 20.9%, due mainly to product mix as well as the decline in raw material pricing.

Operating expenses were $5.2m, cut from $6.5m last quarter (which included $1.2m of professional fees related to the internal investigation of certain potential related party transactions, completed during Q1). However, this is up on $4.7m a year ago, due largely to R&D spending rising from $1m to $1.4m.

Net loss has been slashed from $1m ($0.03 per diluted share) last quarter to $3000 ($0.00 per diluted share), although this compares with a profit of $0.3m ($0.01 per diluted share) a year ago.

Capital expenditure was $1.5m. AXT also used $904,000 in cash to repurchase its stock. During the quarter, cash and investments fell by $1.2m from $47.5m to $46.3m.

"Our financial results in the second quarter were in line with our expectations and we continue to invest and build for the future," states Young.

At the end of July, in an all-cash transaction, AXT acquired privately held firm Crystacomm Inc of Mountain View, CA, USA, which makes InP substrates using the liquid-encapsulated Czochralski (LEC) crystal growth technique, supplementing AXT's vertical gradient freeze (VGF) technique. "The acquisition of Crystacomm is highly synergistic to our current indium phosphide business and provides further competitive differentiation and cost benefits," says Young. "It allows us to broaden our technology base and give us the flexibility to serve customers with varying technical requirements," he adds. The equipment is to be installed in AXT's Freemont facility (where there are already staff that can operate it, so the firm is not adding to the headcount or operating expenses).

"We can use this technology to synthesize polycrystalline material for indium phosphide, which happens to be not a trivial technology, and it's an important part of our cost of goods material cost," says Young. "This will enable us to lower our cost overall and increase our ability to improve our quality."

Crystacomm's founder & CEO Dr George Antypas is staying on as a consultant to assist in bringing up the LEC processes. "George is a pioneer in the development of indium phosphide technology for commercial use," comments Young. "This acquisition comes about opportunistically as the results of our long and positive relationship with Crystacomm. While we are not expecting revenue in this calendar year, we believe that additional capability will provide incremental business opportunities for AXT in the years to come."

For third-quarter 2015, AXT expects some near-term lumpiness in germanium substrate revenue as well as continued pricing weakness in the raw material joint ventures. Revenue should fall to $19.5–20.5m, yielding a loss of $0.03–0.01 per share (compared with a target of $21–22m for breakeven). This is despite InP revenue that is expected to continue good growth year-on-year. "The optoelectronic application is really the driver now," notes Young. "Data-center connectivity is the emerging application which will potentially be a big driver, but it's not a main driver yet."

"While germanium substrate business can be lumpy quarter to quarter, we believe that we have the opportunity to grow and diversify our customer base over time," says Young. "We are pleased to be able to harness extensive industry contacts to engage with a wider set of customers," he adds.

In particular, in late June Dr Hong Hou joined AXT as chief operating officer. "We continue to build strength in our management team," says Young. "Hong has extensive technical and executive level experience in our industry." Hou co-founded Emcore's photovoltaics division and led the commercialization of high-efficiency multi-junction solar cell technology for space power applications. "Having previously served as CEO of Emcore Corp, he has a demonstrated record of success, and he brings the vision and skills necessary to drive further improvement in our operations, and to help us prepare the business for this next level of growth," reckons Young.

www.axt.com

AXT acquires InP substrate maker Crystacomm

LEC-based crystal growth supplements AXT's VGF technique

AXT Inc of Fremont, CA, USA — which makes gallium arsenide, indium phosphide and germanium substrates and raw materials at its facilities in Beijing, China using its vertical gradient freeze (VGF) technique — has acquired privately held firm Crystacomm Inc of Mountain View, CA, USA — which manufactures InP substrates using the liquid encapsulated Czochralski (LEC) crystal growth technique — in an all-cash transaction.

AXT says that indium phosphide is rapidly emerging as a material of choice for both new and existing applications, including optoelectronic devices for fiber-optic telecommunications, passive optical networks (PON) and data-center connectivity, as well as solar cells and next-generation wireless amplifiers. Crystacomm was the first firm in the industry to introduce 2-, 3- and 4-inch InP substrates, and is described as having been a leader in the development of 6-inch InP technology, which has the capability to support the stringent requirements of 5G wireless communications.

"This technology acquisition is highly synergistic to our current InP business and provides further competitive differentiation and cost benefits," says AXT's CEO Morris Young. "It allows us to broaden our technology base, and gives us the flexibility to serve customers with varying technical requirements," he adds. "While we are not expecting revenue from the acquisition in this calendar year, we believe that the additional capabilities will provide valuable and incremental business opportunities for AXT in the years to come."

While still relatively small, the InP market has seen considerable growth over the last two years, driven by fiber-to-the-home (FTTH) network deployments that are actively occurring worldwide, says AXT. For example, China, Singapore and Taiwan have invested heavily in nationwide PON, and network deployments are ongoing in countries such as Australia and New Zealand.

The landscape of InP substrate providers has been limited as a result of the relative technical difficulty in producing substrates that meet the stringent specifications for various optoelectronic and electronic applications. AXT says that it has worked collaboratively with customers to overcome these challenges and has developed robust proprietary manufacturing processes, resulting in significant market share in this expanding market.

The terms of the acquisition (which closed in the second quarter) are not being disclosed. The crystal-growth equipment and processes will be installed in AXT's Fremont facility. Crystacomm's founder & CEO George Antypas will stay on as a consultant to AXT, assisting it in bringing up the Crystacomm LEC-InP crystal growth and poly-synthesis process.

"George's groundbreaking research enabled the early commercialization of InP, and Crystacomm has been at the forefront of the technology progression ever since," comments Young. "We are pleased to bring this valuable technology into our portfolio."

www.crystacomm.com

Veeco enters profit, as EPIK system revenue recognition aids 33% growth in Q2

Most of remaining $55m deferred revenue to be recognized by year-end

For second-quarter 2015, epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA has reported revenue of $131.4m (the highest quarterly revenue since 2012), up 33.7% on $98.3m last quarter and up 38% on $95.1m a year ago. This includes results from Solid State Equipment Holdings LLC (SSEC) of Horsham, PA, USA (now Veeco Precision Surface Processing, i.e. PSP) since its acquisition on 4 December.

The Advanced Packaging, MEMS & RF segment (mainly PSP) contributed 11% of total revenue (relatively level on last quarter). "We are cross-selling into our other market segment, and overall PSP sales were up nearly 28%," notes chief financial officer Sam Maheshwari. "Our Precision Surface Processing business is performing exceptionally well and demand for these products remains healthy," adds chairman & CEO John R. Peeler. "Our differentiated and highly flexible process technology is well established in the broader MEMS market and gaining momentum in the Advanced Packaging space."

The Scientific & Industrial segment comprised 14% of total revenue (level with Q1). Data Storage segment revenue has bounced back, more than doubling sequentially (rising from 7% of revenue to 13%).

The Lighting, Display & Power Electronics segment (mainly MOCVD) contributed 62% of total revenue. Veeco recognized revenue on its first Propel GaN power electronics MOCVD system just six months after its launch last November.

"Our top-line growth has been fueled by the rapid adoption of our TurboDisc EPIK700 MOCVD system [for GaN LED production, launched last September]," says Peeler. "We have now successfully demonstrated the tool's capabilities across multiple customers, which enabled us to begin recognizing revenue upon shipment towards the end of the second quarter," he adds.

"Revenue levels were highly dependent on the timing of the transition of the EPIK product to our standard revenue-upon-shipment model," notes Maheshwari. "We achieved this significant milestone in late May, which was in line with our expectation," he adds. "As a result [in transitioning the new system to a bifurcated revenue model], EPIK tools which shipped after the transition date were included in Q2 revenue; EPIK tools that shipped prior to this transition date will remain in deferred revenue [totalling $55m at the end of Q2] until we receive final customer acceptance."

On a geographic basis, China rose from 45% of total revenue in Q1 to 50%, driven primarily by MOCVD sales to leading LED makers. The remaining 50% of revenue was spread fairly evenly across the USA, EMEA (Europe, the Middle East & Africa) and Rest of the World (including Taiwan, Japan and Korea).

The adverse impact of initial low-margin EPIK revenue was more than offset by the positive effect of higher business volumes combined with a favorable product mix, so — on a non-GAAP basis — gross margin has risen further, from 32.9% a year ago and 37.7% last quarter to 37.9% (above the midpoint of the 36-39% guidance range).

Also, due to the higher business volumes combined with annual merit increases, operating expenses rose from $37.1m last quarter to $40m.

Operating income was $9.75m (compared with a loss of $0.1m last quarter). So, after depreciation of $3m, adjusted earnings before interest, taxes, depreciation and amortization (EBITDA) was $12.75m, up from $2.7m last quarter and compared with a loss of $4.1m a year ago.

Compared with a net loss of $6.1m ($0.16 per diluted share) a year ago and $0.5m ($0.01 per diluted share) last quarter, Veeco has achieved net income of $8.4m ($0.20 per diluted share, above the midpoint of the guidance range).

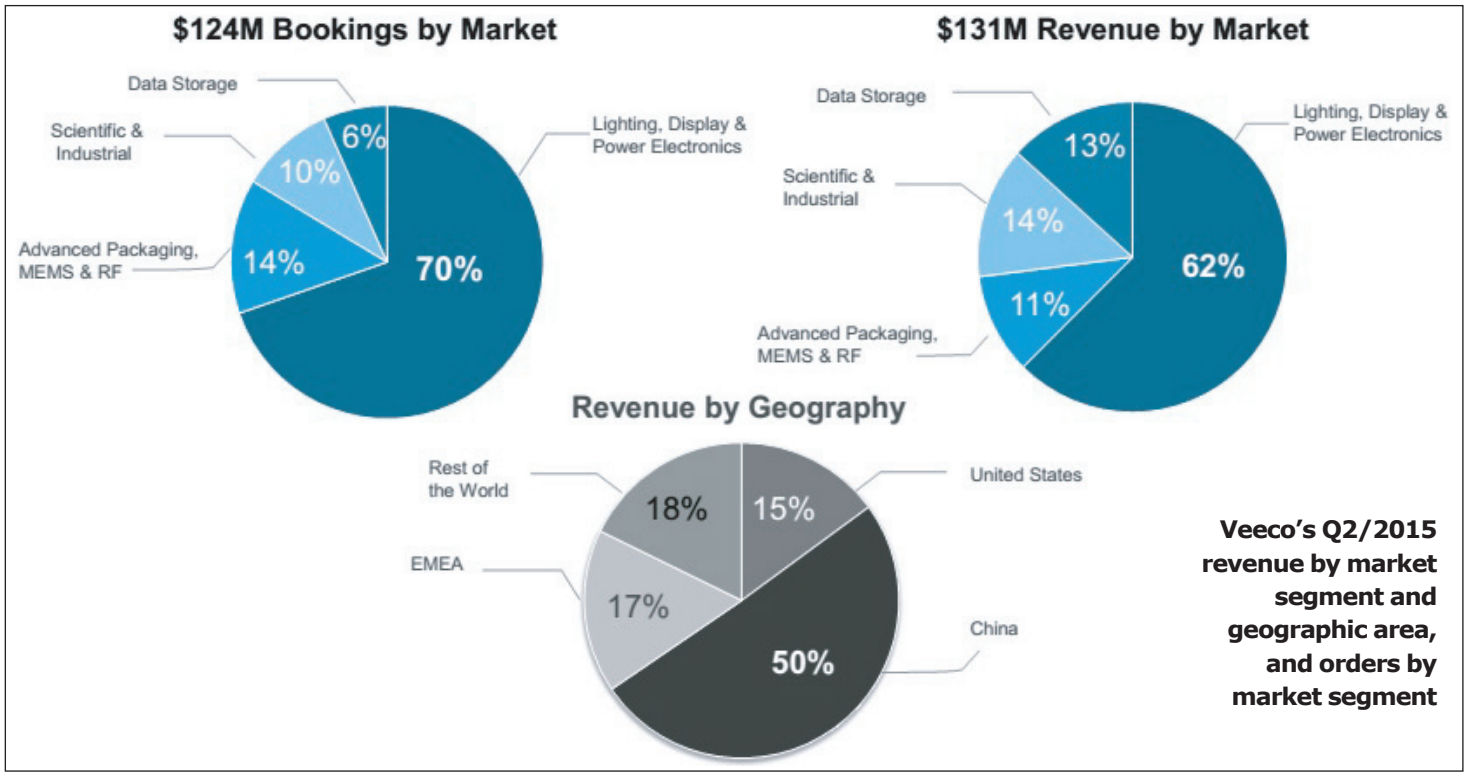
Cash flow from operations has doubled from $4m in Q1 to $8m. During the quarter, cash balance rose slightly from $393m to $396m.

Order bookings were $124m, up about 20% both on last quarter's $102m and $104m a year ago, but lower than the expected $140m due to macro-economic conditions.

Lighting, Display and Power Electronics (mainly MOCVD) rose from 59% of total bookings in Q1 to about 70% in Q2, but they were partially impacted by volatility in the China market. Certain LED makers experienced challenges in accessing capital through the credit markets. "Veeco requires a meaningful cash deposit at the time of booking, which helps to lower our financial risks," says Maheshwari. "Based on discussions with these customers, additional MOCVD capacity is still required and we expect these delayed investments to occur over the next 6–9 months."

Advanced Packaging, MEMS & RF comprised 14% of orders, growing for a fifth consecutive quarter (enhanced by the PSP business). Scientific & Industrial fell from 13% of total orders in Q1 to 10%, while Data Storage fell from 13% to 6%. During the quarter, total order backlog fell from $289m to $279m.

For third-quarter 2015, Veeco expects revenue of $135–160m, driven by strong demand for EPIK. "This latest-generation product offers lower cost of ownership for our customers and improved margin contribution for Veeco, as compared with prior-generation tools," says Peeler. Gross margin should be 37.5–39.5%. Operating expenses



Veeco's Q2/2015 revenue by market segment and geographic area, and orders by market segment

of $40–42m are targeted. Adjusted EBITDA is expected to be $14–24m. Net income should rise to $9–17m ($0.22–0.40 per diluted share).

Importantly, the margin on EPIK tools currently booking is higher than tools shipped in first-half 2015. "We have made excellent progress on our product cost-reduction plans, which we are implementing through the end of this year," says Maheshwari. "We are driving gross margin improvements and target achieving 40% or higher towards the end of this year."

Veeco reiterates its view that full-year 2015 revenue growth will be over 35% (with second-half revenue higher than the first half, boosted by most of the $55m deferred revenue being recognized by year-end). EBITDA is expected to grow faster than revenue.

"We expect LED lighting to drive orders in the near-term and we have indication for additional investments through early 2016," says Maheshwari. "Depending upon the timing of these investments, we would expect second-half bookings to be flat to up compared to the first half of this year."

www.veeco.com

Veeco ships 50th EPIK 700 GaN reactor in under a year

Veeco has shipped the 50th TurboDisc EPIK 700 GaN MOCVD reactor since the system's introduction ten months ago.

Since its launch in September 2014, the EPIK 700 MOCVD system has now been installed, qualified and accepted at multiple LED manufacturers in several key regions around the world. According to recent customer feedback, the TurboDisc EPIK 700 MOCVD system has delivered increased LED wafer production with best-in-class uniformity and easy process transfer between systems, saving both time and money, says Veeco.

"Veeco's EPIK 700 system was designed to facilitate the acceleration of general lighting by combining the LED industry's lowest cost of ownership with its most technologically advanced reactor," says chairman & CEO John Peeler. "These innovations have allowed EPIK 700 customers to better satisfy the demand for solid-state lighting in existing and emerging applications, particularly in the area of general lighting," he adds.

The EPIK 700 is Veeco's latest system in a line of MOCVD reactors. Since the launch of the TurboDisc K465i GaN MOCVD system in 2010, Veeco has steadily grown its market share, becoming the global leader in MOCVD thin-film process equipment, it is reckoned. In 2011, Veeco launched what was said to be the industry's first multi-reactor MOCVD system, the TurboDisc MaxBright GaN system.

"The EPIK 700 system features the advanced TurboDisc reactor design with more than twice the capacity of Veeco's K465i reactor, which translates to higher throughput efficiency to conserve expensive fab floor space," says Jim Jenson, senior VP & general manager, Veeco MOCVD. "Fifty EPIK 700 reactors are the equivalent to more than 100 Veeco K465i MOCVD reactors," he notes. "This increased capacity, improved wafer uniformity and reduced operating expenses enable LED customers to achieve a cost per wafer savings of 20-40% over previous MOCVD systems."

Aixtron's first-half revenue and margin suppressed by delayed customer qualifications for AIX R6 MOCVD tool

Highest order backlog since 2012 to drive strong growth in second-half

For first-half 2015, deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany has reported revenue of €80.7m (down 10% year-on-year on €90.1m in first-half 2014). Of total revenue, 79% came from Asia, 11% from Europe, and 10% from the USA. Equipment revenue was €57.9m (72% of total revenue, with the remaining 28% coming from spare parts & services). Of equipment revenue, by end application, LEDs comprised just 24% (down from 75% in first-half 2014), silicon 32% (up from just 8%), power electronics 19% (up from 5%), and optoelectronics 14% (up from 7%).

In particular, second-quarter 2015 revenue was €40.4m, down by 13% on €46.2m a year ago but roughly levelling off after first-quarter 2015's €40.3m.

Demand for LED chips is growing due to an increasing penetration of LED technology in the lighting market and the demand of LEDs for displays, with high utilization rates at many LED producers. But despite that, orders and shipments in first-half 2015 remained slow.

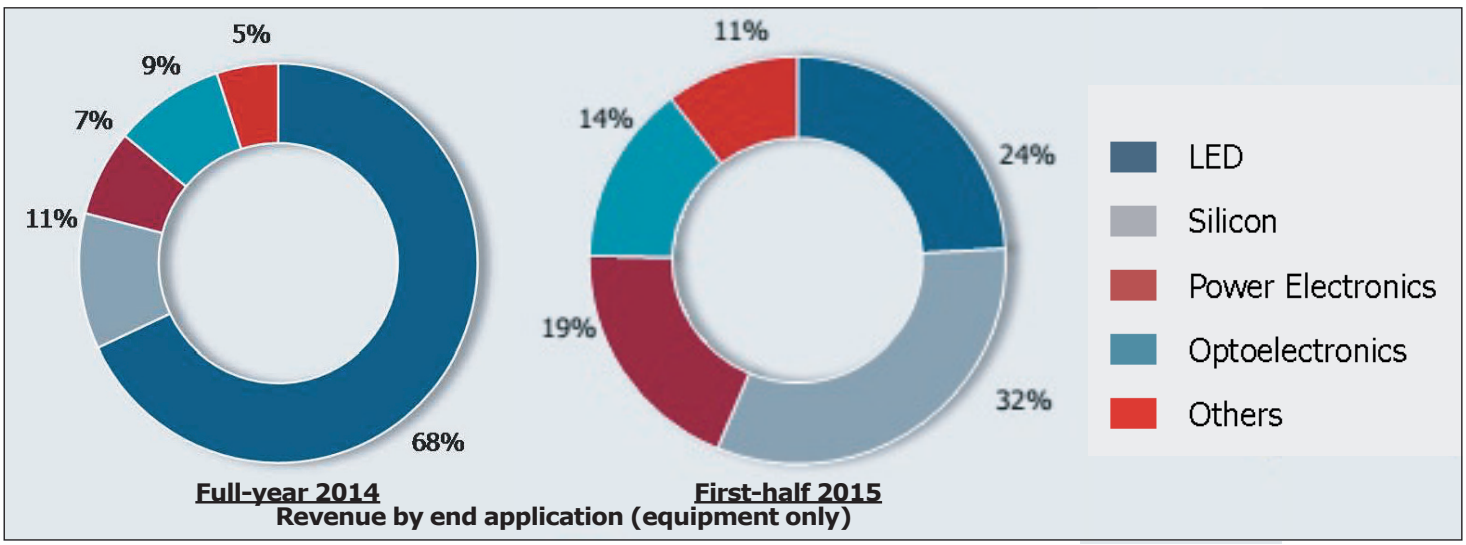
"The weak revenue numbers are a clear reflection of not only the cautious investment behavior of our customers, but also of the AIX R6 qualification process, which has caused potential buyers to wait and see how the product performs other than buying the whole generation of equipment," says president & CEO Martin Goetzeler.

"The AIX R6 Showerhead tool, our latest generation of MOCVD equipment [launched last November for the mass production of LEDs based on gallium nitride (GaN)], is not only important to our overall financial performance in this year but also to the long-term positioning of Aixtron within the LED market," notes chief operating officer Dr Bernd Schulte. "We have had the AIX R6 production qualified at one LED manufacturer. Including this customer, we have secured orders from now eight different customers, up from seven in the previous quarter. We are also getting additional inbound enquiries and interests from customers," he adds. "However, we should not hide the fact, together with our major customers, that it has taken longer than we would have liked to get the AIX R6 to the production stage. Based on detailed programs regarding hardware and process, we are closely collaborating with our customers to support their qualification targets."

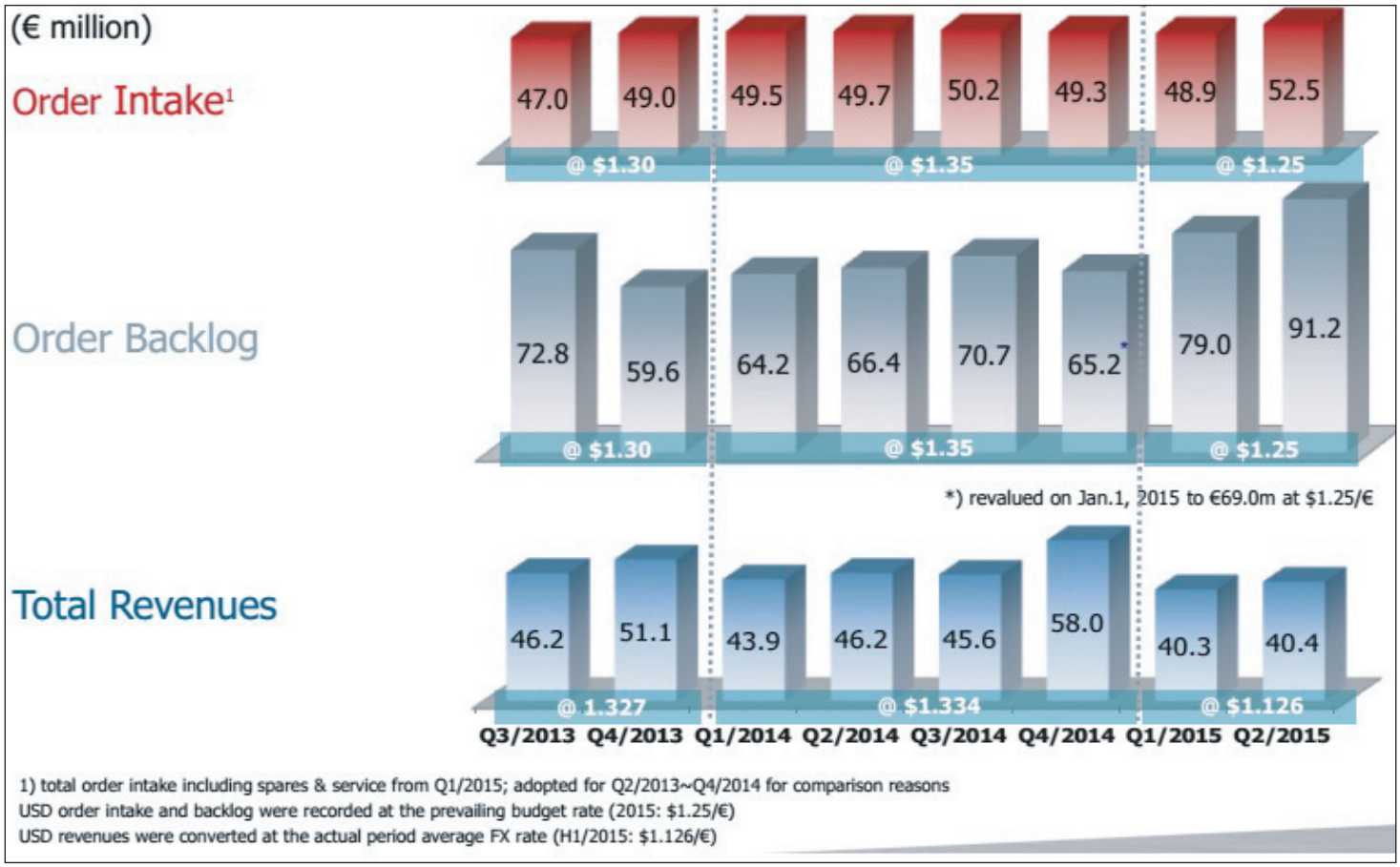
Due mainly to the AIX R6 MOCVD tool's ongoing production qualification process and the resulting actual and anticipated modification costs and inefficiencies, the cost of sales has risen by 17% from €31.5m in Q1/2015 to €36.8m in Q2. Gross margin hence fell to 9% (although, without additional production qualification and modification expenses, it would have improved slightly on first-quarter 2015's 22%). This contributed to first-half 2015 gross margin of 15% being down from first-half 2014's 25%.

Although less than €23.2m a year ago, Q2/2015 operating expenses were €21.5m, up on Q1's €17.6m. This was due to R&D spending being increased by 13% to €14.6m (reflecting order activities including the acquisition of PlasmaSi Inc at the beginning of April as well as work-around on the new-generation MOCVD equipment) plus non-repeating positive currency effects (of €2.7m in Q1). However, for first-half 2015, operating expenses were €39.1m, cut by 11% from €44m in first-half 2014.

Earnings before interest, tax, depreciation & amortization (EBITDA) worsened from –€6.4m in Q1/2015 to –€15.3m in Q2, due in particular to additional qualification expenses for the AIX R6, higher R&D costs, and lower positive currency effects. First-half 2015 EBITDA was hence –€21.8m, a sequential improvement



Revenue by end application (equipment only)



on –€27.9m in second-half 2014 but down year-on-year from –€13.4m in first-half 2014.

However, operating cash flow has improved from negative outflows of –€15.3m a year ago and –€8.6m in Q1/2015 to +€33.7m in Q2, due largely to advanced payments from customers increasing by €15.5m. Free cash flow has improved from –€17.5m a year ago and –€12.1m in Q1 to –€0.1m in Q2, contributing to first-half 2015 free cash flow of –€12.3m being an improvement from –€31.3m in first-half 2014.

During the quarter, cash and cash equivalents (including bank deposits with a maturity of more than three months) fell by €7.8m from €263.2m to €255.4m, due mainly to the currency difference of the US$-based cash and cash equivalents as well as from the acquisition of PlasmaSi.

Equipment order intake (including spares and service) was €101.4m in first-half 2015, up 2% on last year's €99.2m. This was driven by Q2 orders of €52.5m, up 7% on Q1's €48.9m and up 6% on a year ago. Total equipment order backlog at the end of June was €91.2m, up 15% on €79m at the end of first-quarter 2015 and up 37% on €66.4m a year previously (and the highest since 2012). "This gives us good visibility to our revenues for the later part of the year, as the majority of the backlog is shippable in 2015," says Goetzeler.

"We continue to make good progress in the strengthening of our product and technology portfolio," says Goetzeler. "In the field of OLEDs, we are seeing strong interest from customers regarding the technology of the recently acquired PlasmaSi," he adds. Integration of PlasmaSi Inc of Fremont, CA, USA — which provides low-temperature silicon nitride plasma-enhanced chemical vapor deposition (PECVD) systems for the encapsulation of organic thin-films in organic light-emitting diodes (OLEDs) — is going well, with measurable market and customer synergies in OLED technology expected shortly. "First test runs of our Gen8 demonstrator for the production of large-area OLEDs are positive," says Goetzeler. Aixtron forecasts first orders for the Optacap OLED encapsulation technology later this year.

"In the LED space, our business environment for the second half is developing as expected, allowing for the announced growth in shipments compared to the first half of this year," says Goetzeler. "Besides the LED-driven demand, we are expecting strong contributions from our other product groups such as power and memory and logic, both of which will show a year-on-year increase growth in 2015. We are also seeing increased interest for our planetary reactor MOCVD platform for LED, laser and telecommunications applications."

Supported by the increased order backlog, Aixtron reiterates its February revenue forecast of €220–250m for full-year 2015 (based on existing $/€ exchange rates), up on €193.8m in 2014. This also includes expected shipments of AIX R6 MOCVD tools, which still depend on successfully reaching individually agreed milestones within ongoing customer-specific production qualification processes. Management continues to expect to return to EBITDA break-even in second-half 2015.

www.aixtron.com

Asahi Kasei orders Aixtron CCS MOCVD system to start commercial production of DUV LEDs

Equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany says that Tokyo-based chemical company Asahi Kasei has ordered a Close Coupled Showerhead system (CCS) metal-organic chemical vapor deposition (MOCVD) system, for delivery in third-quarter 2015, for pilot production of deep ultraviolet (DUV) LEDs based on aluminium gallium nitride (AlGaN). Asahi Kasei acquired UVC LED maker Crystal IS Inc of Green Island, NY, USA in late 2011.

Aixtron says that Asahi Kasei's decision to purchase a Showerhead reactor for DUV LED production is based on the positive experience with a previous MOCVD tool already in operation. It chose Aixtron's proven CCS technology again as it enables the optimization of the chamber geometry for both high- and low-pressure regimes by the additional dynamic chamber height adjustment.

Aixtron's Close Coupled Showerhead system, in 6x2"-wafer configuration.

"Our MOCVD tool enables pilot production as well as R&D applications with processes that are directly scalable to larger systems," says Aixtron's executive VP & chief operating officer Dr Bernd Schulte. "Enhanced by the reliable 3-zone heater, the system also provides excellent temperature uniformity," he adds. "This leaves Asahi Kasei with a very flexible, high-quality tool, perfectly matching the increasing demand for high-performance deposition systems for new application fields such as DUV LEDs."

High-performance DUV LEDs are used for purification and sterilization in applications including industrial and point-of-use (POU) water purification. DUV LEDs are also used in scientific and industrial instruments to measure the purity of water, air, surfaces and biological samples.

www.asahi-kasei.co.jp
www.cisuvc.com/products/optan
www.aixtron.com

Transfer of ALLOS' 150 and 200mm GaN-on-Si epi technology to Epistar concluded in under 6 months

Reproducible crystal quality achieved with total dislocation density of $2x10^8cm^2$

Technology engineering & licensing firm ALLOS Semiconductors GmbH of Dresden, Germany have concluded its joint project to establish its mature 150 and 200mm gallium nitride on silicon (GaN-on-Si) technology at Epistar Corp of Hsinchu Science Park, Taiwan (the world's largest manufacturer of LED epiwafers and chips).

The project was executed with better-than-expected results and ahead of schedule in less than six months. For example, reproducible crystal quality was achieved with a total dislocation density of $2x10^8cm^2$. It is reckoned that, with this performance, Epistar has caught up with the world-leading results of forerunners that have been developing GaN-on-Si LED technology for some time.

During the project ALLOS established its GaN-on-Si epiwafer process on Epistar's epitaxial reactors. Epistar engineers were trained and worked in the integrated project team with ALLOS to gain full understanding and control over the GaN-on-Si technology. Currently, Epistar's own LED technology is being transferred to GaN-on-Si structures.

"To conduct the technology transfer with ALLOS has proven to be the right decision for Epistar as it allowed us to quickly gain command over their leading GaN-on-Si technology in a very cost-efficient and reliable way," comments Epistar's president Dr M. J. Jou. "In a second phase we will now be focussing on realising the cost advantages of GaN-on-Si LEDs and to unlock the application benefits," he adds.

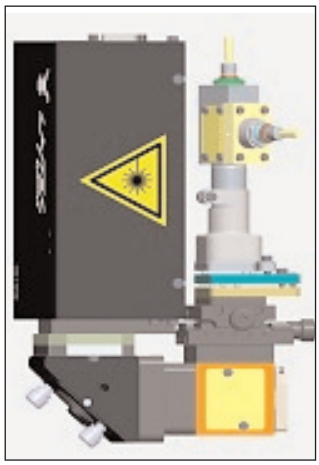
"To accomplish a project of this size and complexity with such results is a complete success," comments ALLOS' CEO & co-founder Burkhard Slischka. "This result underlines ALLOS' project execution skills as well as our technical capabilities to grow crack-free wafers with market-leading crystal quality," he claims. "This is an example that our fast, cost-effective and successful implementation of GaN-on-Si helps our customers to reduce development risk and to save time and money."

www.epistar.com.tw
www.allos-semiconductors.com

LayTec develops new EpiCurve TT for large single wafers in D125 high-speed rotation reactors

In-situ metrology system maker LayTec AG of Berlin, Germany has developed a new version of its EpiCurve TT tool for combined reflectance, wafer temperature and wafer bow measurements on large single wafers in D125 high-speed rotation metal-organic chemical vapor deposition (MOCVD) reactors. The first system will be shipped to a customer in USA in September.

LayTec says that the new version of the EpiCurve TT closes a technology gap formerly existing for large single-wafer configurations in high-speed rotation reactors due to the limitations of scanning single-beam deflectometry. In the system, LayTec combined its high-resolution multi-beam wafer bow sensing with three-wavelength reflectance and wafer temperature measurement.



The EpiTT optical head (right) and Curvature sensor head (left) are combined. A compact design enables upgrades in confined space conditions.

The system is equipped with LayTec's latest EpiNet software package, which allows thickness and composition monitoring for specific material classes at an accuracy level formerly reached only by x-ray diffraction (XRD), it is claimed.

www.laytec.de/epicurve

Improved n.k database for III-nitrides

LayTec and its R&D partners recently published high-accuracy high-temperature n.k data for arsenides and phosphides, enabling in-situ process control of layer thickness and composition at the same level of accuracy as x-ray diffraction or photoluminescence [May's CS MANTECH and June's EWMOVPE].

Now, at the International Conference on Nitride Semiconductors (ICNS) in Beijing, China (30 August — 4 September), LayTec has presented a similarly expanded and improved n.k database for the III-nitrides as part of the latest version of its EpiNet software.

LayTec reckons the high-accuracy n.k data, in conjunction with Pyro 400 wafer temperature control, should enable more comprehensive and direct statistical process control of III-nitride-based manufacturing on patterned sapphire substrates, silicon and gallium nitride wafers.

SPTS receives a $16m multi-system etch and deposition order for GaAs foundry WIN's third fab

SPTS Technologies Ltd of Newport, Wales, UK (an Orbotech company that manufactures etch, PVD and CVD wafer processing solutions for the MEMS, advanced packaging, LED, high-speed RF on GaAs, and power management device markets) has received an order worth about $16m for multiple etch and deposition systems from Taiwan's WIN Semiconductors Corp (the world's largest pure-play gallium arsenide foundry services for wireless infrastructure and networking markets), for shipment in second-half 2015. The systems will be used to make heterojunction bipolar transistor (HBT) and pseudomorphic high-electron-mobility transistor (pHEMT) devices in WIN's Fab C (its third and newest fab).

SPTS Technologies been a supplier to WIN since the foundry's inception in 1999. "They recently announced their 1 millionth GaAs wafer shipment, and our systems have added value to every one of those wafers," notes Kevin Crofton, president of SPTS and corporate VP at Orbotech. "Over those 16 years, our technology roadmaps have been shaped by leaders such as WIN, and this repeat order confirms that our etch and deposition solutions continue to deliver production advantages," he adds.

"The GaAs device market is entering a phase of growth, driven by the increasing complexity of RF designs inside smartphones and the accompanying infrastructure," says WIN senior VP Steve Chen. The leading smartphones contain up to five power amplifiers (PAs), and the increasing complexity in dealing with multiple RF bands from 2G up to 4G, and the uptake of more capable smartphones, are expected to support the market's continued growth. "We have the flexibility and technology bandwidth to react to the fast-changing demands of a consumer-driven market, and SPTS has the same mindset," he adds. "Sixteen years ago, we selected SPTS to join us in the new world of GaAs foundry services, and today we own approximately 60% of the foundry market share and are opening our third fab. The support and commitment of SPTS has contributed to that success."

www.winfoundry.com
www.spts.com

SPTS achieves UK's Investors in People Silver Standard

SPTS Technologies Ltd of Newport, Wales, UK has been awarded the UK's Investors in People Silver standard for demonstrating "commitment to realizing the potential of its workforce by going above and beyond for its staff".

Named an 'Anchor Company' by the Welsh Government in 2014, SPTS has nearly 300 staff at its headquarters and main manufacturing site in Newport, South Wales, plus an additional 200 in Europe, Asia and North America. SPTS' equipment is used to manufacture semiconductor and microelectronic devices found in consumer electronic products, domestic appliances and automobiles, including almost every smartphone, energy management and control sensors in appliances, and automobile safety systems.

Investors in People is the UK's leading accreditation for business improvement through people management, and provides resources for businesses to innovate, improve and grow.

Investors in People Silver standard is "the sign of a company which is very committed to good people management practice," states Paul Devoy, head of Investors in People. "It is important to ensure that all employees have the opportunity to develop the skills they need to effectively perform their duties and for individual career development" comments Kevin Crofton, president of SPTS and corporate VP of Orbotech. "Clearly defining shared goals for the company and setting individual objectives toward those goals have been key contributors to our success," he adds. "By working with and investing in our people, we have been rewarded with a sustainable and profitable business."

www.investorsinpeople.co.uk

Plasma-Therm workshop at Taiwan's National Tsing Hua University

More than 145 people from 18 companies and seven universities and research institutes recently attended a workshop hosted by plasma processing equipment maker Plasma-Therm LLC of St Petersburg, FL, USA at National Tsing Hua University (NTHU) in Hsinchu, Taiwan.

In addition to talks discussing the basics of plasma processing and presentations addressing etching of dielectrics, compound semiconductors and deep silicon etching, for the first time the workshop included an overview of plasma dicing (which is expected to supplant the use of saws for wafer dicing). Plasma-Therm's plasma Singulator systems allow manufacturers to place more dies on each wafer, increase throughput, improve die strength, and implement solutions for advanced packaging issues, such as dicing ultrathin wafers and designing dies shaped to avoid corner-stress complications.

www.plasmatherm.com

Oxford Instruments schedules fourth Indian nanotechnology seminar for November at IIT Madras

On 3–4 November, UK-based Oxford Instruments is holding the fourth in its series of nanotechnology seminars in India, showcasing nanotechnology tools and their use in multiple fields.

The two-day seminar 'Bringing the Nanoworld Together 2015' at the Indian Institute of Technology Madras (IIT-M), Chennai, will consist of over 24 talks from Indian and international expert speakers as well as Oxford Instruments scientists, and will also include technical poster sessions.

The keynote speaker is professor Rudolf Gross of Walther-Meissner-Institute at the Technical University of Munich, Germany, who conducts research in low-temperature solid-state physics. The main focus of his research is innovative superconducting and magnetic materials and nanosystems, the application of solid nanostructures in quantum information processing, spin electronics, and modern manufacturing methods for oxidized heterostructures. Gross is a board member of the Excellence Cluster Nanosystems Initiative Munich (NIM) and is a spokesman for the Collaborative Research Center on Solid State Quantum Information Processing.

The first day comprises plenary talks with the theme 'Convergence of the Nanosciences' followed by parallel sessions on day two:

- Session A: 'Thin Film Processing and NanoAnalysis sessions' — Fabrication of wide-bandgap semiconductors and the latest advances in sensor fabrication, followed by sessions on nano-analysis technology and applications.
- Session B: 'Materials Characterization, Surface Science and Cryogenic Environments' — Topics including cryo-free low-temperature solutions, atomic force microscopy (AFM), nanomechanics and in-situ heating. Andor Technology will also showcase high-performance optical cameras and software used in the physical and bio sciences.

"We dedicate these educational seminars to our customers to enhance their knowledge and keep them informed of the latest technological advances their systems have to offer," says Oxford Instruments' group business development director Charles Holroyd. "We aim to provide ample opportunities for networking, debate and discussion around the ever progressing nanotech world."

www.oxford-instruments.com/btnt

Rubicon's revenue falls 20% in Q2, as 2-inch sapphire core sales and pricing are hit by weak mobile market

Resource sharing agreement with sapphire polisher to speed cost reduction

For second-quarter 2015, Rubicon Technology Inc of Bensenville, IL, USA (which makes monocrystalline sapphire substrates and products for the LED, semiconductor and optical industries) has reported revenue of $7.1m, down 51% on $14.5m a year ago and down 20% on $8.9m last quarter due to weaker sapphire demand (most likely resulting from increased TV inventory levels and some seasonality in the LED light bulb market) and lower pricing.

"While sapphire pricing rose in the first half of last year, pricing has declined over the past several quarters and the current pricing environment is particularly tough," says president & CEO Bill Weissman. "The continued oversupply in the market along with weak currencies in Russia and Japan have been compounded by the current softness in the market."

Specifically, demand from the mobile market was weaker, resulting particularly in lower 2-inch core volumes and additional pressure on pricing (which is down 18% on last quarter and almost halved from a year ago). Revenue from 2-inch cores has hence fallen further, from $6.4m a year ago and $4m last quarter to just $2.6m. Revenue from 4-inch cores rose from $1m to $1.2m, although that is still down on $3.2m a year ago. Revenue from 6-inch cores rose from just $23,000 last quarter to $171,000. Total revenue for cores fell further, from $9.6m a year ago and $5.1m last quarter to $4m.

Overall wafer revenue was roughly unchanged sequentially. However, polished wafer sales have fallen further, from $2.6m a year ago and $1.43m last quarter to $0.84m because the firm's focus on wafer sales has shifted exclusively to patterned wafers, where it believe there is greater margin opportunity. Patterned sapphire substrate (PSS) wafer sales have hence begun to accelerate, from $0.26m a year ago then nearly doubling from $0.46m last quarter to $0.9m.

Optical revenue fell by $578,000 from $1.77m last quarter to $1.19m due to lower sales volume.

Crystal growth operations continued to run at full capacity, but wafer polishing and patterning operations remained under-utilized. However, idled plant costs fell from $2.2m to $1.6m as PSS production was increased at Rubicon's facility in Penang, Malaysia.

Operating expenses were $3.17m, up from $2.84m last quarter due mainly to R&D spending (on personnel and projects) rising from $0.43m to $0.6m, as well as an increase in legal fees.

Raw material inventory balance was lowered further, by $1.4m from $12.9m to $11.5m. "In addition to reducing our per-unit costs through our internal raw material process, we have also reduced the total quantities in inventory," says Weissman. However, total inventory levels increased by $320,000, as working process inventory rose by $1.2m because Rubicon built in advance some inventory for third-quarter shipments.

Given the lower 2-inch demand, Rubicon has also temporarily scaled back some of its crystal growth operations from full production to about two-thirds capacity, as well as limiting its raw material production. We are retaining key personnel to ensure we can scale back up to full production quickly as market conditions improve

Given the lower 2-inch demand, Rubicon has also temporarily scaled back some of its crystal growth operations from full production to about two-thirds capacity, as well as limiting its raw material production. "While we expect the market to improve, it is difficult to predict the timing, and we want to avoid building inventory," says chief financial officer Mardel Graffy. "The reduced throughput will still give us sufficient crystals to support our growing PSS business and support our key core customers, while allowing us to reduce inventory levels, particularly in raw materials," he adds. "Reducing raw material and crystal inventory will improve cash flow in the near-term, and we are retaining key personnel to ensure we can scale back up to full production quickly as market conditions improve."

While the sequential price decline put additional pressure on operating results, net loss was $8.6m ($0.33 per share), up only slightly from $8.3m ($0.32 per share) last quarter and still better than $10m ($0.39 per share) a year ago.

Net cash used in operating activities has risen from $3.9m last quarter to $5.1m (doubling from $2.5m a year ago). During the quarter, cash and short-term investments hence fell from $41m to $36m (with no debt).

"One of the objectives this year is to become cash-flow positive by the end of this year," says Weissman. "While it will be difficult to hit that target this year without some pricing increases, we remain focused on that objective," he adds. "The time it will take for the excess capacity in the marketplace to be absorbed is difficult to predict. At this time,

we are placing intense focus on reducing product costs and introducing new products, while tightly managing cash flow."

"Through yield improvement and raw material cost reductions, we have reduced our crystal growth costs by about 15% in the past year," Weissman says. "We continue to work on process improvement and design changes to continue to drive crystal costs lower. One such change is the conversion of our 83kg furnaces to 93kg, which will allow us to increase throughput for a nominal incremental cost, and also increase yield. The conversion is being done gradually according to our maintenance schedule to avoid premature replacing expensive parts," he adds.

"We have also made progress in reducing wafer costs. Our original polishing operation was focused only on 6-inch wafers and we subsequently added 4-inch polishing to support our entry into 4- as well as 6-inch PSS," says Weissman. "A key to optimizing the potential of our PSS capacity is to further reduce our polishing costs, and this has been a top priority for us this year, but reducing polishing costs has progressed more slowly than we have expected."

Resource sharing agreement

To expedite polishing cost reductions, Rubicon has hence also recently signed a resource sharing agreement with a leading sapphire polisher, under which it will receive a 4-inch polishing process that should halve its polishing costs, Rubicon believes, in exchange for making available to the other party the use of about half of Rubicon's under-utilized slicing and polishing capacity in Malaysia. Despite relinquishing about half of its existing installed capacity, the new lower-cost process is also higher throughput, so Rubicon's polishing capacity will only shrink to about 70%.

"The capacity we retain should be ample to meet our full PSS capacity needs and will allow us to spread some of our manufacturing overhead to further reduce costs," says Weissman. Rubicon will continue to use its existing 6-inch polishing process but believes that some of the process modifications made for 4-inch will be transferrable to 6-inch and result in reduced cost for that product as well. The process improvement is not expected to require any additional capital expenditure.

We are focusing on PSS wafer sales because we believe this product has greater margin potential than polished wafers. The resource sharing agreement will allow us to reduce [slicing and polishing] costs faster than internal development, especially for 4-inch wafers

"The industry got too much capacity and there needs to be consolidation in one form or another," believes Weissman. "We need to make sure that the capacity that's out there is being used efficiently. This agreement works very well for both parties and makes us more cost-efficient and provides them with what they need, which is some additional capacity," he adds.

"During the current down cycle in the market, we have been focusing on a number of key initiatives: aggressively pursuing our PSS potential; targeting high-margin optical applications; driving down product costs; and developing new products… we are making progress on each of these fronts," says Weissman. "Our goal is to focus on products that require more intellectual property to produce like PSS wafers, particularly in larger diameters, and optical products."

Rubicon recently received a $9m purchase order from a new user of 6-inch PSS wafers (to be delivered over 12 months starting this October). Another major LED maker was moving to 6-inch PSS this year, but they are going at a slower pace than expected so far, says Weissman, while the other major 6-inch user in Asia is also a bit slower (both slowdowns resulting from weakness in general market conditions)."Overall, we are still seeing more interest in 6-inch," he adds. Rubicon hence expects PSS wafer sales to continue to ramp towards meaningful volumes through the rest of 2015. "We are focusing on PSS wafer sales because we believe this product has greater margin potential than polished wafers; however, we must reduce slicing and polishing costs in order to realize the potential… The resource sharing agreement will allow us to reduce those costs faster than internal development, especially for 4-inch wafers," Weissman adds. Due to the new resource sharing agreement plus the continuing increase in PSS wafer orders, Rubicon expects utilization of its Malaysia factory to increase significantly.

Rubicon expects the challenging market to continue in the third quarter. While PSS wafer sales are expected to increase, visibility on 2- and 4-inch core sales is limited, so Q3 revenue should be at or below Q2 levels. PSS revenue is expected to continue to grow in the fourth quarter, when demand for 2- and 4-inch core should also strengthen, the firm believes.

Process changes associated with the resource sharing agreement will be made over the remainder of 2015. "The extent and timing of cost reductions from these changes will be better understood as the changes are implemented," says Graffy. However, for Q3, loss per share is expected to be at or higher than Q2.

"While the timing is uncertain, we believe that the pricing environment will improve. This improvement, along with the actions we are taking this year in cost reduction, technology development and new product introductions will position the company to generate strong margins once again," concludes Weissman.

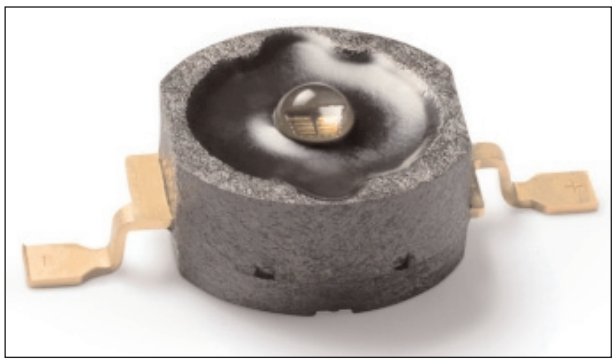
www.rubicon-es2.com

Crystal IS launches surface-mount Optan UVC LED for sensor and instrumentation makers

Crystal IS Inc of Green Island, NY, USA, an Asahi Kasei company that makes proprietary ultraviolet light-emitting diodes (UVC LEDs) grown pseudomorphically (strained) on aluminum nitride (AlN) substrates, has launched its latest Optan UVC LED product. Operating from a maximum drive current of 300mA in continuous mode, the Optan SMD (surface-mount device) UVC LED emits at wavelengths of 260–275nm over a wide viewing angle of 100° with light output of more than 2mW. The typical L50 life-time is 3000 hours at 100mA.

Targeted at manufacturers of sensors and instrumentation in ocean and industrial process applications (for which performance and reliability are critical), the Optan SMD is a long-life solution with low power consumption, giving users an increase in intervals for instrument maintenance.

Optan SMD is environmentally friendly, which is essential for the control of damage from bacteria and biofilms (which has a wide-ranging impact across industries that is estimated to cost several hundred billion dollars annually). However, solutions available currently are either not completely effective or being phased out due to toxicity concerns. "Our customers came to us with a difficult situation in controlling biofouling, where coatings, traditional UV lamps or mechanical wipers weren't that effective," says CEO Larry Felton. "Our latest Optan product will solve that problem, especially when it comes to ocean and industrial process instrumentation." Crystal IS says that the Optan SMD enables more effective and efficient biofilm and biofouling control.



Crystal IS' new Optan SMD (surface-mount device) UVC LED.

The Optan SMD also supports total organic carbon (TOC) monitoring in water (since high levels of TOC can degrade industrial water purification systems, reducing semiconductor yields, contaminating pharmaceutical batches and damaging power and steam generation equipment).

In addition, the Optan SMD can be used as a low-voltage source of UVC light for the calibration of cameras, photodetectors, etc.

Samples of the Optan SMD are available now.

www.cisuvc.com/products/optan

Intertronics launches versatile multi-wand UV LED spot curing system

Intertronics of Kidlington, UK has launched the DYMAX BlueWave QX4, which brings together the benefits of LED UV curing in a small and compact package that enables users to operate quickly and with more control, it is claimed.

The QX4 multi-wand UV spot curing system puts the high-intensity LEDs and lenses close to the substrate in each emitting head, with lightweight flexible connecting leads in place of light guides. This enables easy placement of up to four heads of high output power (up to 1W per head), which can deal with complex geometries or multiple cure points.

The system is modular with wands available in three wavelengths — 365nm, 385nm and 405nm — to suit varying compatible adhesives, coatings, sealants or other light cure materials. Lenses of 3mm, 5mm and 8mm diameter can be changed on each wand to refine the cure window.

Intertronics' new high-performance UV LED cure system.

Intertronics says that the QX4's small form factor is useful on crowded workstations in streamlining production space. It also offers a simple, easy-to-use interactive touch-screen control panel and foot pedal operation, or PLC interface for fully automated output.

The BlueWave QX4 features instant on/off operation with no warm up required, low operating temperature, 20,000-hour light source life with no performance degradation, and low energy consumption.

www.intertronics.co.uk/qx4

RayVio expands UV LED manufacturing capacity and global sales force

Expansion to reduce cycle time and produce 2 million LEDs annually

RayVio Corp of Haywood, CA, USA, which is commercializing deep-ultraviolet (UV) LEDs and consumer disinfection solutions, is expanding its international sales force and manufacturing capacity to support increased customer demands. The facility expansion at the original site is scheduled to be complete by year-end.

RayVio's core technology was invented by co-founder Dr Yitao Liao (chief technology officer) and professor Theodore Moustakas, and is exclusively licensed from Boston University. The patent-protected UV LED technology is based on a proprietary and fundamentally different approach compared with techniques that have been attempted by the industry unsuccessfully for the past 15 years, it is claimed, enabling the firm to provide the highest optical power at the lowest cost than is otherwise commercially available.

RayVio's existing Silicon Valley headquarters houses its wafer growth, chip fabrication, packaging and test R&D and prototyping capabilities. The expansion of the facility should enable RayVio to reduce cycle time and produce in excess of 2 million LED units annually through the installation of additional manufacturing and test equipment. Combined with its contract manufacturing strategy, RayVio says that it aims to keep pace with the increasing demand of the fast-growing deep UV LED market.

Demand is being driven by industrial and consumer applications ranging from water disinfection to consumer medical devices serving multiple global markets. With the demonstration of power levels up to 45mW from a single-emitter device, and multi-chip offerings capable of delivering much higher power, RayVio says its complete product suite is tailored to meet the needs of all UV applications.

With the funding we received earlier this year, we have the capital required to grow the company aggressively

"Our proven, novel technology platform is producing best-in-class performance," claims Dr Doug Collins, VP of engineering and operations, "and at the same time we are executing against our cost-reduction roadmap, allowing our downstream partners to make their products a reality."

Until recent achievements in both performance and cost, UV LEDs were limited to niche applications, notes the firm. With the availability of high-optical-power UV LEDs, and system-level pricing that is competitive with alternative UV sources, the UV LED industry is seeing a major uptake in solutions being provided, it adds.

"With the funding we received earlier this year, we have the capital required to grow the company aggressively," comments co-founder & CEO Dr Robert C. Walker. RayVio came out of stealth mode at the beginning of 2015 after closing its $9.3m series B round of financing. It is currently sampling selected customers, and working closely with partners in the UV LED curing, medical device and water, surface & air disinfection markets.

www.rayvio.com

HexaTech signs Okaya as sole representative in Japan

Okaya makes direct equity investment in HexaTech

HexaTech Inc of Morrisville, NC, USA, which manufactures aluminium nitride (AlN) substrates and is developing long-life UV-C LEDs and high-voltage power devices, has signed a broad, strategic agreement with Okaya & Co Ltd of Nagoya, Japan, and its US subsidiary Okaya USA Inc that establishes Okaya as the sole representative for HexaTech's AlN substrate products in Japan, as well as including a direct equity investment by Okaya in HexaTech. The agreement further sets the stage for Okaya to assume a leadership position to market and sell HexaTech's line of UV-C light-emitting diodes (targeted for launch later this year).

HexaTech says that its AlN materials have been shown to be an essential foundation for record-setting UV-C LEDs, which have the potential to revolutionize the sterilization and purification markets, by providing compact, highly efficient, long-life sources of light.

"Their strong belief in HexaTech and our current and future products, as supported by the Japanese market, highlight that our business strategy is ideally positioned and customer-focused," says HexaTech's CEO John Goehrke regarding Okaya. "Further, as we look to our upcoming UV-C LED launch, we anticipate a further integration of our business activities, relying on Okaya's strengths in this important market," he adds.

"HexaTech's current substrate products, as we know from our customers, are not only world-leading but we foresee their future LED products to be in great demand, creating significant opportunities for both companies," remarks Okaya's senior management.

www.okayausa.com/index.php

Seoul Viosys' acquisition of controlling stake in SETi approved by US DoD

SETi's UV-LED production capacity to be expanded threefold by end 2016

UV LED firm Seoul Viosys Co Ltd has acquired a majority stake (over 50%) in Sensor Electronic Technology Inc (SETi) of Columbia, SC, USA, which manufactures deep-ultraviolet (DUV) LED devices and modules emitting at wavelengths of 240–355nm.

Seoul Viosys has subsequently decided to expand SETi's UV LED production capacity threefold by the end of 2016.

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

Viosys produced 365–405nm UV-A (near-UV) LEDs for the first time in 2002. But in 2005 the firm made an equity investment in SETi, and subsequently produced its first 254–340nm UV-C and UV-B (deep UV) LEDs. Viosys has since maintained close technical cooperation with SETi for over 10 years to commercialize UV LED chips with wavelengths below 350nm. Viosys is now capable of producing LEDs spanning the entire UV wavelength range (from 230nm to 405nm), and holds over 10,000 patents related to the field. Applications include the bio, hardening, forgery detection, medical appliances and sterilization markets.

Viosys is now capable of producing LEDs spanning the entire UV wavelength range (from 230nm to 405nm). The source technology of short-wavelength UVC and RF we recently secured by obtaining the approval of the US Department of Defense is the future technology essential for the space industry and defense industry

Since SETi's UV LED chip patents are critical components in the aerospace and defense industries, Seoul Viosys had to pass US Department of Defense (DoD) International Traffic Arms Regulations (ITAR) and to get approval from the US Committee on Foreign Investment in the United States (CFIUS), which Seoul Viosys had been trying to achieve for the past three years.

"The source technology of short-wavelength UVC and RF we recently secured by obtaining the approval of the US Department of Defense is the future technology essential for the space industry and defense industry," notes Viosys' representative Jae-jo Kim. "Seoul Viosys will expand this business globally based on related patents and mass-production technology."

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

Seoul Semiconductor wins US patent infringement lawsuit against Craig Electronics

After South Korean LED maker Seoul Semiconductor filed a lawsuit in July 2014 asserting that US-based Craig Electronics' sales of LED back-lighting unit (BLU) products infringed five of its patents, the US Federal District Court has now issued a judgment stating that Craig has acknowledged infringement of all the asserted patents as well as the validity of the patents.

The patents cover a wide range of technologies including, but not limited to, back-lighting units (BLUs), LED packaging, LED chips and epitaxial layers, and black hole lenses. Together, the patented technologies cover essential components and features of modern back-lighting units, including manufacturing systems, LED displays, and optical devices. In particular, Seoul Semiconductor's patented technology for lenses - having a curved shape at the center – helps to ensure uniform illumination across the entire area of the liquid-crystal display for back-lighting units, enhancing image quality on the LCD display, the firm claims.

"To safeguard our licensees' and customers' interests in using Seoul Semiconductor's patented technology, Seoul Semiconductor will continue to discover infringing LED application products in the market and maintains an enforcement program that will consider any and all enforcement options against third-party infringers who do not respect Seoul Semiconductor's intellectual property rights," states the firm. "Indeed, we are pursuing another patent infringement lawsuit against suspected infringers."

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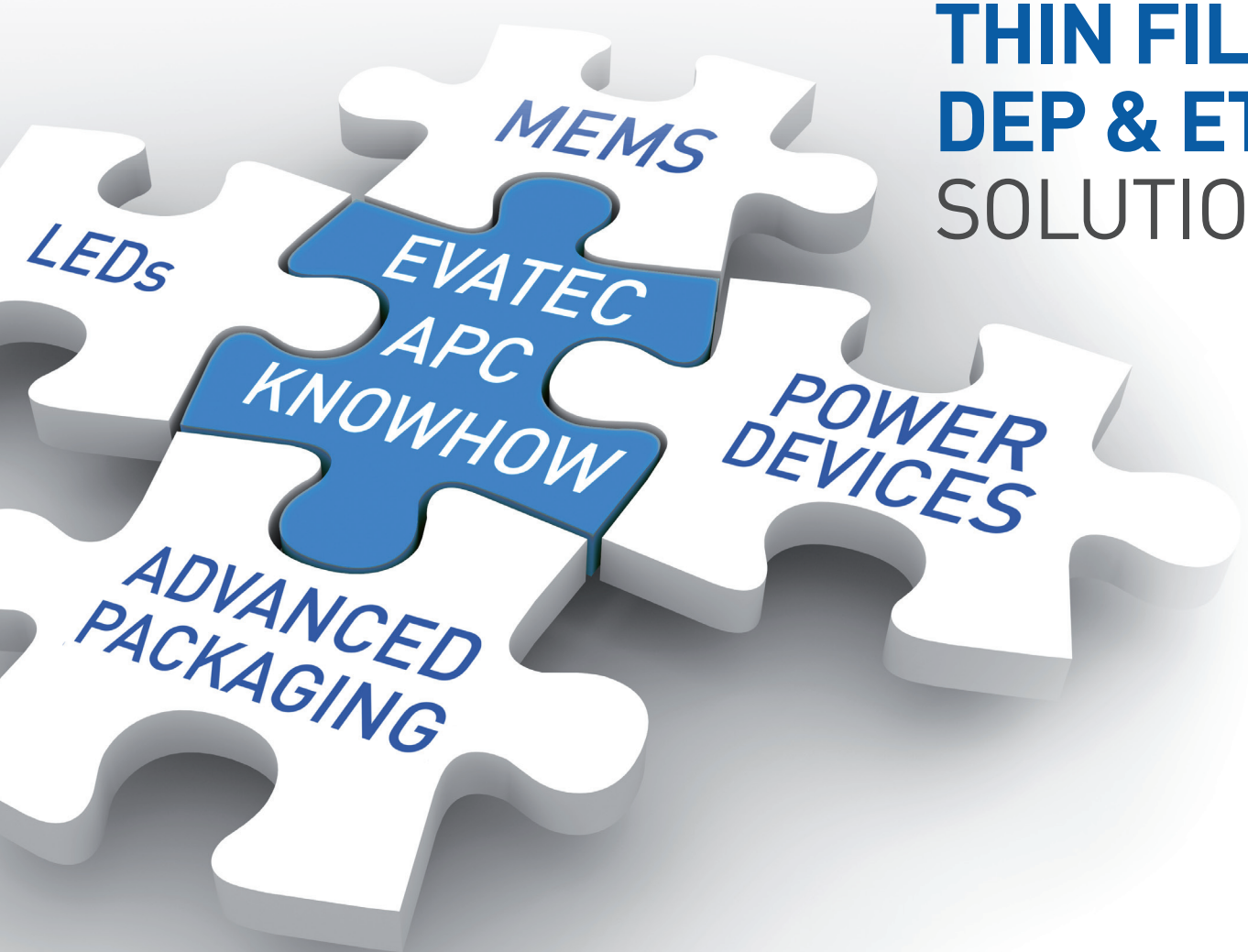

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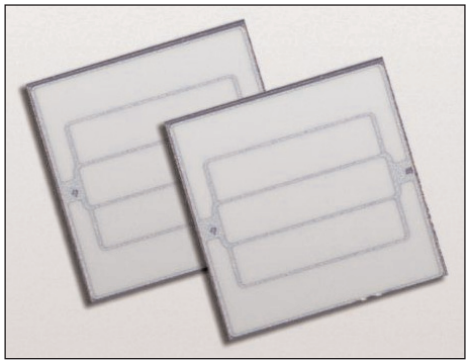
Plessey releases range of GaN-on-silicon blue LED die

UK-based Plessey has announced the release of its range of MaGIC (Manufactured on GaN-on-Si I/C) LED die, manufactured on the company's patented GaN-on-silicon technology. The blue die (sometimes referred to as blue pump for their ability to pump phosphor to a white colour range) are the latest innovation in high brightness LED die designed for a wide range of medium to high power applications including general lighting, signage, commercial, residential and street lighting.

"We have developed a wide range of LED die for a number of applications and our GaN-on-silicon technology works particularly well in higher-power applications such as high-bay, street lights, projector lamps, spot lamps and floodlighting," says chief technology officer Dr Keith Strickland. "This current process technology will become the base for our application-specific LEDs, the ASLED, which bridges the gap between LED component suppliers, solid-state lighting fixture designers and the OEMs."



Plessey's 1mm die for 350mA.

The manufacturing process produces a vertical LED structure that has the anode as bottom contact and the cathode formed in the top metal layer. The layout of the top metal layer is optimized for a particular LED size and die operating current, and includes one or more bond pads for connecting to the cathode.

"We are seeing a definite move away from discrete PLCC designs, especially in the higher-power applications," notes Giuliano Cassataro, VP global sales. "By having our own growth and semiconductor processing facility in Plymouth, Plessey provides the flexibility and speed of response required for a vast range of high-end applications that can use the thermal and light output from our silicon LED die," he adds.

Plessey is offering its range of blue die in various wavelength options. Capable of a light output efficiency (wall-plug efficiency, WPE) of over 60%, the die are supplied to a standard thickness of 150μm (although other thicknesses can be supplied, down to a minimum of 75μm).

The die are supplied on a blue tape in single intensity and colour bins to provide close uniformity, and are intended to be used with standard pick & place machines. Samples are available in a variety of die pack formats with blue die wavelengths ranging from 420nm to 480nm and from 1mW to 10W, with the PExS4500 range having a typical optical output power of 4000mW from a drive current of 3A.

www.plesseysemiconductors.com/led-plessey-semiconductors.php

Plessey expands dotLED range for wearables CSP versions

UK-based Plessey has expanded its dotLED range (designed specifically for wearable applications) with a wider selection of colors, including red, green and blue. The extremely small LED die have a footprint of only 0.2mm x 0.2mm, suiting low-profile electronic wearable applications.

"We continue to win designs in the growing market for wearables and are now producing millions of LEDs every month," says VP of sales Giuliano Cassataro. "Our dotLED product range addresses the optical, mechanical and cost requirements for the typical wearable applications. These include wristbands trackers for health and fitness as well as many other applications for dot matrix displays," he adds.

Plessey's CSP-300 dotLED blue.

The white dotLED is available in a 1005 SMT package (1.0mm x 0.5mm) — a standard electronic component size easily handled by standard surface-mount machines used in high-volume, consumer electronics manufacturing.

Delivering up to 1.0lm of white light with a 130 degree viewing angle from a 5mA drive current, the PLW13D003 meets the demand for ever smaller displays, says the firm. A blue version (the PLB13D003) is also available in a variety of wavelengths from 460nm to 480nm.

"The increasing popularity of our dotLEDs has led us to develop our first chip-scale package (CSP) solution around the fit and performance of this product range," says chief technology officer Dr Keith Strickland. "Samples for this even smaller form factor will be available September this year in a selection of temperatures and colours."

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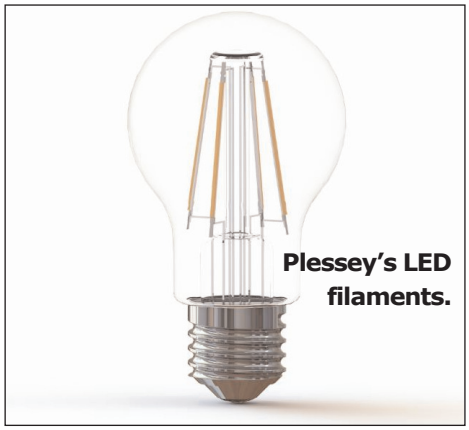
Plessey launches LED filaments using GaN-on-Si die

UK-based Plessey has launched its range of LED filaments, manufactured with the firm's MaGIC (Manufactured on GaN-on-Si I/C) gallium nitride on silicon LEDs. The filaments are designed for the surging filament bulb market, where these replacement lamps have far better performance but still maintain the physical appearance of incandescent lamps.

Plessey says that its chip-on-board (COB) LED filaments create the same amount of light while consuming less energy and offering longer life than a traditional tungsten incandescent light bulb.

The LED filaments are designed with unique terminations so they can be handled and spot welded by existing high-volume fully automated glass lamp manufacturing lines. In addition, Plessey has incorporated a bespoke approach to controlling the current and forward voltage (V_f) of the filaments when they are driven in a bridge configuration.



Plessey's LED filaments.

"We have taken our existing chip-scale packaging [CSP] technology, also used for our dotLEDs, into a revised format for the filament," says chief technology officer Dr Keith Strickland. "Not only do we have an improvement in terms of manufacturability with GaN-on-Si and enhanced the power control for filament resistors, but Plessey will also be incorporating other active and passive electronic components for chip-on-board and chip-scale packaging solutions in the next generation of filaments," he adds. "Thermal performance and customization are key to our filament product portfolio, and Plessey remains committed to bring to market unique LED products through our integrated approach to solid-state lighting applications."

The PLF series of filaments come in a variety of lengths, light output and correlated color temperatures, from very warm 2200K to 6500K.

Plessey retrofits its manufacturing facility with MaGIC LED kits

Plessey is retrofitting its manufacturing facility in Plymouth, UK with LED modules designed using its Manufactured on GaN-on-Si I/C (MaGIC) GaN-on-silicon LEDs. The retrofit involves replacing aging fluorescent tubes and compact fluorescent bulbs in existing fixtures to use new LED light modules produced in the same facility.

The site currently has about 2700 fixtures with 4200 fluorescent lamps that consume 1,000,000kW/h of electricity at a cost of £100,000 a year and costs about £5000 in materials and 200 man hours a year to maintain. After the retrofit is completed, the firm expects to see a 25–40% reduction in electricity consumption, saving tens of thousands of pounds per year.

Lighting solutions using LED technology are over 50% more efficient that their fluorescent and compact fluorescent (CFL) counterparts, notes the firm. LED lights can be dimmed, have higher-quality colour control and do not use highly toxic mercury. LED lights also have much longer working life expectancy than any other forms of artificial lighting, lasting up to 100,000 hours versus 10,000 hours for fluorescent tubes and 1000 hours for tungsten filament light bulbs.

Market research firm Strategies Unlimited's 2015 report projects a global LED-retrofit-lamp market exceeding $3.7bn by 2016. The growth in solid-state lighting (SSL) products intended for existing sockets is from a $2.2bn base in 2011, projecting 30% annual growth in units sold.

"With recent process enhancements, our LED modules create efficiencies well above existing lighting technologies," claims Plessey's operation director Mike Snaith. "We have not only developed an efficient fixture, but have developed cost-effective ways to implement the retrofits, which is key in the return-on-investment calculation," he adds. "Generally, all lamps on-site are replaced annually. Fluorescent lamps, due to their mercury content, cannot just be thrown in the bin and have to be processed by a special waste facility. Therefore, they also present a toxic hazard when carrying out maintenance should a lamp break."

Predominantly illuminated by conventional fluorescent technology, Plessey's facility has three main types of fixture: the batten, the pod-style downlight, and the reflector-style ceiling troffer. It also has a selection of high-intensity discharge (HID) lighting in the form of high-bay and low-bay fixtures.

"The LED retrofit kits offer the facilities engineers and installation contractors a cost-effective, quick and easy method to take advantage of the new technology," says Plessey's senior facilities engineer Thomas Abbott. "Another benefit is the dramatically reduced power consumption," he adds. "It only takes between 5–10 minutes to retrofit a fixture and, as a result, the emergency light fixtures now require less or smaller battery backup, meaning increased cost savings as well as reduced frequency for maintenance."

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Cree's quarterly LED product revenue falls 21% amidst restructuring

Consolidation of chip fabs focuses on high-power LEDs while outsourcing mid-power LEDs

For full-year fiscal 2015 (ended 28 June), Cree Inc of Durham, NC, USA has reported revenue of $1.63bn, down just 1% on fiscal 2014's record $1.65bn. Specifically, revenue for Lighting Products (mainly LED lighting systems and bulbs) grew 28% from $706.4m (43% of total revenue) in fiscal 2014 to $906.5m (55% of total revenue), driven by commercial lighting growing 37% while consumer lighting grew just 2%. This was offset by revenue for LED Products (LED components, LED chips, and silicon carbide materials) falling 28% from $833.7m (51% of total revenue) to $602m (37% of total revenue). Power & RF Product revenue grew 15% from $107.5m (6% of total revenue) to $124m (8% of total revenue), driven by Power products.

For fiscal fourth-quarter 2015, revenue was $382.2m (well below the $420–440m forecast given in April, but slightly above 24 June's revision to $375m). This is down 12% on $436.3m a year ago and 7% on $409.5m last quarter. Specifically, Power & RF Product revenue was steady at $30.8m (8% of total revenue). Lighting Product revenue was $229m (60% of total revenue), up 2% on $224m last quarter (55% of total revenue) — driven by double-digit growth in commercial lighting – and up 10% on $208.4m (just 48% of total revenue) a year ago. However, this was mostly offset by a larger-than-expected seasonal decline in LED Product revenue to $122.2m (32% of total revenue), down 21% on $154.4m (38% of total revenue) last quarter — due primarily to lower consumer bulk sales, higher-than-expected erosion of LED average selling prices (ASPs), and Cree's restructuring (which reduced available LED fab capacity by about 40% during fiscal Q4) — and down 39% on $199.5m (as much as 46% of total revenue) a year ago.

On 24 June, in order to improve cost structure, Cree announced a restructuring of its LED business to reduce excess capacity and overhead (by consolidating two fabs in Durham into one, taking till the end of the December quarter). The firm is also increasing LED reserves to reflect the more aggressive pricing environment during the quarter, and to factor in a more conservative pricing outlook for fiscal 2016. During the quarter, Cree hence recognized $84m of restructuring charges ($27m of LED revenue reserves, $11m of LED inventory reserves, and $46m of factory capacity and overhead cost reductions).

On a non-GAAP basis, due mainly to the LED restructuring charges, gross margin fell further, from 37.9% a year ago and 31.4% last quarter to 21% (well below the originally forecast 32%). Specifically, LED Product gross margin plummeted from 35.9% last quarter to just 7% (in line with updated targets provided on 24 June). Power & RF Product gross margin was 52.5% (similar to last quarter). Lighting Product gross margin fell from 26% to 24.8%, slightly lower than targeted due primarily to lower consumer lighting margins (as a result of lower sales volumes) and year-end items related to commercial lighting (which was otherwise in line with last quarter).

Restructuring will better position the LED business to focus on our new market-leading high-power products with a reduced cost structure. Factory execution continues to be critical

For full-year fiscal 2015, Lighting Product gross margin was 26%, down year-on-year due mainly to lower LED bulb margins (in a more competitive pricing environment). LED Product margin fell to 31.7%. Power & RF Product margin was 54.7%. Overall gross margin fell from 38.2% in fiscal 2014 to 29.9%.

Quarterly operating expenses were level with last quarter, at $108m (within the revised targeted range excluding restructuring costs).

Due mainly to the LED restructuring, for fiscal Q4/2015 Cree made a net loss of $20.5m ($0.19 per diluted share), compared with the originally forecasted net income of $26–31m ($0.24–0.28 per diluted share), and net income of $25m ($0.22 per diluted share) last quarter and $51.3m ($0.42 per diluted share) a year ago. For full-year fiscal 2015, net income was $72m ($0.64 per diluted share), down from $203m ($1.65 per diluted share) for fiscal 2014, as profit growth in Lightning and Power & RF was insufficient to offset the large drop in LED profits and the related restructuring costs.

Cash generated from operations rose from $65.6m last quarter to $88m. As well as the regular patent spending of about $5m, spending on property, plant & equipment has risen from $44.9m to $48m, raising total capital expenditure from $50m to $53m. Free cash inflow was hence $35m (the highest quarterly level in a year and a half), more than doubling from $15.8m last quarter. However, during the quarter Cree spent $160m on repurchasing its stock. Cash and investments hence fell by $69m from $782m at the end of fiscal Q3/2015 to $713m.

Also, in mid-May, Cree submitted a draft registration statement to the US Securities and Exchange Commission (SEC) for a potential initial public offering (IPO) in fiscal

2016 of its Power & RF business. The spin-off aims to raise capital to invest directly in the business to support targeted future growth, while also enabling Cree's management to focus on its LED and Lighting businesses. As part of the separate focus on the Power & RF business, in early July Cree acquired power module provider Arkansas Power Electronics International Inc (APEI) of Fayetteville, AR, USA, aiming to accelerate the market for its Power & RF business' SiC power modules.

"The restructuring will better position the LED business to focus on our new market-leading high-power products with a reduced cost structure going forward," says Swoboda. Over the last year, Cree has added manufacturing partners (such as Taiwan's Lextar) for both low/mid-power LED chips and LED lighting products that should provide long-term cost leverage, enabling Cree's factories to focus on new-product introduction and technology, especially high-power LED chips (which Cree continues to make itself, because it can get the performance — "We still can't buy them on the open market," notes Swoboda). "We believe the LED market will remain very competitive for at least the next year, but target the combination of design wins for our new SC5 LED products [launched last October with XHP Extreme High Power LEDs] and lower cost structure to help offset the competitive challenges in the market," he adds.

"The actions we took in Q4 to restructure our LED business [once fully completed in fiscal Q2/2016] position us for solid revenue growth and margin expansion in fiscal 2016, driven by the strength of our commercial lighting business," says Swoboda. "Q1 total company backlog is tracking with our targets for the quarter as commercial lighting orders are ahead of Q4."

For fiscal first-quarter 2016 (ending 27 September 2015), Cree targets revenue of $410–430m, driven by Lighting sales (with strong growth in commercial lighting sales plus LED bulb sales flat to slightly higher), LED sales in a similar range to fiscal Q4/2015 (excluding the impact of the revenue restructuring reserves), and incrementally higher Power & RF revenue. Aided by the restructuring, gross margin should rebound to 32%, with LED Product margin boosted by benefits from a global LED chip patent cross-licensing deal agreed with Epistar in early August (under which Cree receives a licensing fee and royalty payments from Epistar). Operating expenses are targeted to be roughly level at $107m, as core spending reductions are partially offset by higher IP litigation spending. Net income is expected to be $19–24m ($0.18–0.23 per diluted share).

"The LED business remains very competitive and we are taking a cautious approach to this market with our distributors," says Swoboda. "Our targets for fiscal 2016 include managing LED distributor inventory to increase their returns and further reduce our exposure to changes in pricing going forward."

Factory utilization is improving in LEDs as Cree executes its restructuring plan, and is targeted to recover to 85% by the end of December when factory consolidation is completed. "Factory execution continues to be critical to achieving our targets," comments Swoboda.

Cree now targets total restructuring cost to be $102m, including $18m of additional charges in the first and second quarters of fiscal 2016 as it completes the consolidation of its LED factories. "Primarily related to additional capacity and overhead cost reduction identified during the factory consolidation process, we're finding the estimated fair values on certain equipment being held for sale," says chief financial officer Michael McDevitt.

For fiscal 2016, Cree aims for revenue growth of 10% to $1.8bn (with growth driven by commercial lighting, compensating for consumer lighting being flat to slightly down), with operating margin of 8%. The firm targets property, plant & equipment (PP&E) spending to be lower than fiscal 2015, at $150m (primarily in first-half fiscal 2016), in order to complete certain existing infrastructural projects and to provide Lighting and Power & RF with incremental capacity. Free cash flow is targeted to be $85m (more in the second half of fiscal 2016 than the first half). Finally, Cree's board of directors has approved a $500m stock buyback program for fiscal 2016.

Cree and Epistar agree nitride LED chip patent cross-license

Cree and Taiwan's Epistar Corp (the world's largest manufacturer of LED epiwafers and chips) have signed a worldwide patent cross-license agreement for LED chips.

Cree and Epistar both hold broad portfolios of LED chip patents for making blue LEDs (the foundation of white LEDs). Each party gains a license to the other's nitride LED chip patents and is granted certain rights to non-nitride LED chip patents. Over the term of the agreement, Cree will receive a licensing fee and royalty payments from Epistar. No technology transfer between the parties is involved.

"This agreement underscores both companies' commitment to accelerating the adoption of LED lighting while respecting the value and importance of international intellectual property laws," says Cree's chairman & CEO Chuck Swoboda.

"The patent license agreement we have achieved will help us to accelerate R&D activities," comments Epistar's chairman BJ Lee. "By entering into this cross-license agreement with Cree, Epistar is able to provide LED chips that ultimately benefit our customers across the world."

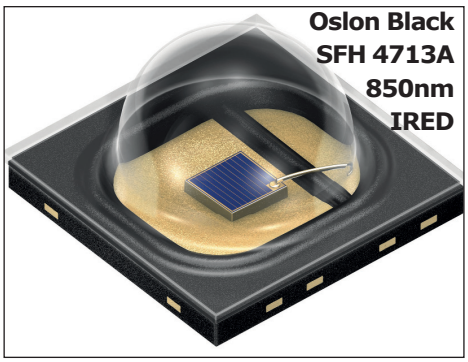
www.epistar.com.tw
www.cree.com

Osram launches mid-power Oslon Black infrared LED providing near-range illumination for camera surveillance

Osram Opto Semiconductors GmbH of Regensburg, Germany has launched the Oslon Black SFH 4713A, an infrared LED (IRED) with a wavelength of 850nm suited to security applications such as camera surveillance of public spaces, company premises, and entrances to banks and shopping centers. While previous Oslon Black high-flux IREDs were designed for systems with a range of up to 100m, the SFH 4713A supports efficient designs for short- to mid-range infrared illumination systems from 10m to 50m.

To create the new infrared LED, Osram transferred the high-performance technology behind its Oslon Black, with an optical output of over 1W, to the mid-range power class of about 760mW, rounding off its IRED portfolio.

The new IREDs are the result of advances in chip and package technology — developments that enabled Osram, less than a year



ago, to engineer an Oslon Black with unprecedented electro-optical efficiency. The SFH 4713A now makes these advances available in the mid-range power classes too. "With this new version of the Oslon Black, our customers can use the same designs they did before for high-end, long-range applications to engineer systems with mid- to short-ranges, all while cutting costs," says IR product marketing manager Rajeev Thakur.

The new high-efficiency IRED offers an optical output of 760mW at a current of 1A. Two to five IREDs are typically adequate for achieving ranges between 10m and 50m. Due in part to the smaller chip size, the new IRED is a lower-cost alternative to the SFH 4715A for systems with mid-range output requirements.

The SFH 4713A is currently available with a beam angle of 90°, but in autumn it will be complemented by the SFH 4714A variant with a beam angle of 150° and an optical output of 720mW.

The new components close the gap between the extremely small Oslon Compact (which offers optical output of 270mW at 0.5A) and the high-output Oslon Black versions (with optical outputs of over 1135mW at 1.5A). The result is a product portfolio of high-efficiency 850nm IREDs that serves the entire spectrum of infrared lighting applications and output requirements.

www.osram-os.com

Mobile iris scanning IRED wins Kaiser Friedrich Research Award

A new IRED from Osram Opto, developed for mobile iris scanning, has been presented with the 2015 Kaiser Friedrich Research Award. For the first time, the 810nm IRED from Osram provides for secure, reliable and cost-effective biometric identification based on iris scanning using mobile devices.

To achieve this, it was necessary to develop a new epitaxial design and an LED chip with characteristics specifically tailored to the physiognomy of the eye. The wavelength of the nanostack IRED was changed to 810nm so that iris patterns could be identified without any problems, irrespective of the color of the eye. High optical output was also necessary so that the distance between the iris scanner and the eye could be as great as possible. Optimizing the epitaxy and the chip design resulted in the

outstanding radiant intensity of up to 3.8W/sr. This means that reliable measurements can be taken at a comfortable distance of up to 40cm.

Iris scanning involves illuminating the eye with infrared light. A camera simultaneously takes a picture of the iris in which characteristic features are then identified. This method is extremely secure so it is becoming increasingly popular as a means of biometric identification for cell phones and tablet computers because these devices are being increasingly used for sensitive applications such as online banking and online shopping.

The Kaiser Friedrich Research Award carries a prize of €15,000 and is presented to German scientists and developers every two years for a particular aspect of optical technology. The theme for 2015 was 'LED technologies'. The award honors research projects that offer a high degree of innovation potential for technical and scientific developments and a clear ability to be implemented in new products and processes.

www.kaiser-friedrich-forschungspreis.de

Osram launches sensor for fitness tracking in smart watches and fitness armbands

Osram Opto Semiconductors GmbH of Regensburg, Germany has expanded its portfolio of optical sensors for the optical measurement of pulse rates and the oxygen saturation level of blood.

Offering what is claimed to be excellent signal quality and low energy consumption, the main market segment for the new SFH 7060 includes wearable mobile devices such as smart watches and fitness armbands for continuously monitoring fitness levels. The integrated optical sensor contains five light-emitting diodes with three different wavelengths and one high-sensitivity photodiode.

As a development of the SFH 7050 optical sensor (introduced in fall 2014), the SFH 7060 performs the same functions but with improved power consumption and signal quality. The SFH 7060 consists of three green LEDs, one red LED, one infrared LED and one large-format photodiode, which is optically separated from the emitters by an opaque barrier. It works by shining light into the skin. Different amounts of this light are absorbed by blood and the surrounding tissue. The light that is not absorbed is reflected to the detector. Absorption measurements with different wavelengths are used to determine the pulse rate and the saturation level of oxygen in the blood.

Efficient and reliable pulse measurements

Green light is best for measuring the pulse at the wrist. The SFH 7060 is equipped with three green LEDs with a wavelength of 530nm based on Osram's latest high-efficiency UX:3 chip technology. At their optimum operating point at a current of 20mA, they are particularly efficient and typically deliver an optical output of 3.4mW at a voltage of 3.2V per chip, says the firm. The higher light output, compared with the SFH 7050, results in better signal quality and more stable pulse measurements, it adds. The lower power consumption also means longer battery life in the device.

The new SFH 7060 sensor for pulse rate and blood oxygen measurements in fitness armbands and smart watches provides more stable signals and consumes less energy than its predecessor.

More accurate blood oxygen measurements

Oxygen saturation in the blood is calculated from the different absorption rates of red (660nm) and infrared (940nm) light. The quality of the measurements depends to a large extent on the achievable signal-to-noise ratio and on the linearity of the photodetector. The integrated photodiode, with its active surface of 1.3mm x 1.3mm, meets these requirements, says Osram. In addition, the distance between the two transmitters and the photodiode in the SFH 7060 is greater than in the SFH 7050, so the light penetrates deeper into the skin before it is reflected to the detector, leading to more stable signals and a better signal-to-noise ratio. As in the case with its predecessor, the wavelength of the red transmitter is specified with a very narrow tolerance of ±3nm to ensure accurate measurements.

The new sensor is Osram Opto's latest addition to its portfolio for fitness tracking applications, designed to meet all the latest requirements. "The market for fitness tracking is growing at a rapid pace, and some of the requirements that the components have to meet are also changing rapidly," says product marketing manager Christoph Goeltner. "We are working very closely with our customers so that we are always in a position to offer suitable products continuously and quickly." Users can now choose between a highly efficient solution designed for pulse rate measurements, an extremely compact sensor for combined pulse rate and blood oxygen measurements, and a slightly larger version with the same features but with significantly improved functionality, says the firm.

The new integrated SFH 7060 optical sensor for measuring pulse rate and blood oxygen levels has been optimized in terms of power consumption and measurement accuracy. It contains a highly sensitive photodiode, three green LEDs, one red LED and one infrared LED.

www.osram-

University of Delaware awarded $1m Keck Foundation grant to develop upconversion of red light to blue

Solar cell, medical imaging and cancer treatment applications targeted

The University of Delaware (UD) has received a $1m grant from the W.M. Keck Foundation to explore a new idea that could improve solar cells, medical imaging and even cancer treatments. The goal is to turn low-energy colors of light (such as red) into higher-energy colors (e.g. blue or green).

Changing the color of light would give solar technology a considerable boost. A traditional solar cell can only absorb light with energy above a certain threshold. Infrared light passes through, with its energy untapped. However, if that low-energy light could be transformed into higher-energy light, a solar cell could absorb much more of the sun's energy. The team predicts that their novel approach could increase the efficiency of commercial solar cells by 25–30%.

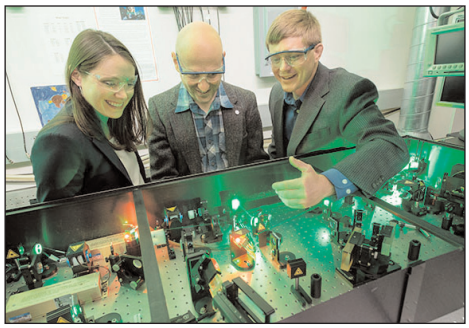
Based in UD's College of Engineering, the research team is led by project leader Matthew Doty, associate professor of materials science & engineering and associate director of UD's Nanofabrication Facility. Doty's co-investigators include Joshua Zide, Diane Sellers and Chris Kloxin (all in the Department of Materials Science and Engineering) and Emily Day and John Slater (both in the Department of Biomedical Engineering).

Changing the color of light

"The energy of each photon is directly related to the color of the light — a photon of red light has less energy than a photon of blue light," notes Doty. "You can't simply turn a red photon into a blue one, but you can combine the energy from two or more red photons to make one blue photon."

For such a photon upconversion process, the team wants to design a new kind of nanostructure that will act like a ratchet: it will absorb two red photons, one after the other, to push an electron into an excited state, when it can emit a single high-energy (blue) photon.

"Think of the electrons in this structure as if they were at a water park," Doty says. "The first red photon has only enough energy to push an electron half-way up the ladder of the water slide. The second red photon pushes it the rest of the way up. Then the electron goes down the slide, releasing all of that energy in a single process, with the emission of the blue photon. The trick is to make sure the electron doesn't slip down the ladder before the second photon arrives. The semiconductor ratchet structure is how we trap the electron in the middle of the ladder until the second photon arrives to push it the rest of the way up," says Doty.



Ultra-fast laser system in Doty's lab, for probing material properties.

The UD team aims to develop new structures containing multiple layers of different materials, such as aluminum arsenide and gallium bismuth arsenide, each just a few nanometers thick. This 'tailored landscape' will control the flow of electrons into states with varying potential energy, turning once-wasted photons into useful energy.

The team has shown theoretically that their structures could reach an upconversion efficiency of 86%, which would be a vast improvement over the 36% demonstrated by the best materials currently. Also, the amount of light absorbed and energy emitted by the structures could be customized for a variety of applications, from lightbulbs to laser-guided surgery, Doty says.

The team will use molecular beam epitaxy (MBE) to fabricate the nanostructures. Each structure will be tested to see how well it absorbs and emits light, and the results will be used to tailor the structure to improve performance.

However, the researchers will also develop a solution filled with millions of identical individual nanoparticles, each containing multiple layers of different materials that will implement the photon ratchet idea. Through such work, the team envisions a future upconversion 'paint' that could be easily applied to solar cells, windows and other commercial products.

Improving medical tests and treatments

While the initial focus of the three-year project is on improving solar energy harvesting, the team will also explore biomedical applications.

A number of diagnostic tests and medical treatments, ranging from computerized tomography (CT) and positron emission tomography (PET) scans to chemotherapy, rely on the release of fluorescent dyes and pharmaceutical drugs. Ideally, such payloads are delivered both at specific disease sites and at specific times, but this is hard to control in practice.

The UD team aims to develop an upconversion nanoparticle that can be triggered by light to release its payload. The goal is to achieve the controlled release of drug therapies even deep within diseased human tissue while reducing the peripheral damage to normal tissue by minimizing the laser power required.

"This is high-risk, high-reward research," Doty comments. "High-risk because we don't yet have proof-of-concept data. High-reward because it has such a huge potential impact in renewable energy to medicine… this same technology could be used to harvest more solar energy and to treat cancer."

www.engr.udel.edu
www.wmkeck.org

UCLA demonstrates first electroluminescence from multi-layer molybdenum disulphide

The California NanoSystems Institute (CNSI) at University of California Los Angeles (UCLA) has demonstrated the first electroluminescence from multi-layer molybdenum disulphide (MoS_2), which could lead to a new class of materials for making LEDs ('Electric-field-induced strong enhancement of electroluminescence in multilayer molybdenum disulfide', Nature Communications 6 7509).

In its single-layer form, molybdenum disulfide is optically active (i.e. it emits light when electric current is run through it or when it is shot with a non-destructive laser). Multi-layer molybdenum disulfide, by contrast, is easier and less expensive to produce, but it is not normally luminescent. In the new study, chemistry and biochemistry professor Xianfeng Duan and first author Dehui Li (a postdoctoral scholar in Duan's lab) created what is claimed to be the first multi-layer molybdenum disulfide device that shows strong luminescence when electrical current is passed through it.

"We were trying to make a vertically stacked light-emitting device based on monolayer MoS_2, but it was difficult to get the efficiency as high as we wanted," says Duan. "On the other hand, it was rather surprising for us to discover that similar vertical devices made of multi-layer MoS_2 somehow showed very strong electroluminescence, which was completely unexpected since the multi-layer MoS_2 is generally believed to be optically inactive," he adds. "So we followed this new lead to investigate the underlying mechanism and the potential of multi-layer MoS_2 in light-emitting devices."

Duan and his team used the technique of electric-field-induced enhancement, which relocates the electrons from a dark state to a luminescent state, to increase the material's ability to convert electrons into lphotons. Multi-layer MoS_2 is hence at least as efficient as monolayer MoS_2.

Duan's team is currently applying this approach to similar transition-metal dichalcogenide materials, including tungsten diselenide, molybdenum diselenide and tungsten disulphide, with the goal of helping to create a new generation of LEDs from two-dimensional layered materials that are less expensive and easier to use in manufacturing.

www.nature.com/ncomms/2015/150701/ncomms8509/full/ncomms8509.html
http://xduan.chem.ucla.edu

II-VI Inc unveils 1W 980nm pump laser module

Engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA has launched its high-power (1W) 980nm pump laser module, which leverages the proven high-reliability laser diode technology from the firm's in-house wafer fab at its Laser Enterprise Division in Zurich, Switzerland.

"This advancement in pump laser technology delivers the most efficient commercially available 980nm pump laser in the world, both in terms of laser conversion efficiency and total module power consumption," claims II-VI Pump Laser Division general manager Simon Loten.

The new 1W pump laser module enables up to 1050mW of kink-free optical power through a grating-stabilized single-mode fiber for easier integration into the EDFA system. The module is housed in the established 10-pin, mBTF (mini-Butterfly) format package, which is rapidly becoming adopted as the new market standard, says the firm, providing an electrically and mechanically compatible pin-out to legacy 14-pin packages, in a 75% smaller package. The product is fully qualified to the requirements of Telcordia GR-468-CORE and is RoHS 6/6 compliant.

"It provides EDFA [erbium-doped fiber amplifier] designers with new options to increase output power per stage within high-power DWDM solutions, while being more efficient and reducing overall cost of network ownership," he adds. "The new module can also be used to replace pairs of lower-power modules, enabling cost-effective, more thermally efficient and environmentally conscious designs," continues Loten. "When compared with 14xx nm and competing 980nm solutions, the II-VI pump laser modules achieve very high power at significantly lower drive current and thermo-electric cooler power."

The new 1W module is sampling to customers now, and will be ramping through third-quarter 2015.

II-VI also says it has surpassed the 2 million milestone of pump laser modules shipped. Originally established in the mid-1990s, now II-VI's pump laser modules represent a key foundation of modern DWDM optical transport systems, the firm adds. For two decades, the key laser technology has been developed and refined to enable increased output power, lower power consumption, improved reliability and performance.

The original pump laser modules were capable of producing about 100mW of usable optical power. Today, pump laser modules operate at an order of magnitude higher power, enabling EDFA technology to continue to be the backbone of the bandwidth explosion, with more flexible and efficient designs. II-VI says this evolution has been enabled by the continuous relationship between the firm's chip designers in Switzerland and the advanced packaging teams in the UK and China.

www.ii-vi-photonics.com

MACOM launches ultra-high-sensitivity TIA for GPON optical network units

M/A-COM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog RF, microwave, millimeter-wave and photonic applications) has launched the M02027 next-generation high-performance transimpedance amplifier (TIA) targeted for GPON optical network unit (ONU) equipment. "The new GPON ONU TIA offers superior optical sensitivity and overload performance with low cost PIN photodiode at best in class power dissipation"

The M02027 enables Gigabit passive optical network (GPON) receivers to utilize lower-cost PIN photodiodes while offering performance margin in the stringent GPON BOSA-on-board environment. MACOM says that the device delivers ultra high sensitivity with PIN photodiodes and wide dynamic operating range while offering best-in-class power dissipation.

The M02027 is targeted at GPON ONU, SONET, CPRI base-station and SFF/SFP module applications. It supports multi-data rates between 100Mbps to 3.125Gbps with wire bonding flexibility and a single supply of 3.3V. It provides an output data polarity invert function and output average photodiode current for photo-alignment and receiver signal strength indicator (RSSI) average power monitoring.

The new addition to the TIA product line complements MACOM's comprehensive PON product portfolio, which already includes high-performance laser diodes and highly integrated laser drivers with digital monitoring and dual-closed-loop operation for complete PON solutions.

"The new GPON ONU TIA offers superior optical sensitivity and overload performance with low-cost PIN photodiode at best-in-class power dissipation," claims Angus Lai, director of product marketing, High-Performance Analog. "We believe the M02027 offers a competitive cost-performance ratio and enables our customers to tackle fast-growing GPON deployments."

The M02027 is in mass production now and available as bare die in waffle pack and wafer on grip frame. It is being shown in private demonstrations at the 17th China International Optoelectronic Expo (CIOE 2015) in Shenzhen (31 August–3 September).

www.macomtech.com

JDSU renamed Viavi after spinning off Lumentum

Network Enablement, Service Enablement and Optical Security and Performance Products businesses become Viavi Solutions

On 1 August, JDSU of Milpitas, CA, USA completed the spinoff of its Communications and Commercial Optical Product business segment (CCOP), which is now Lumentum Holdings Inc.

JDSU's remaining businesses — Network Enablement (NE), Service Enablement (SE), and Optical Security and Performance Products (OSP) — collectively have hence been renamed Viavi Solutions Inc.

Viavi will commence 'regular-way' trading on the NASDAQ Stock Market on 4 August under the ticker symbol VIAV. The JDSU ticker symbol is being retired from trading at the close of market on 3 August.

"This is an important milestone as we mark the successful completion of the spinoff," says Viavi's president & CEO Tom Waechter. "Viavi is poised to capture the opportunities created by the industry's transition to new network architectures and the need for increased network and application visibility," he adds. "The spinoff will improve Viavi's agility and increase focus, allowing us to accelerate our progress," he believes.

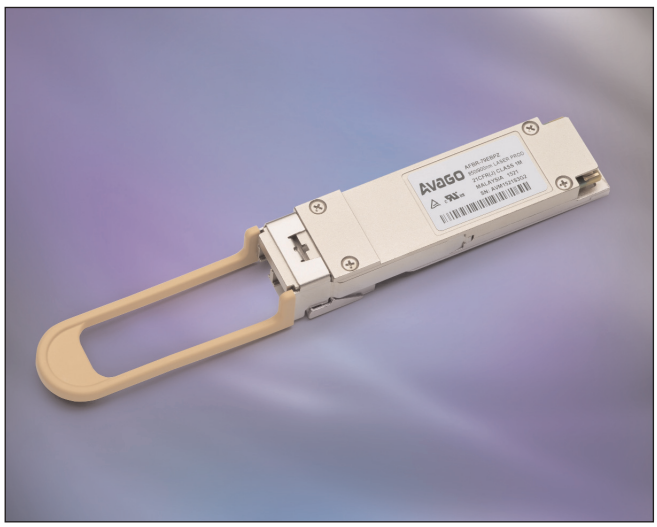
www.viavisolutions.com

Avago announces general availability of 40G bi-directional multimode fiber QSFP+ transceiver for data centers and cloud infrastructure

Avago Technologies Ltd (which designs and supplies III-V-based analog interface components for communications, storage, consumer and industrial applications) has announced general availability of its AFBR-79EBPZ 40G bi-directional (BiDi) multimode fiber (MMF) QSFP+ transceiver module, a field-proven 40G bi-directional fiber-optics solution designed for high-speed data-center interconnect and networking applications.

Based on 2x20G BiDi optics, the module operates over two fibers with an LC connector as opposed to the eight fibers with an MPO connector of conventional 40G QSFP+ MMF solutions. It can hence enable 40 Gigabit Ethernet (40GbE) links on existing installed LC duplex multimode fiber of 10G networks, providing a cost-effective upgrade path to 40G Ethernet in the data center. The AFBR-79EBPZ supports 40GbE data transfer over 100m of OM3 fiber or 150m of OM4 fiber.

Avago says that the 40G BiDi MMF QSFP+ transceiver can provide a seamless and cost-effective transition from 10G to 40G Ethernet using existing 10G MMF cabling infrastructure. As well as being compliant to the QSFP+ SFF-8436 specification, it is also compliant to the 40GbE XLPPI electrical specification per IEEE 802.3ba-2010.



Avago's new AFBR-79EBPZ 40G bi-directional multimode fiber QSFP+ transceiver module.

"Our 40G BiDi transceiver technology is an important breakthrough that has facilitated many of our end customers to transition from 10G to 40G network to meet the ever increasing demand for bandwidth," says Philip Gadd, senior VP & general manager of the Fiber Optics Product Division. "With the general availability of the Avago 40G BiDi MMF QSFP+ transceiver, there will be an accelerated market adoption of 40G Ethernet for data centers," he reckons.

"40G Ethernet is an important technology in the data center as enterprises transition the aggregation/spine layers of their network towards higher speeds," comments Alan Weckel, VP of Ethernet Switch Market research at market research firm Dell'Oro Group. "As this transition occurs, we expect 40G Ethernet switches to surpass 10 million ports in 2017, almost a four-fold increase from 2014 levels, especially with the increased availability of high-ROI [return on investment], low-TCO [total cost of ownership] solutions that leverage the existing 10G cabling infrastructure," he adds.

Avago has shipped high-volume production quantities of the 40G BiDi fiber optics solution and is now accepting orders for the AFBR-79EBPZ.

www.avagotech.com/products/fiber-optics/optical-transceivers/qsfp/afbr-79ebpz

Oclaro's CFP 100G client-side transceiver capacity expansion compensates for drop in 40G telecom sales

Full-year cost cutting of 25% to enable breakeven this fiscal year

For fiscal 2015 (ended 27 June), Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications) has reported revenue of $341.3m, down 12.7% on fiscal 2014's $390.9m. This is due to a 25% decline in legacy 10G and telecom 40G products plus the sale of the Industrial & Consumer business late last October (which had contributed $9.3m in fiscal 2015 up to then, versus $32.2m in full-year 2014), partially offset by 50%-plus growth in 100G products.

For fiscal fourth-quarter 2015, revenue was $82.2m, down 1% on $83m last quarter and 14% on $95.9m a year ago, but at the high end of the $77-83m guidance.

Revenue from 10G-and-lower products was $34m (41% of total revenue), down 14% on $39.4m a year ago although roughly level with $33.8m last quarter. "We continue to see strong demand for our 10G tunable laser product lines, and our laser photodetector chips," notes CEO Greg Dougherty. "We have been successful selling our laser and avalanche photodetector chips into select markets, where we do not intend to compete at the transceiver level," he adds. "For example, we are enjoying strong demand for our 10G laser chips, which go into customized 40G modules for data-center applications."

Revenue from 40G & 100G products was $48m (58% of total revenue), down slightly from $49.2m last quarter and $48.8m a year ago.

Revenue for 40G products in particular fell further, to just $14m (17% of total revenue), down 26% on $19m (23% of total revenue) last quarter and down 43% on $24.5m (26% of total revenue) a year ago. However, the decline in 40G telecom products was mostly offset by further growth in 100G product revenue, to $34m (41% of total revenue), up 12.6% on $30.2m (36% of total revenue) last quarter (when capacity constraints limited the strong growth in 100G client-side CFP and CFP2 modules) and up 40% on $24.3m (just 25% of total revenue) a year ago.

"About three months ago, we announced that we were increasing our capacity for our CFPx family of 100G client-side transceivers," says Dougherty. Another contributor to 100G growth was the narrow-linewidth micro-iTLA laser. Oclaro also realized early revenue from its coherent CFP2-ACO transceiver.

Driven by 100G sales, datacom applications have grown from $40.4m (46% of total revenue) last quarter to $41.9m (51% of total revenue), while telecoms applications fell from $42.6m (54% of total revenue) to $40.3m (49% of total revenue).

By regional (compared with last quarter), China grew further, from 35% to 36% of total revenue, while the Americas rebounded from 26% to 31% and Europe from 20% to 22%, as Southeast Asia fell further from 16% to 10%, and Japan fell back from 3% to just 1%. Showing increasing diversification, Oclaro's top four customers represented 16%, 15%, 13% and 11% of total revenue, respectively.

On a non-GAAP basis, gross margin has risen further, from 14.1% a year ago and 15.8% last quarter to 19.9% (above the guidance of 15–19%), driven by both a richer product mix and better operational efficiencies. Full-year gross margin rose from 14% in fiscal 2014 to 17.2% for fiscal 2015.

We have been successful selling our laser and avalanche photodetector chips into select markets, where we do not intend to compete at the transceiver level

Resulting from the firm's restructuring programs, operating expenses were cut further, from $27.8m a year ago and $22.6m last quarter to $21.8m. Full-year operating expenses have been cut by $33m (25%) from $132.2m in fiscal 2014 to $99.2m for fiscal 2015.

Operating loss has been cut from $14.3m a year ago and $9.5m last quarter to $5.4m, contributing to full-year operating loss being almost halved from $74.7m in fiscal 2014 to $38.4m for fiscal 2015.

Improved gross margin, coupled with the tight expense control, has led to adjusted EBITDA (earnings before interest, taxes, depreciation and amortization) improving further, from –$9.4m a year ago and –$5.3m last quarter to –$1.2m (better than the guidance of between –$6m and –$2m). Due to this, plus increased capital expenditure (CapEx) of $4.1m (up on $3m last quarter) and restructuring charges of $2.5m, the firm's cash, cash equivalents, restricted cash, and short-term investments hence fell during the quarter from $123.9m to $115.1m.

"Q4 results show substantial progress towards realizing our initial stated objective of achieving adjusted EBITDA breakeven," says Dougherty. Full-year adjusted EBITDA was –$20.9m for fiscal 2015, an improvement of $30.6m from fiscal 2014 and $70m from fiscal 2013, driven primarily by cost cutting, operational improvements, and strong 100G product lines.

"Our fourth quarter results demonstrate the significant progress we made over the prior period and highlight how far we have come in just 12 months," says Dougherty. "A little over two years ago, we embarked on an aggressive turnaround journey. We emphasized that it would not be quick, and that we were building a company for long-term success. Many painful steps were taken to

reduce our infrastructure costs. We simplified the company in many ways, and we focus our strategy on 100G, which we believe was an area where we could differentiate ourselves in the marketplace," he adds. "At that time, we decided to continue to spend heavily in R&D."

For fiscal first-quarter 2016 (ending 26 September 2015), Oclaro expects revenues of $82–88m (up $3m, at the mid-point, on last quarter). Gross margin should be steady at 18–22%. Adjusted EBITDA is expected to be between negative $3m and breakeven.

"Over the next several quarters, we expect to see our 10G business remain relatively flat, with some ups and downs, as our legacy 10G products are gradually replaced by new higher-margin products [e.g. 10G laser chips]," says Dougherty.

Oclaro expects 40G telecom revenue to step down by $4m to $10m, and remain at that level for the rest of fiscal 2016. "This represents an improvement in our visibility from last quarter's call, at which time we stated that we expected a decrease in sales to beneath the $10m level for 40G during the first half of calendar 2016," notes Dougherty.

However, the decline in 40G should be replaced by growth in 100G products. "We began to realize the benefits of this additional [100G client-side transceiver] capacity on net income in [fiscal] Q4, and expect these benefits to be even stronger in this quarter," says Dougherty. "We expect to see continued sales growth for our entire 100G portfolio, which continues to gain momentum in the marketplace… We began to ramp shipments of pre-production units of our coherent CFP2-ACO product for customer system integration and verification. We will continue to see volumes grow this quarter, and we are expecting meaningful revenue in our December quarter." For the balance of this calendar year, the CFP2-ACO will be primarily shipped from Oclaro's UK production line. In addition, Oclaro has begun trading builds for the coherent CFP2-ACO in its Shenzhen facility. "We will begin building Shenzhen qualification modules during this quarter, as we prepare to go into higher levels of volume production in Asia during the first half of 2016," Dougherty adds. CapEx for fiscal 2016 should be $30–40m, as Oclaro invests in additional capacity for both the 100G client- and line-side growth.

"By continuing to build on our 100G product success, for both client- and line-side applications, we believe we can generate the sales growth necessary to meet our objective of becoming profitable on a non-GAAP operating basis during fiscal year 2016," continues Dougherty. "We believe our non-GAAP operating breakeven model can be achieved when both gross margins and operating expense reach 25% of revenue [starting from a base of $23m per quarter for the September quarter onwards]," adds chief financial officer Pete Mangan.

"One dynamic that we are seeing is stronger market demand for coherent CFP2 transceivers, which operate at both 100 and 200 gigabits," notes Dougherty. "To reinforce our strong position in the CFP2 ACO space, we want to emphasize the fact that we have been successfully shipping CFP2 ACO product for use in both 100G and 200G applications… about one year ago, at ECOC 2014, Oclaro demonstrated the industry's first CFP2 ACO operating at 200G." he adds. "The design-in process for coherent CFP2-ACO is quite lengthy and complicated. There are many hand-shaking functions and interactions between the transceiver and the customer's DSP [digital signal processor]. For these reasons, we believe that there is a significant advantage to being first to market, and we believe we are the leading supplier."

Beyond that, in addition to broadening its 100G product portfolio successfully at both the component and module levels to micro-iTLA narrow-linewidth lasers and lithium niobate modulators, Oclaro is already shipping early prototype examples of higher-bandwidth lithium niobate modulator products for use in single-wavelength 400G systems. "We continue to invest in our future with the intention of being the leading player in 100G and beyond," concludes Dougherty.

www.oclaro.com

GigOptix public offering raises $14.73m to support enhanced strategic growth through acquisitions

GigOptix Inc of San Jose, CA, USA (a fabless supplier of analog semiconductor and optical communications components for fiber-optic and wireless networks) has closed a public offering of 9,218,000 newly issued shares of common stock at a price of $1.70 per share to raise gross proceeds of $15.67m.

Net proceeds (after underwriting discounts and commissions) were $14.73m. In addition, certain officers and directors (as selling stockholders) sold 282,000 shares of previously issued shares in the underwritten public offering under an effective equity incentive plan registration statement on file with the US Securities and Exchange Commission (SEC). The firm is receiving none of the proceeds from the sale of shares by the selling stockholders.

GigOptix expects to use the net proceeds (from the shares it is selling) for potential acquisitions for strategic growth, including the acquisition of critical technologies and scalable businesses. The firm says the focus will be on multiple attractive global targets, including entities that it has been tracking for the last couple of years.

www.gigoptix.com

NeoPhotonics' revenue grows 5% in Q2 to record $85.4m, driven by 100G products

Low-margin product pruning aids fourth consecutive quarter of profit

For second-quarter 2015, NeoPhotonics Corp of San Jose, CA, USA (a vertically integrated designer and manufacturer of hybrid photonic integrated optoelectronic modules and subsystems for high-speed communications networks) has reported record revenue of $85.4m, up 10.2% on $77.5m a year ago and up 4.9% on $81.4m last quarter. This is despite the firm pruning from its portfolio products that contributed $2.5m in Q1 (as part of a program announced a year ago — completed by the end of Q2/2015 — to prune low-margin products that contributed $23m in 2014).

"With strong traction of our High Speed Products (for 100G-and-beyond) in transport and metro markets as well as in rapidly growing data-center interconnect (DCI) system applications, a record 59% of our revenue [up from 57% last quarter] was from 100G-and-above High Speed Products [mostly 100G coherent]," says chairman & CEO Tim Jenks.

Network Products and Solutions (<100Gb/s) represented 41% of total revenue (down from 43% last quarter), with sales of products for broadband access networks (level at 20% of total revenue) remaining firm in China (although NeoPhotonics continues to view this product group as a mature business).

"NeoPhotonics is a market share leader for key products used in coherent transmission, at 100, 200 and 400Gb/s, such as our integrated coherent receivers (ICRs) and narrow-linewidth tunable lasers. Our broad suite of 100G products is used in long-haul and metro transport and also in data-center interconnect and enterprise applications," says Jenks. "Telecom service providers represent our largest end-use market, notably for both High Speed 100G products and for Network Products and Solutions, including broadband access products, and both of these markets have deployments underway for infrastructure build-outs in China that are expected to span several years," he adds.

Of total revenue, China rose from 48% to 50%, while the Americas fell from 30% to 28% and Japan fell from 5% to 4%. The rest of the world rose from 17% to 18%. Specifically, NeoPhotonics saw lumpiness in Europe due to inventory re-balancing (primarily associated with the pending acquisition of Alcatel-Lucent by Nokia). "While we expect order patterns to return to normal after the optical transport manufacturing operations of Alcatel-Lucent are transitioned to a contract manufacturer as a part of the acquisition, this and general EU softness may remain hard to predict and possibly continue to be lumpy going forward," comments Jenks. Contributing 11% of total revenue in Q2, Alcatel-Lucent joined the two existing 10%-or-greater customers: US-based Ciena (22%) and China-based Huawei Technologies (40%).

On a non-GAAP basis, gross margin has risen for a fourth consecutive quarter, from 20.8% a year ago and 31.3% last quarter to 32.3% (above the expected 28-32%). Margin improvement continues to be driven by demand for High-Speed Products (100G and above), with additional volumes in the second quarter, along with cost improvements driving lower manufacturing costs.

For the remainder of the year and through 2016, High Speed 100G coherent long-haul deployments, including in China, will remain a primary contributor

Operating expenses were $21.1m (24.8% of revenue), up 5% on $20.2m last quarter but still cut from $22.3m (28.7% of revenue) a year ago. "The operating expense run rate continues to reflect the vigilant management and controls we established in the second half of last year to be consistent with our target model and as we drive for overall profitability improvement," says chief financial officer Ray Wallin. "Now we have successfully operated at our target model of 25% operating expenses for the last four quarters." This is despite expenses from the integration of personnel and associated costs related to acquiring the Emcore tunable laser product line on 2 January.

Operating income was $6.4m (an operating margin of 7.5% of revenue), an improvement from $5.3m (6.6% of revenue) last quarter and a loss of $6.2m (–8% of revenue) a year ago.

As a result of its continued revenue growth, margin expansion and operating cost discipline, NeoPhotonics has hence posted its fourth consecutive quarter of profitability: net income was $5.3m ($0.14 per diluted share), an improvement on $4.2m ($0.13 per diluted share) last quarter and a loss of $7.5m ($0.24 per diluted share) a year ago.

Operating cash generation was $7.7m (up from $7.4m last quarter). Hence, after capital expenditure of $3.5m, free cash flow was $4.2m — the fourth consecutive quarter of positive cash flow from operations and free cash flow, as the firm focuses on effective management of working capital assets and on driving profitability improvements.

"We continue to strengthen our liquidity in the quarter, both through our equity offering in May and the subsequent repayment of a portion of our outstanding debt," notes Wallin. In April, NeoPhotonics repaid early the Emcore note for $15.7m

that was part of the consideration for acquiring the tunable laser product line. In May, NeoPhotonics raised $45.6m in net proceeds from a public offering of 6.9 million shares. Also, to continue to manage interest costs, NeoPhotonics reduced its short-term bank borrowings by $5m. In conjunction with debt restructuring actions in first-quarter 2015, the net cash position is over $58m. During the quarter, cash and cash equivalents, short-term investments, and restricted cash and investments, rose by $30.1m from $74.3m to $104.4m.

"Our goal is to be a leader in High Speed 100G and beyond product solutions and to deliver sustained profitability. Our second quarter results continue to demonstrate our strong execution towards our profitability goals and our target model with sequential increases in revenue, gross margins, profitability, EBITDA and operating cash flow," says Jenks.

Driven by preparations for both new product launches in manufacturing and build plans supporting second-half 2015, net inventory rose by $4.9m during Q2 to $69.7m (from 102 days on hand to 106 days).

"We continue to be excited about the traction of our High Speed 100G-and-beyond products in rapidly growing data-center interconnect system applications, as this contributed to our strong high-speed product group results, and within the China market we continued to experience strong demand for all our products, including 100G coherent solutions during the second quarter," says Jenks. "Beginning in the second half of 2014, we saw a significant acceleration of long-haul optical deployments within China, which continued through the first half of this year. As we look to the growth drivers of our business for the remainder of the year and through 2016, High Speed 100G coherent long-haul deployments, including in China, will remain a primary contributor," he adds.

"Our near-term outlook is reflecting timing differences in the next two quarters that are driven most notably by deployment of 100G infrastructure supporting transport and related mobile networks in China," says Jenks. "The timing of these deployments results in our more conservative outlook for the third quarter."

Taking into account the now completed pruning of products (that contributed about $2.5m to Q2 revenue), plus the timing variations in China infrastructure build-outs and the temporary Alcatel-Lucent rebalancing, for third-quarter 2015 NeoPhotonics expects drops in revenue to $77–83m, in gross margin to 29–32%, and in diluted earnings per share to $0.01–0.09. "We are going to continue to run the factory consistent with the prior quarter because of what we are feeling about the second half, and we continue to generate manufacturing efficiencies and improvements," says Wallin. "So we have a little bit lower volume of the higher-margin products." NeoPhotonics still expects full-year revenue growth of 10% in 2015.

"During the last several quarters we introduced our long-term operating model," says Wallin. "Now we anticipate making steady progress towards our target model goal, which is non-GAAP gross margin of 35%, R&D expenses in the 14% range, SG&A expenses in the 11% range (i.e. total operating expenses of 25% of revenue) and non-GAAP operating margin of 10%."

www.neophotonics.com

Transmode shareholders accept Infinera acquisition offer

Infinera Corp of Sunnyvale, CA, USA, a vertically integrated manufacturer of digital optical transport networking systems incorporating its own indium phosphide-based photonic integrated circuits (PICs), says the public offer that it initiated on 9 April to acquire Transmode AB of Stockholm, Sweden (a provider of packet-optical networking solutions) has been accepted by shareholders representing about 95.8% of the outstanding shares and votes in Transmode. The transaction was due to close around 20 August.

Of the shares tendered, about 63% were tendered under the cash and stock mix alternative, and about 37% under the all-cash alternative. The final consideration will hence consist of about 7.9 million shares of Infinera common stock and the remainder in cash.

Infinera says that combining the firms brings together into one company a complementary set of customers, products and technologies. Transmode's strength in metro packet-optical applications complements Infinera's long-haul and metro Cloud solutions. The combination enables Infinera to offer an end-to-end portfolio addressing the metro aggregation market including metro core, metro edge and metro access with solutions optimized for fast-growing applications including mobile front-haul and back-haul, broadband aggregation, and business Ethernet services with Metro Ethernet Forum (MEF) certification.

"The combination of Infinera and Transmode makes sense from both a market and cultural perspective," comments Andrew Schmitt, research director, Carrier Transport Networking, at market analyst firm IHS Research. "This acquisition positions Infinera to capitalize on the growing metro market as it begins a transition to 100G," he adds.

"By bringing together two highly successful teams, we can offer an end-to-end portfolio to fully address the metro and long-haul optical transport markets," says Infinera's CEO Tom Fallon. "The deal accelerates our entry into the emerging 100G metro market, building upon our leadership position in long-haul and metro Cloud," he adds.

www.infinera.com
www.transmode.com

Emcore reports higher-than-expected quarterly revenue growth of 11.2%

Continuing Broadband Fiber-Optics business enters profit following sales of PV and Telecoms Fiber Optics businesses

For fiscal third-quarter 2015 (to end-June), Emcore Corp of Alhambra, CA, USA (which provides compound semiconductor-based chip-level devices, optical components, subsystems and systems for broadband and specialty fiber-optics markets) has reported revenue of $21.2m (exceeding the guidance of $19-21m). This is up 11.2% on $19m last quarter and up 55.9% on $13.6m a year ago, driven by significantly higher sales of CATV products (primarily to US customers) and chip-level devices.

Emcore completed the sales of its Space Photovoltaics business in mid-December 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 fiscal Q3, sales of CATV products, which include quadrature amplitude modulation (QAM) transmitters and receivers, represented the largest percentage of total fiber optics-related revenue. Sales of chip-level device products, which include avalanche photodiodes (APDs) and gain chips, rose as Emcore expanded sales to customers, primarily in Asia.

By region, $15.5m of revenue came from the USA, $3.7m from Asia, and $1.7m from Europe.

"In addition to top-line growth across our major product lines, we are also beginning to realize the benefits of improved performance in operations from our lean manufacturing initiatives," says president & CEO Jeffrey Rittichier.

Performance marks three important financial milestones; a return to GAAP profitability from continuing operations, stronger non-GAAP net income and generation of positive cash flows

On a non-GAAP basis (for continuing operations), gross margin has risen further, from 33.5% last quarter (the highest in the past five years) to 36.3%.

Total operating expenses were $6.8m, cut from $8m last quarter, due to selling, general & administrative (SG&A) expenses being cut from $6m to $4.5m, as the firm begins to benefit from the relocation of its corporate headquarters late last year from Albuquerque, NM, to Alhambra, CA.

Income from continuing operations was $1.3m, compared with roughly breakeven last quarter and a loss of $4.1m a year ago.

On 15 May, Emcore announced a modified Dutch auction tender offer, which it completed on 15 June with the purchase of 6.9 million shares of its common stock at a purchase price of $6.55 per share (for a total of $45m, excluding related fees and expenses).

During the quarter, cash and cash equivalents fell from $141m to $114.1m.

"This quarter's performance marks three important financial milestones for Emcore; a return to GAAP profitability from continuing operations, stronger non-GAAP net income and generation of positive cash flows from operations," says Rittichier.

For fiscal fourth-quarter (to 30 September 2015), Emcore expects revenue to grow to $22–24m.

www.emcore.com

OSI unveils 1490nm pulsed laser diode modules for optical testing applications

At LASER World of PHOTONICS 2015 in Munich, Germany in June, OSI Laser Diode Inc (LDI) of Edison, NJ, USA premiered its SCW 1430 series of laser diode modules.

Operating typically at a center wavelength of 1490nm (1470nm minimum to 1510nm maximum), the Al RWG (ridge-waveguide) FP (Fabry–Perot) laser diode series is designed for optical testing applications where high peak pulsed power is required, such as optical time-domain reflectometers (OTDRs) and optical spectrum analyzers (OSAs).

Four RoHS-compliant packages are available: 14-pin dual in-line (DIL), 14-pin butterfly, 3-pin coaxial or 3-pin transistor outline (TO56).

The high-peak pulsed laser diode modules deliver at least 100mW of optical power (fiber) and a minimum of 300mW (TO56). The higher power offers greater dynamic range capability to OTDR manufacturers. The SCW 1430 series also features what is said to be excellent pulse drift performance and high stability.

www.laserdiode.com

Soitec ends negotiations to sell solar assets to ConcenSolar, but continues to refocus on core electronics business

Soitec of Bernin, Grenoble, France, which makes engineered substrates including silicon-on-insulator (SOI) wafers, says that despite the signature on 20 May of an agreement for the sale of a portion of its solar business (including technology assets and manufacturing operations in Germany and in the USA) to privately held firm ConcenSolar — a business partner of concentrator photovoltaic (CPV) firm Suncore Photovoltaic Technology Co Ltd of Huainan, Anhui Province, China (which is owned by San'an Optoelectronics Co Ltd, the largest LED maker in China) — the closing will not occur.

Due to the depreciated book values of the assets as of the fiscal year to end-March 2015, Soitec will not record additional depreciation in its accounts.

Soitec says that it will continue its plan to refocus on its core electronics business and to transition away from its solar business activities, with maximizing opportunities to realize value from its solar assets remaining a priority. The firm will also continue to support its existing solar energy customers.

www.soitec.com

Ascent Solar's revenue grows 235% in Q2 to $2.2m

For second-quarter 2015, Ascent Solar Technologies Inc of Thornton, CO, USA — which makes lightweight, flexible copper indium gallium diselenide (CIGS) thin-film photovoltaic modules integrated into off-grid applications and its EnerPlex series of consumer products — has reported revenue of $2.2m, up 105% on a year ago and up 235% on last quarter. Loss from operations was ($6.9m), an improvement of about $1m (12.6%) from ($7.9m) a year ago.

For first-half 2015, revenue was $2.9m, up 57% year-on-year from $1.8m in first-half 2014. Loss from operations improved by about $1.7m (11%) from $15.5m in first-half 2014 to $13.8m in first-half 2015, due to a combination of increasing sales and improved operational efficiencies while keeping operating expenses marginally down. These expenses are expected to remain relatively flat while the firm continues to ramp up revenue growth.

The repositioning of Ascent Solar over the past three years is beginning to yield results, particularly in regards to the accelerating growth and acceptance of the EnerPlex line of products in retail channels

"With the ongoing expansion of our distribution channels, I am optimistic to set yet another significant revenue milestone of over $10m for fiscal year 2015 [after delivering revenue of $5m for the first time in 2014]," says president & CEO Victor Lee. "The repositioning of Ascent Solar over the past three years is beginning to yield results, particularly in regards to the accelerating growth and acceptance of the EnerPlex line of products in retail channels," he adds. "We are fully prepared to execute our business plan both in the consumer category as well as the high-value PV markets."

www.AscentSolar.com

EnerPlex launches European expansion; products now available in 172 Maplin Electronics stores across UK

Ascent Solar Technologies Inc has launched its EnerPlex products in 172 Maplin Electronics stores throughout the UK.

Maplin is one of the largest consumer electronics retailers in the UK and has cemented its position as experts in consumer electronics for British consumers.

Maplin now carries core EnerPlex products including: the Jumpr Stack 3 & 6 powerbanks, integrated with micro-USB and Lightning cables enabling consumers to charge up their devices without worrying about carrying extra cables, the Jumpr Slate 5k & 10k razor thin power banks, and the ultra-thin EnerPlex Surfr battery & solar case for the iPhone 5, 5s and iPhone 6.

Ascent says that, for solar-integrated consumer electronics, EnerPlex provides lightweight, powerful and durable charging solutions for portable electronics. Surfr, a line of solar and battery integrated phone cases, allows users to charge their phone anywhere and in cases of emergency. The Kickr line of portable solar chargers provides a charging solution for nearly all devices, enabling power to be generated almost anywhere and in nearly every situation, suiting emergency preparedness. With the addition of Jumpr line of portable batteries, EnerPlex now provides a complete, integrated, solar charging and storage solution, says the firm.

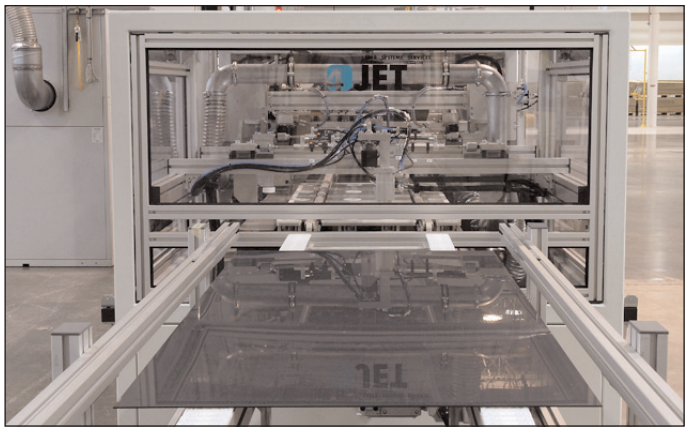
www.goenerplex.com

Stion purchases $5.8m of Avaco's tools

CIGS PV module production capacity to double to 120MW/year

Avaco Co Ltd of Daegu, South Korea, which manufactures thin-film processing equipment including sputtering physical vapor deposition (PVD) vacuum deposition systems, has received a purchase order of $5.8m for production tools under a capital lease agreement from Stion Corp of San Jose, CA, USA, a manufacturer of nanostructure-based CIGS (copper indium gallium sulphur-diselenide) thin-film solar modules founded in 2006 with backing by Khosla Ventures. "As our product has become more widely accepted for larger megawatt-scale projects, increased capacity has become the key. We feel confident in AVACO as the equipment partner for this expansion."

The tools will complete the first full production line in Stion's high-volume manufacturing facility in Hattiesburg, MS, USA (opened in 2012), helping to double production output from 60MW to 120MW per year. As part of the deal, the two firms will also extend their engineering services agreement.



Equipment in Stion's manufacturing plant in Hattiesburg.

Avaco is providing six thermal processing furnaces for the absorber formation process, and two TCO (transparent conducting oxide) deposition tools. The systems will allow Stion to eliminate bottlenecks within the production line. The build-out, along with other productivity improvements, will allow the line to reach its full target output of 120MW per year.

Avaco has traditionally specialized in the manufacturing of flat-panel display (FPD) equipment, and is continuing to grow its presence in the photovoltaic (PV) market by leveraging its thin-film coating and system engineering expertise. The firm has already assisted Stion in building and retrofitting several key tools for its Hattiesburg factory.

"This partnership represents an exceptional opportunity for Stion to take advantage of strong demand in the US and other global markets," believes Stion's CEO Chet Farris. "As our product has become more widely accepted for larger megawatt-scale projects, increased capacity has become the key. We feel confident in Avaco as the equipment partner for this expansion," he adds.

Avaco is continuing to expand its presence in the US solar market, says Jimyung Wee, Avaco's executive VP of strategy & planning. "Our partnership with Stion shows our belief in and commitment to CIGS technology," he adds.

www.avaco.com
www.stion.com

Stion's CIGS modules approved for product listing in Dubai market

Stion Corp of San Jose, CA, USA says that its STO Elevation Series framed modules are the first CIGS (copper indium gallium selenium) based thin-film solar modules approved as eligible photovoltaic (PV) equipment in Dubai as part of DEWA's First Initiative: Shams Dubai.

DEWA (Dubai Electricity and Water Authority) is launching the Connecting Solar Electricity to Houses and Building Smart Initiative, with the aim of encouraging consumers to adopt solar energy as a mean of producing their own electricity, and in line with the vision of Dubai as world leaders in the green economy. Any surplus of production will be fed into the electricity network and credited for off-setting future consumption.

DEWA says that, for these installations, it has set eligibility criteria based on international standards on quality and safety. Stion says that its modules are made using a reliable glass/glass packaging design, and are backed by a 10-year workmanship and 25-year performance warranty. With average summer highs in Dubai of 106°F, what is claimed to be the industry-leading temperature coefficient of Stion's PV modules will also provide superior performance and returns to consumers and project investors.

As part of its Distributed Renewable Resource Generation program, DEWA's First Initiative supports the vision of HH Sheikh Mohammed bin Rashid Al Maktoum, Vice President and Prime Minister of the United Arab Emirates (UAE) and Ruler of Dubai, to make Dubai the smartest city in the world. The First Initiative also supports diversifying the energy mix by promoting the use of clean and renewable energy sources to build a sustainable future for the Emirates.

www.dewa.gov.ae/smartinitiatives/firstinitiative
www.energevity.us
www.stion.com

TSMC terminating CIGS PV manufacturing

Late market entry and lack of economies of scale led to substantial cost disadvantage

The world's biggest silicon wafer foundry Taiwan Semiconductor Manufacturing Co Inc (TSMC) says its subsidiary TSMC Solar Ltd — founded in 2009 to make copper indium gallium diselenide (CIGS) photovoltaic modules — is ceasing manufacturing operations at the end of August as its solar business is "no longer economically sustainable".

TSMC will continue to honor all product warranties offered to existing customers, and will also extend employment offers to all staff currently working at TSMC Solar upon the closure of its fab in Central Taiwan Science Park in Taichung.

TSMC Solar's late entry into the market and lack of economies of scale led to a substantial cost disadvantage, acknowledges TSMC's senior VP & chief financial officer Lora Ho. The firm has come to the conclusion that, despite what it claims is world-class solar energy conversion efficiency for CIGS technology, TSMC Solar will not be viable even with the most aggressive cost reduction plan.

"TSMC continues to believe that solar power is an important source of green energy and that solar module manufacturing remains a robust and growing industry but, despite six years of hard work, we have not found a way to make a sustainable profit," says Steve Tso, chairman of TSMC Solar and senior VP of TSMC. "Upon ceasing manufacturing operations at TSMC Solar, our most important concern will be the continued employment of our workers there."

TSMC estimates that charges related to closing the solar subsidiary's fab will impact third-quarter 2015 earnings per share by NT$0.07. Remaining solar panel inventory will be installed at TSMC buildings and facilities.

www.tsmc-solar.com

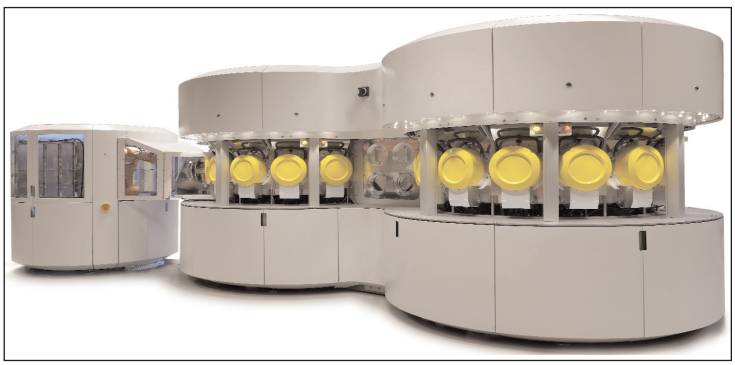
Sweden's Midsummer granted SEK10m loan from regional development agency Almi

Loan to fund continued development of CIGS solar cell production equipment

Regional development agency Almi Företagspartner Stockholm Sörmland AB has granted a SEK10m ($1.18m) loan — part of which is guaranteed by the European Investment Fund (EIF) — to Midsummer AB of Järfälla, near Stockholm, Sweden, a supplier of turnkey production lines for manufacturing flexible copper indium gallium diselenide (CIGS) thin-film photovoltaic (PV) solar cells. The purpose of the loan is to support Midsummer's focus on production and sales of its DUO manufacturing system, in particular to provide increased resources for R&D.

"Our loan intends to provide opportunity for innovative companies to develop innovations and business ideas that provide growth and profitability," says Almi Företagspartner's financial advisor Fredrik Larsson.

"We sold a DUO system this spring to a foreign multi-national company, which is yet another proof of the market potential for our system," says Midsummer's CEO Sven Lindström. "The DUO is a compact, fully automated system for production of CIGS solar cells. It is designed for high productivity, operational stability and superior material utilization," he adds.



Midsummer's DUO manufacturing system.

Midsummer says that an increasing number of manufacturers see the benefits of flexible thin-film solar cell technology as it can be easily integrated into buildings (BIPV) — a rapidly growing segment.

"Through the funding we hope to provide Midsummer with the opportunity to develop and pursue its commercialization," Larsson says. "It is hoped that Midsummer can become a model for other Swedish environmental technology companies."

Midsummer has been named as one of Sweden's hottest technology companies and has repeatedly been featured on the list of the nation's fastest-growing technology companies. In particular, it was the fastest-growing cleantech company in the Europe, Middle East & Africa (EMEA) region in 2007–2011 (according to Deloitte's Fast 500).

www.almi.se

www.midsummer.se/duo.html

Grading gallium indium nitride arsenide for multi-junction solar cells

A slanted bandgap across a 1μm absorber layer has enhanced the extraction of photo-generated carriers from 34% to 36.7% at 900–1100nm wavelengths.

Researchers based in Germany and the UK have been developing growth processes of gallium indium nitride arsenide (GaInNAs) with graded composition for use in multi-junction solar cells [F. Langer et al, Appl. Phys. Lett., vol106, p233902, 2015]. The grading produced a slanted bandgap of 39meV across a 1μm absorber layer that enhanced the extraction of photo-generated carriers from 34.0% to 36.7% in the 900–1100nm wavelength range.

Lattice-matched GaInNAs 1eV bandgap layers could extend the performance of standard monolithic multi-junction devices of gallium indium phosphide/gallium indium arsenide/germanium. However, the introduction of nitrogen into the GaInAs structure tends to introduce deep-level defects that increase residual carrier densities from ~10^{15}/cm^3 to the mid-10^{16}/cm^3 range, inhibiting the extraction of photo-generated carriers. By grading the GaInNAs composition, photo-generated carriers can be extracted more efficiently.

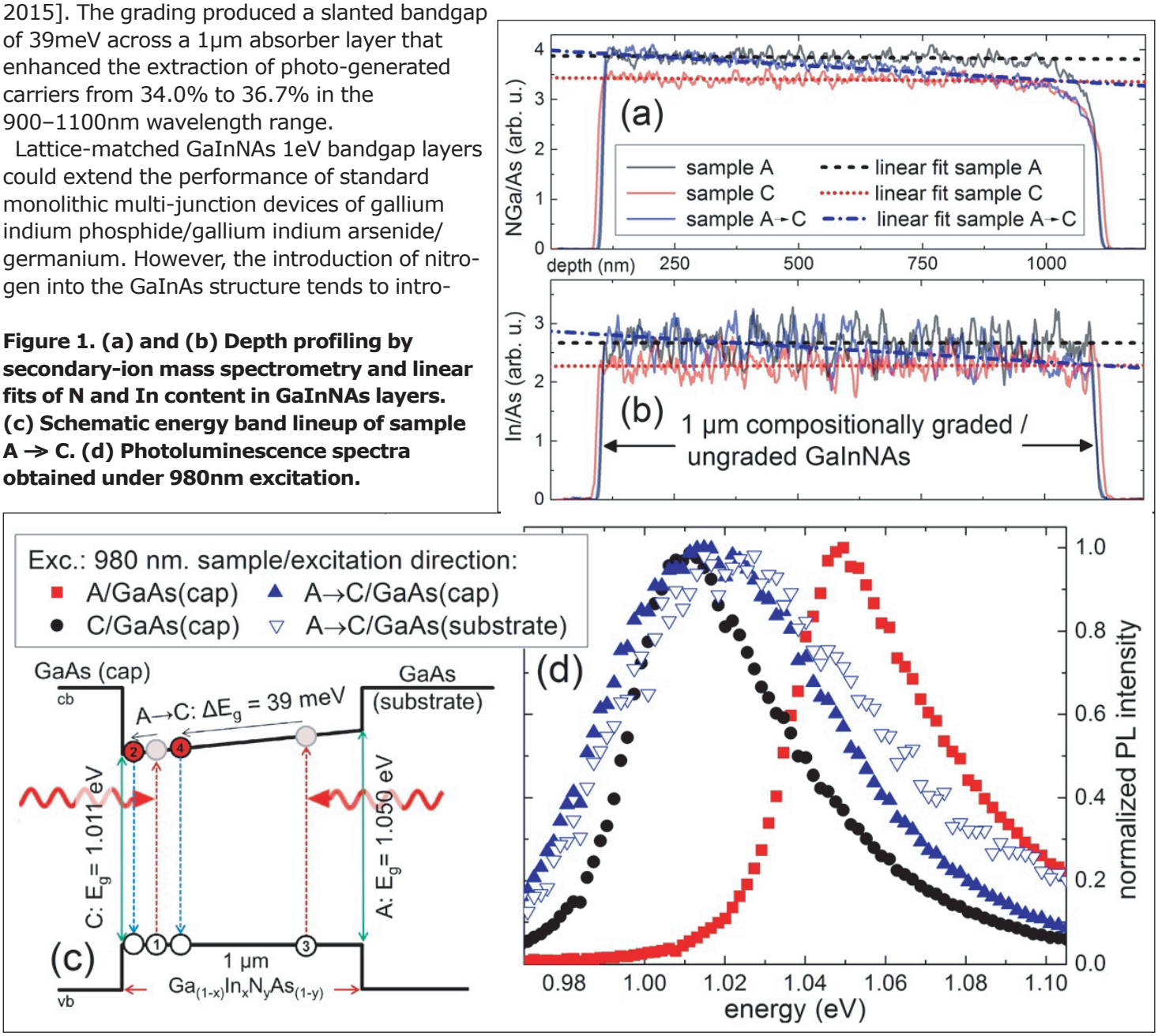


Figure 1. (a) and (b) Depth profiling by secondary-ion mass spectrometry and linear fits of N and In content in GaInNAs layers. (c) Schematic energy band lineup of sample A → C. (d) Photoluminescence spectra obtained under 980nm excitation.

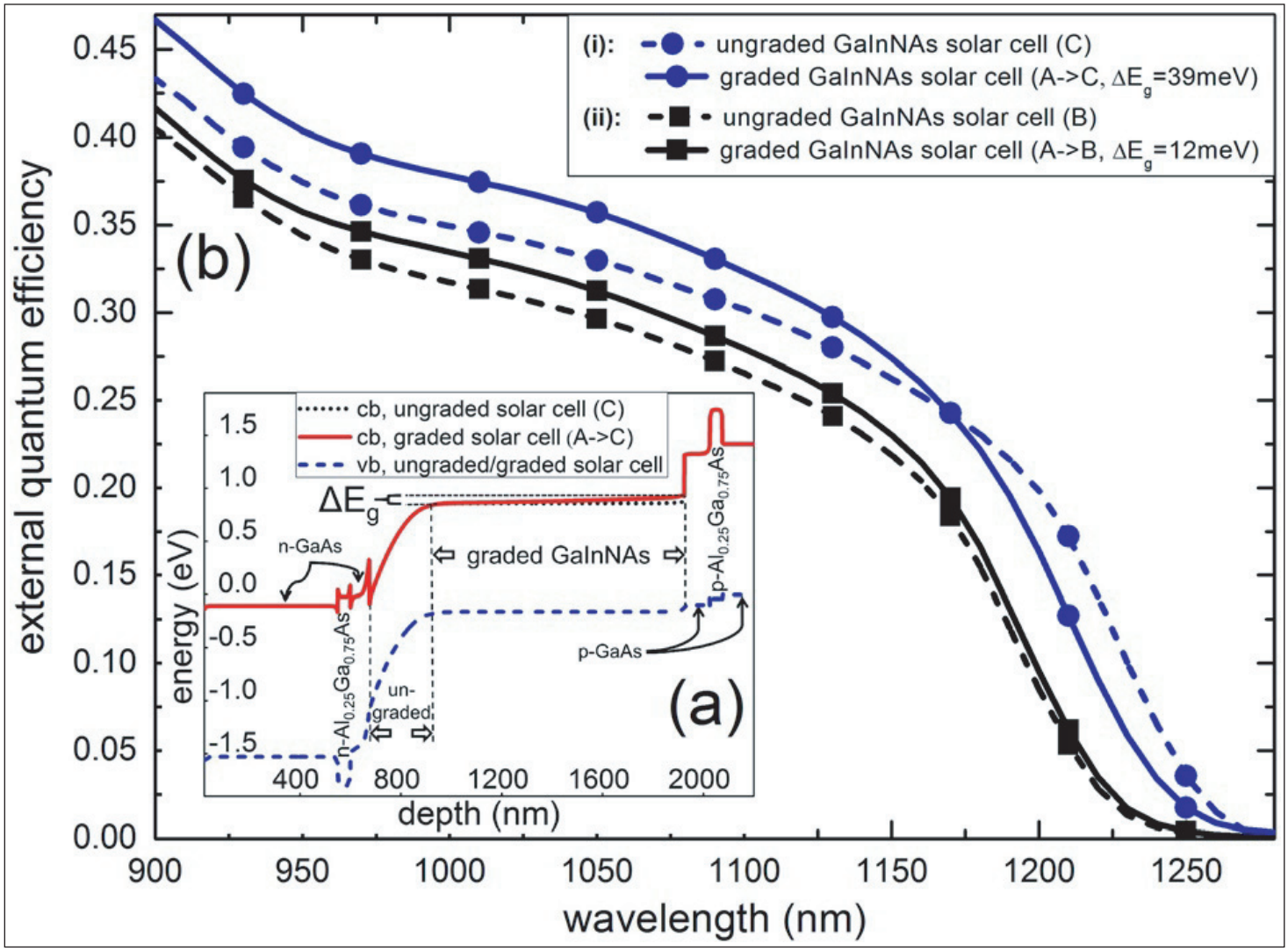


Figure 2. (a) Band lineup of pin-GaInNAs solar cells. (b) EQE measurements of GaInNAs solar cells with compositionally graded and ungraded GaInNAs layers.

University of Würzburg and University of St Andrews grew their heterostructures by molecular beam epitaxy (MBE) with the nitrogen supplied as radio-frequency plasma and the other atomic species generated by solid sources. The substrates were zinc-doped (100) GaAs wafers offcut 6° to the (111)B plane.

Layers of $Ga_{1-x}In_xNyAs_{1-y}$ were grown at 380°C. Different compositions were achieved through control of the flux from the Ga solid-source effusion cell. Lattice matching with the underlying GaAs was achieved by keeping the x fraction at about three times the y fraction. A post-deposition anneal was carried out at 700°C.

Various ungraded and graded 1µm layers of GaInNAs were grown on 200nm GaAs buffer (Table 1). The structure was completed with a 100nm GaAs cap.

The researchers believe that the main effect of the grading is felt by the conduction band rather than the valence band. Hence, the grading will mainly affect the behavior of photo-generated electrons. Photoluminescence through the cap and substrate supported this picture (Figure 1).

Compositional grading processes were used to create solar cells with p-i-n diode structures (Figure 2). Aluminium gallium arsenide ($Al_{0.25}Ga_{0.75}As$) was used for 50nm blocking layers. The active GaInNAs material was 1250nm — 1000nm graded and 250nm ungraded.

The p- and n-type regions were GaAs. The 500nm n-GaAs cap was heavily doped to $5x10^{17}/cm^2$ density. The p-type doping was $1x10^{17}/cm^2$. The undoped GaInNAs region had p-type conductivity with a carrier density in the low $10^{16}/cm^2$ range. The depletion layer

Table 1. Grown $Ga_{1-x}In_xNyAs_{1-y}$ films.

Sample	x/Δx	y/Δy	$E_g/\Delta E_g$	Lattice mismatch
A	0.069/0	0.0230/0	1.050eV/0	0.012%
B	0.075/0	0.0250/0	1.038eV/0	0.005%
C	0.083/0	0.0277/0	1.011eV/0	0.008%
A → C	–/0.014	–/0.0047	–/0.039eV	0.027%
A → B	–/0.006	–/0.0020	–/0.012eV	0.005%

Table 2. Performance parameters under xenon lamp.

GaInNAs layer	Open-circuit voltage	Short-circuit current density	Fill factor
A → C	0.40V	3.71mA/cm^2	63%
A → B	0.39V	3.21mA/cm^2	60%
C	0.42V	3.51mA/cm^2	65%
B	0.42V	3.05mA/cm^2	63%

between the n-GaAs and p-GaInNAs extended about 250nm into the ungraded part of the GaInNAs.

The fabricated cells had front contacts with 30μm-broad fingers and planar back contacts and mesa isolation of the p-i-n junction. The contact metal was annealed gold-germanium alloy.

The illumination source was a xenon lamp with about a one-third AM0 power density. The graded GaInNAs layers showed slightly degraded open-circuit voltage (V_{OC}) (Table 2), attributed to the complex process resulting in more defects. Although the graded cells had higher short-circuit current density (J_{SC}), the fill factor was lower due to the shifted absorption edge.

The electric field induced from grading increased the external quantum efficiency (EQE) by 5% and 8% on average for A→B and A→C graded GaInNAs, respectively (Figure 2).

The researchers conclude: "We believe that it should, in principle, be possible to solve the trade-off between the increased J_{SC} and the decreased V_{OC} by further optimizing the growth process of the graded material to increase its crystal quality. Our initial results show that a material grading can in principle help to improve the charge carrier extraction in a GaInNAs solar cell. However, an optimized layout of a GaInNAs solar cell must be carefully chosen and the material gradient might only be one feature among others (e.g. doping gradient, broad depletion width) promoting the current generation." ■

http://dx.doi.org/10.1063/1.4922279

Author: Mike Cooke

Creating heterojunctions between black phosphorous and gallium arsenide

Photo-response of phosphorene on GaAs is found to be comparable to that of phosphorene on molybdenum disulfide.

Researchers based in Germany and Switzerland have been studying the p–n diode properties of heterojunctions of thin-layer black phosphorous and gallium arsenide (GaAs) [Pascal Gehring et al, Appl. Phys. Lett., vol106, p233110, 2015].

Monolayer black phosphorous (phosphorene) has recently joined the ranks of two-dimensional electronic materials such as graphene and transition-metal dichalcogenides (TMDCs) as potential components of future ultra-small electronics.

Phosphorene tends to have p-type conductivity and has previously been combined with n-type molybdenum disulfide (MoS_2) to create p-n junctions with sizable photo-response. Theoretical studies suggest bilayer phosphorene could be used for solar energy harvesting through photovoltaic effects with an external quantum efficiency (EQE) of up to 18%.

The team from Max Planck Institute for Solid State Research in Germany and Ecole Polytechnique Federale de Lausanne in Switzerland used heavily tellurium-doped n^+-GaAs substrates with gold-germanium-nickel (AuGeNi) ohmic contacts. The substrate was thermally annealed to diffuse and alloy the contact metals into the GaAs substrate.

Thin flakes of 'phosphorene' were exfoliated from bulk black phosphorous crystal onto the suitably cleaned substrate, using the Scotch tape method frequently employed for graphene. The flakes had lateral diameters of up to several microns and the thickness was as low as 10nm. The conductivity of the flakes was found to be p-type — i.e. the carriers are holes. The level of p-type conductivity varies with thickness.

A 100nm silicon dioxide film was deposited at the contact regions to avoid trivial Schottky contacts being formed between the phosphorene contacts and the substrate. Nickel-gold was used as the phosphorene contact and as electrode to the nearest AuGeNi GaAs contact (Figure 1).

The device was protected from ambient degradation with a 50nm spin-on layer of poly(methyl methacrylate)

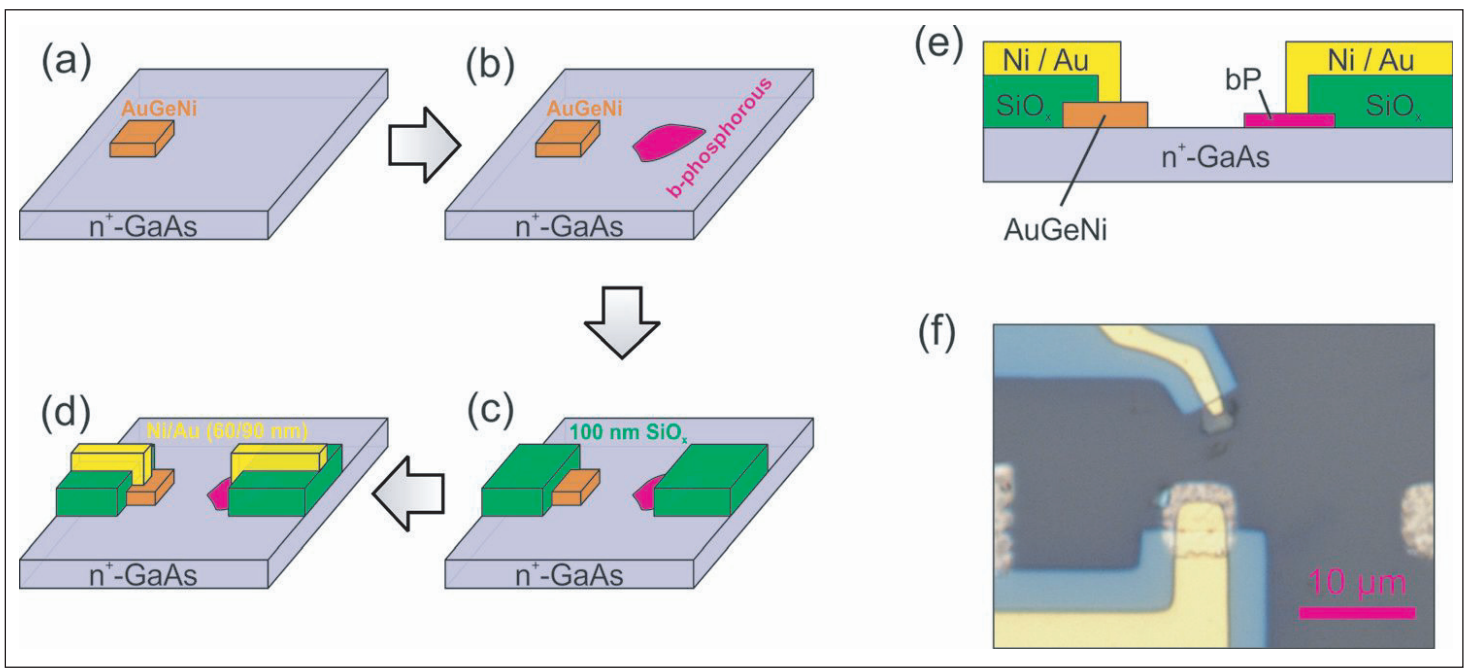


Figure 1. (a)–(d) Schematic representation of fabrication steps for thin-layer black phosphorous/GaAs p-n heterojunction devices. (e) Sketch of cross-section of completed device, and (f) optical micrograph of heterojunction device (top view).

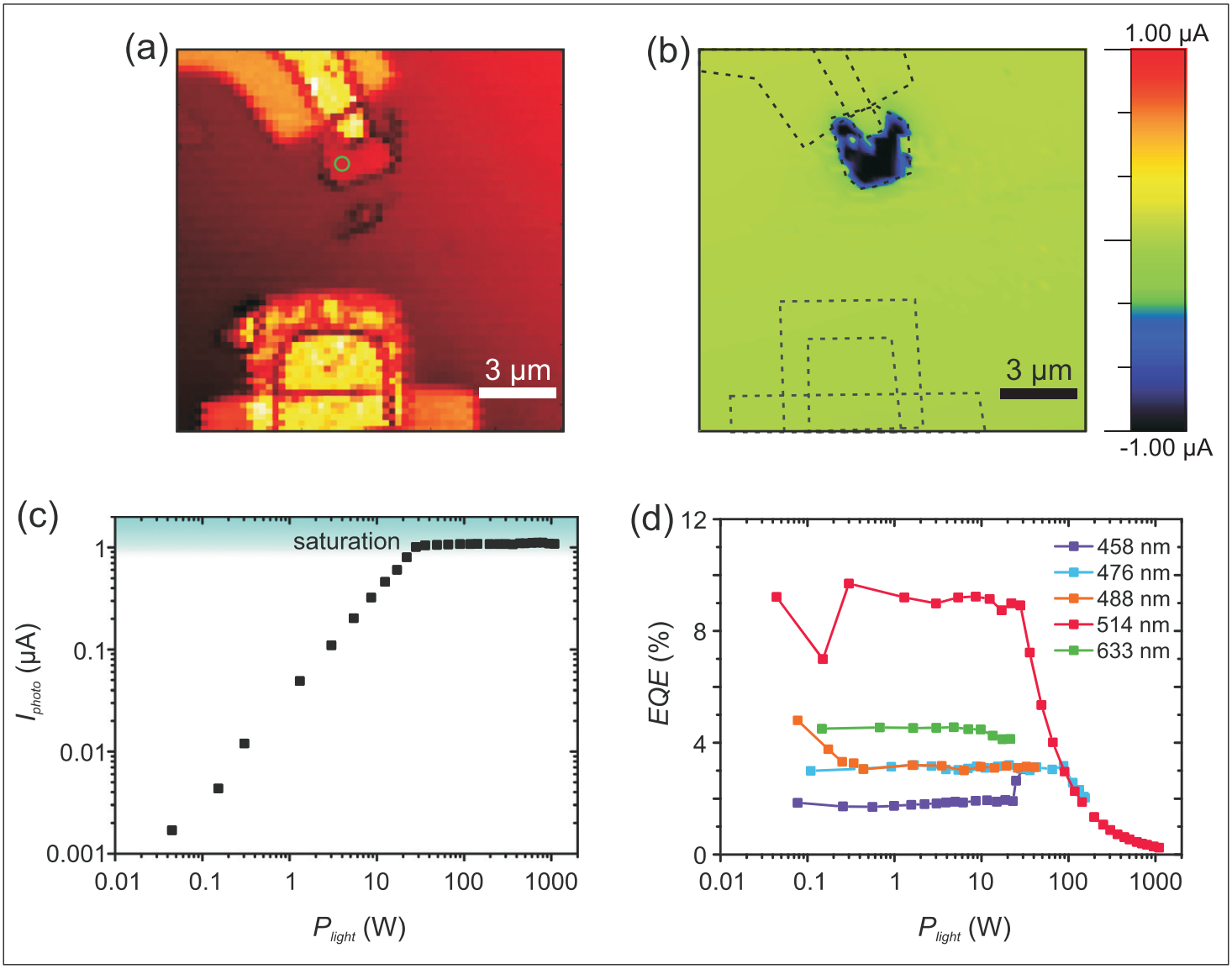


Figure 2. (a) Optical reflection image and (b) photocurrent map of device in Figure 1(f), recorded at zero source–drain bias. (c) Photocurrent as a function of laser power at 514nm wavelength. The signal was acquired from the green circle in panel (a). The blue-shaded region indicates current saturation. (d) EQE as a function of laser power for different laser light wavelengths.

(PMMA) thermoplastic.

The devices were rectifying, with the rectification ratio/asymmetry of the currents at +1V/−1V ranging between 100 and 1000. The large range is attributed to the varying areas and thicknesses of the flakes.

The low-bias ideality factor of 2 is said to be typical of theoretical diodes where the main mechanism of rectification is recombination current at the junction. At higher biases, the ideality factor increased. A device with 120 asymmetry had an ideality of 9.7 at 0.8V.

The researchers comment: "Such a high value indicates strong recombination due to defects, which might comprise intrinsic point defects inside the black phosphorous, surface defects on it arising from chemical degradation, or due to a bad contact between black phosphorous and GaAs. Another explanation involves the presence of an alternative transport channel (shunt resistance)."

Increased diffusion current above 0.8V caused the ideality to fall.

The photocurrent at zero bias of one device was measured under various laser wavelengths and powers (Figure 2). Under 514nm light, responsivity in the linear region was 37mA/W – the researchers say this is comparable with values for black phosphorous or carbon nanotubes on molybdenum disulfide heterojunctions under 'sizable bias'. The response flattened above 30μW to about 1.1μA "owing to the saturated optical absorption of the black phosphorous flake at high light intensities".

The researchers comment: "In the present device, due to the very high doping level of the GaAs, the space-charge region is mostly confined to the black phosphorous layer, whereas only a very thin positive space-charge region exists in GaAs. Hence, the magnitude of the photocurrent is mainly governed by

the number of available charge carriers inside the black phosphorous flake. Another reason is screening by the photo-generated carriers, which eliminates the bias across the depletion layer."

The 514nm wavelength gave the best zero-bias external quantum efficiency of 9.7% — "the same order of magnitude as reported for atomically thin TMDC heterostructures," according to the researchers. The enhanced performance at 514nm is attributed to van Hove singularities in the joint density of states.

The EQE under bias had a maximum of up to 31% with –2.5V reverse bias under 8.6μW 514nm wavelength over the range of devices produced.

The researchers believe that improved performance would result from better control of the chemical nature of the black phosphorous surface, complemented by the implementation of improved electrical contacts

The researchers also studied the photovoltaic performance under 514nm laser light. The maximum open-circuit voltage was ~0.6V, close to that estimated from the black phosphorous 0.56eV bandgap for a 15nm thick sheet. The maximum fill factor was ~0.3. Conventional solar cells reach 0.5–0.8. The researchers blame a low shunt resistance (leakage) and high series resistance. The high series resistance is thought to be due to high contact resistance of the black phosphorous and nickel/gold electrode. Lower values of contact resistance have been achieved on black phosphorous by other groups.

The photo-conversion efficiency — the ratio of electric power output to light power input — was measured with a maximum of 0.24%, again comparable with black phosphorous on MoS_2.

The researchers believe that improved performance would result from "better control of the chemical nature of the black phosphorous surface, complemented by the implementation of improved electrical contacts". ■

http://dx.doi.org/10.1063/1.4922531

Author: Mike Cooke

Creating n-InP/p-Si heterojunctions with lateral overgrowth

KTH in Sweden believes that the CELOG technique opens the door for low-cost and high-efficiency solar cells and photonic integration of III-Vs on silicon.

KTH-Royal Institute of Technology in Sweden has used corrugated epitaxial lateral overgrowth (CELOG) to create heterojunctions consisting of n-type indium phosphide (n-InP) and p-type silicon (p-Si) [Y. T. Sun et al, Appl. Phys. Lett., vol106, p213504, 2015]. Usually such junctions suffer from high dislocation density due to an 8% lattice mismatch. The CELOG technique allowed KTH to create hetero-junction photodiodes (HJPDs).

The researchers comment: "This demonstration of epitaxially grown InP/Si heterojunction photodiodes will open the door for low-cost and high-efficiency solar cells and photonic integration of III-Vs on silicon." They add that CELOG "is a generic technology and can be used to create functional heterojunction structures by integrating various III-V semiconductors on silicon substrate."

Monolithic realization of III-Vs on silicon could lead to photonic integrated circuits (PICs), optical interconnects for CMOS electronics, and silicon-based multi-junction solar cells. Although the paper does not mention it, InP is also frequently used as a substrate or buffer layer for the growth of indium gallium arsenide (InGaAs) — a high-mobility channel material that is proposed for integration into future high-speed CMOS electronics.

KTH used (001) p-Si substrates offcut 4° in the <111> direction. The processing began with metal-organic vapor phase epitaxy (MOVPE) of 50nm gallium arsenide (GaAs) buffer and 2μm indium phosphide seed layers. Then 30μm-diameter circular openings were etched down to the p-Si substrate in a triangular lattice with 33μm center-to-center distance (Figure 1). Wet etching was used to remove residual GaAs in these openings.

The structure was covered with 200nm silicon nitride from plasma-enhanced chemical vapor deposition (PECVD). The silicon nitride was subjected to reactive ion etch with trifluoromethane (CHF_3) which, due to its anisotropic action, removed the silicon nitride from the horizontal surfaces of the InP seed layer and the bottoms of the openings.

After cleaning, the CELOG process consisted in 590°C 20mbar low-pressure hydride vapor phase epitaxy (HVPE) of semi-insulating iron-doped InP (5 minutes) and unintentionally doped (UID) n-InP (25 minutes). The sources for the component atoms were indium chloride and phosphine (PH_3).

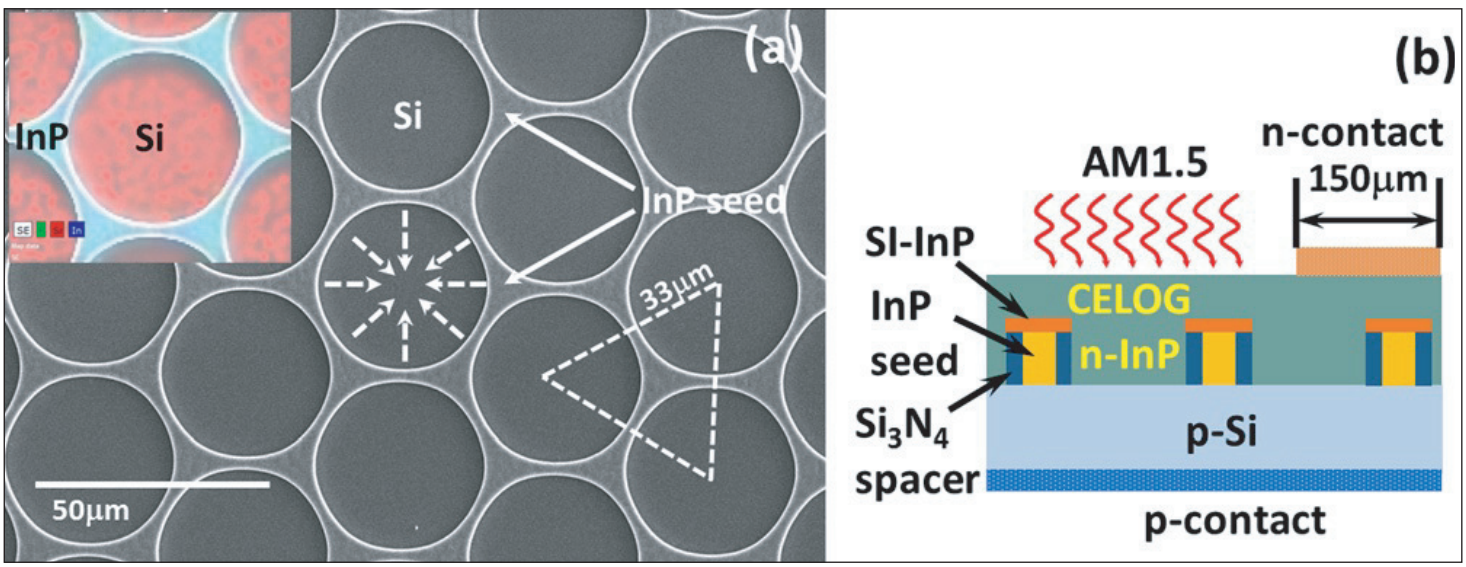


Figure 1. (a) Top-view SEM image of engineered seed InP/Si substrate for CELOG with Si surface exposed as circular openings in InP seed layer. Dashed lines indicate directions of growth initiated from surface of seed InP mesa. Inset: SEM/EDS mapping of InP and Si distribution. (b) Cross-section n-InP/p-Si HJPD, not to scale.

The aim of the semi-insulating InP material was to avoid the formation of shunt paths through the seed material in the fabricated photodiodes. The semi-insulating InP had a resistivity of more than $2x10^8\Omega$-cm.

The carrier concentration of n-InP grown on semi-insulating InP substrates is around $1.5x10^{15}/cm^3$. The researchers comment: "We chose to use this UID layer of low carrier concentration to form n-InP/p-Si heterojunction due to its higher lateral growth than highly doped n-InP so that a complete coverage of the open circle can be achieved with facility."

Heterojunction photodiodes (HJPDs) were fabricated with gold-germanium/nickel/gold n-InP ohmic contacts and 600nm aluminium ohmic p-contacts on the back-side of the p-Si substrate, thinned to 100μm. The structure was annealed at 380°C for 5 minutes. The 5mmx5mm chips had 25 150μmx150μm n-contact pads, giving around 98% exposed n-InP surface. The n-InP/p-Si regions of the HJPDs had an effective area of $0.185cm^2$ out of the $0.25cm^2$ total.

Scanning electron microscope (SEM) studies showed that the lateral growth proceeds downwards from the SI-InP material to cover the silicon surface. Also, triangular voids form between the lateral InP material and the silicon nitride spacer covering the vertical walls of the InP seed material.

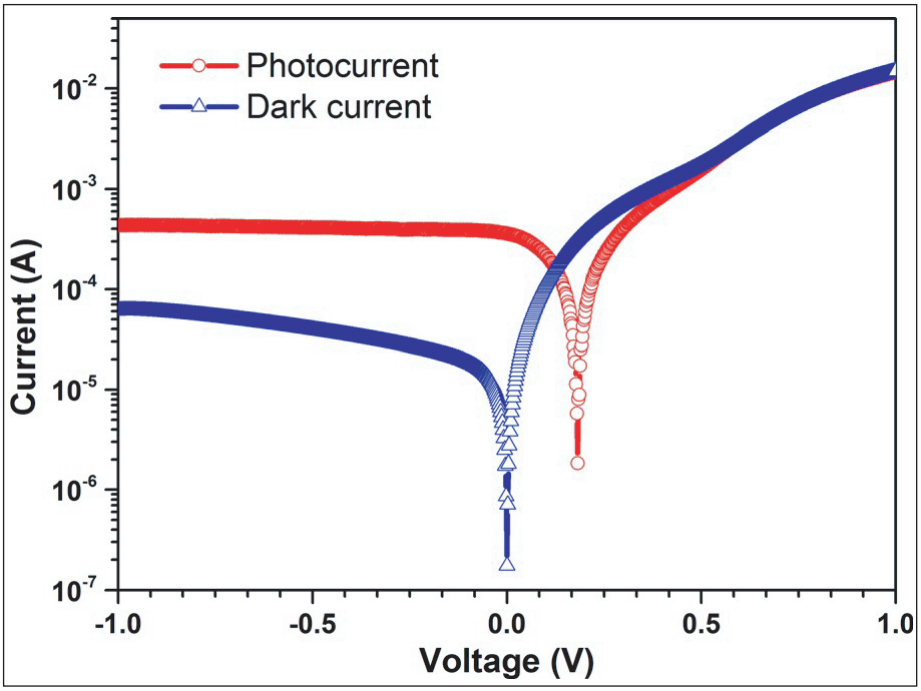


Figure 2. Dark-current and photo-current characteristics of CELOG n-InP/p-Si HJPD in semi-log plot.

PL study of bandgap narrowing suggests a higher impurity concentration of $5.6x10^{15}/cm^3$ in the region near the n-InP/p-Si CELOG interface... opposite to the conventional direct heteroepitaxial growth of III-Vs on silicon, in which the high-density defects accumulate close to the III-V/Si interface

The n-InP/p-Si junction has a type-II band alignment where the valence-band and conduction-band energy levels step upwards together from n-InP to p-Si. Such an alignment can be used in photodiodes and photovoltaic cells. The InP has a wider bandgap of 1.35eV, compared with silicon's 1.12eV. Thus, the InP can act as a window layer, filtering out high-energy photons.

The equilibrium depletion region of the pn junction is estimated to be 1.5μm. The built-in electric field in the depletion region will sweep photo-generated electrons and holes into the n-InP and the p-Si regions, respectively, giving a photocurrent. The junction region has an effective indirect bandgap of 0.74eV between the n-InP conduction band and p-Si valence band.

Photoluminescence study of bandgap narrowing suggests a higher impurity concentration of $5.6x10^{15}/cm^3$ in the region near the n-InP/p-Si CELOG interface. The researchers attribute the higher concentration to silicon incorporation from the substrate into the InP during CELOG. The PL near the n-InP/p-Si interface is also more intense than that at the CELOG InP surface. The researchers comment: "This is opposite to the conventional direct heteroepitaxial growth of III-V semiconductors on Si, in which the high-density defects accumulate close to the III-V/Si interface and cause low PL intensity."

In fact, the n-InP/p-Si PL was even more intense than that of an n-InP layer grown on an iron-doped InP substrate. The CELOG surface n-InP showed the lowest PL — attributed by the researchers to threading dislocations escaping from the seed region. The dislocation density of the seed was estimated to be $\sim10^9/cm^2$ — a high value.

The dark current of the HJPD at −1V reverse-bias leakage was 60μA (Figure 2). Expressed as a current density of $0.324mA/cm^2$, this is much smaller than for wafer-bonded germanium/silicon HJPDs. The photovoltaic effect under AM1.5 solar illumination gave an open-circuit voltage of 180mV and a short-circuit current density of $1.89mA/cm^2$. The external quantum efficiency (EQE) was estimated at 4.3%. Taking into account the reflection of photons from the InP surface, the internal quantum efficiency (IQE) was 6.4%.

The researchers believe that higher current and efficiencies could be achieved with thinner CELOG InP emitter layers. ■

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Author: Mike Cooke

Arizona State demonstrates first monolithic white lasers

Arizona State University has fabricated a monolithic multi-segment nanosheet of ZnCdSSe that is dynamically tunable over the full visible color range.

Arizona State University (ASU) has proven that monolithic semiconductor lasers are capable of emitting over the full visible color spectrum, which is necessary to produce a white laser ('A monolithic white laser', Fan et al, Nature Nanotechnology (2015); doi:10.1038/nnano.2015.149).

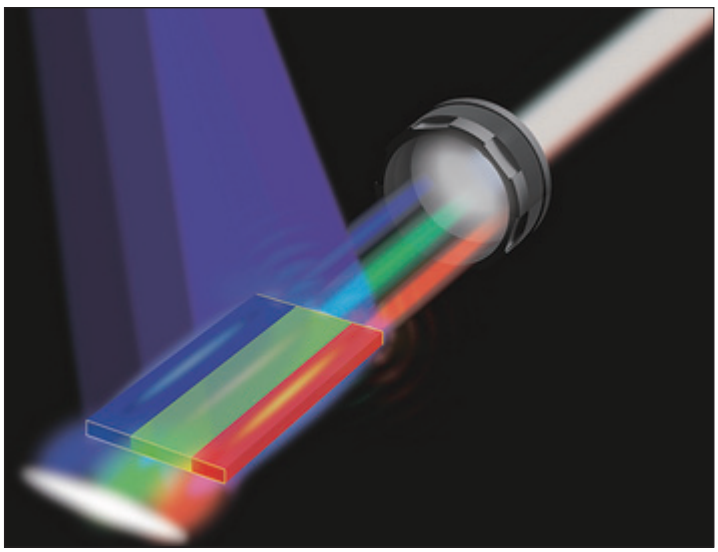
Researchers led by Cun-Zheng Ning, professor in the School of Electrical, Computer and Energy Engineering, have created a novel nanosheet based on a quaternary alloy of zinc, cadmium, sulfur and selenium (ZnCdSSe) with three parallel segments, each supporting simultaneously lasing in one of the three elementary colors red, green and blue. The device is therefore capable of lasing in any visible color, completely tunable dynamically over the full visible color range from red, green to blue, or any color in between. When the total field is collected, a white color emerges.

The development puts lasers one step closer to being a mainstream light source and potential replacement or alternative to light-emitting diodes (LEDs), it is reckoned, since lasers are brighter, more energy efficient, and can potentially provide more accurate and vivid colors for displays like computer screens and televisions. Ning's group has already shown that their structures could cover as much as 70% more perceptible colors than the existing standard for the display industry.

Another key application in the future could be visible light communications, in which the same room lighting systems could be used for both illumination and communication (Li-Fi for light-based wireless communication, as opposed to Wi-Fi using radio waves). Li-Fi could be more than 10 times faster than existing Wi-Fi technology, and white laser Li-Fi could be 10–100 times faster than LED-based Li-Fi currently still under development.

"The concept of white lasers first seems counter-intuitive because the light from a typical laser contains exactly one color, a specific wavelength of the electromagnetic spectrum, rather than a broad-range of different wavelengths," says Ning (who also spent extended time at China's Tsinghua University during several years of the research). "White light is typically viewed as a complete mixture of all of the wavelengths of the visible spectrum," he adds.

In typical LED-based lighting, a blue LED is coated with phosphor materials to convert a portion of the blue light to green, yellow and red light. This mixture of colored light is perceived as white light and can therefore be used for general illumination.



Schematic illustrating nanosheet with three parallel segments, each supporting lasing in one of three elementary colors. The device can lase in any visible color, completely tunable from red, green to blue, or any color in between. When the total field is collected, a white color emerges. Photo by ASU/Nature Nanotechnology.

In 2011, the USA's Sandia National Laboratories produced high-quality white light from four separate large lasers. The researchers showed that the human eye is as comfortable with white light generated by diode lasers as with that produced by LEDs, inspiring others to advance the technology.

"While this pioneering proof-of-concept demonstration is impressive, those independent lasers cannot be used for room lighting or in displays," Ning says. "A single tiny piece of semiconductor material emitting laser light in all colors or in white is desired."

The most preferred light-emitting semiconductor material is indium gallium nitride (InGaN), although other materials such as cadmium sulfide and cadmium selenide are also used for emitting visible colors.

The main challenge lies in the way light-emitting semiconductor materials are grown and how they work to emit light of different colors. Typically, a given semiconductor emits light of a single color — blue, green or red — that is determined by its unique atomic structure and energy bandgap. To produce all possible

wavelengths in the visible spectral range, several semiconductors of very different lattice constants and energy bandgaps are needed.

"Our goal is to achieve a single semiconductor piece capable of laser operation in the three fundamental lasing colors," says Fan. "The piece should be small enough, so that people can perceive only one overall mixed color, instead of three individual colors," he adds.

The key obstacle is the lattice constant being too different for the various materials required. "We have not been able to grow different semiconductor crystals together in high enough quality, using traditional techniques, if their lattice constants are too different," says co-author Zhicheng Liu (a doctoral student at the time of the research).

The most desired solution would be to have a single semiconductor structure that emits all needed colors, says Ning. The key is that, at the nanometer scale, larger mismatches can be better tolerated than in traditional growth techniques for bulk materials. High-quality crystals can be grown even with large mismatch of different lattice constants.

Recognizing this unique possibility early on, Ning's group started pursuing the distinctive properties of nanomaterials such as nanowires or nanosheets more than 10 years ago. He and his students have been researching various nanomaterials to see how far they could push the limit of advantages of nanomaterials to explore the high-crystal quality growth of very dissimilar materials.

Six years ago, with funding from the US Army Research Office, the group demonstrated that nanowire materials could be grown in a wide range of energy bandgaps so that color-tunable lasing from red to green can be achieved on a single substrate about 1cm long. Later they realized simultaneous laser operation in green and red from a single semiconductor nanosheet or nanowires. These achievements triggered Ning's thought to push the envelope further to see if a single white laser is possible.

Blue, necessary to produce white, proved to be a greater challenge, due to its wide energy bandgap and very different material properties. "We have struggled for almost two years to grow blue-emitting materials in nanosheet form, which is required to demonstrate eventual white lasers," says co-author Sunay Turkdogan, fellow doctoral student at the time and now assistant professor at University of Yalova in Turkey.

The group finally devised a strategy to create the required shape first, and then convert the materials into the appropriate alloy contents to emit the blue color. "To the best of our knowledge, our unique growth strategy is the first demonstration of an interesting growth process called dual ion exchange process that enabled the needed structure," says Turkdogan.

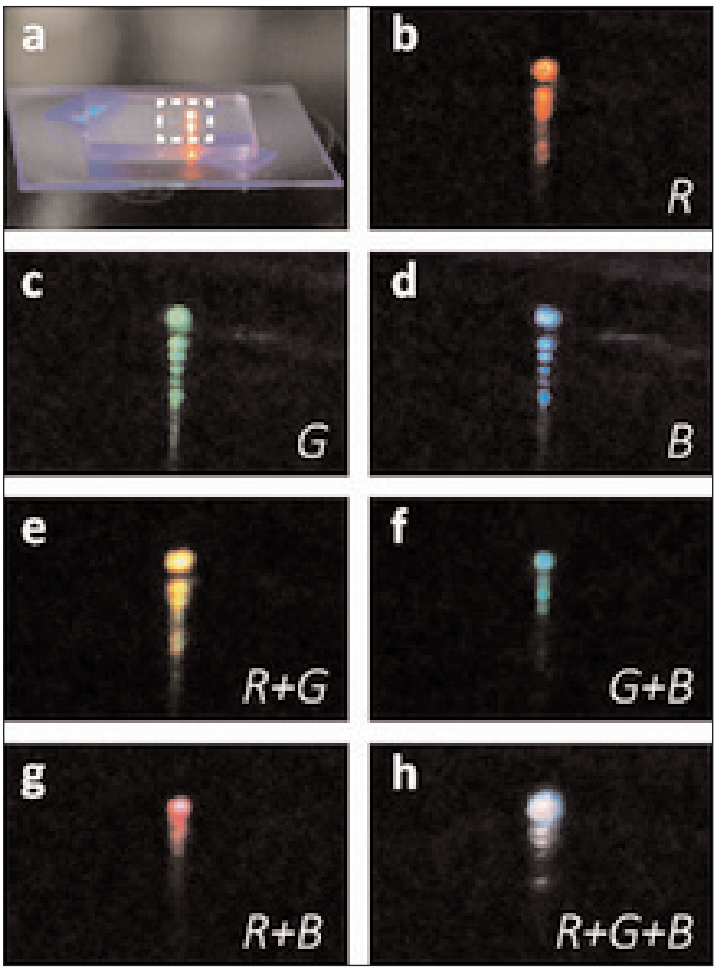


Photo collage showing mixed-emission red, green, blue, yellow, cyan, magenta and white colors from multi-segment nanosheet. The top dots in each photo are the direct image of laser emission, while the tails under these dots are the reflection from the substrate. Photo by: ASU/Nature Nanotechnology.

This strategy of decoupling structural shapes and composition represents a major change of strategy and the breakthrough that finally made it possible to grow a single piece of structure containing three segments of different semiconductors emitting all the required colors. "This is not the case, typically, in the material growth where shapes and compositions are achieved simultaneously," notes Turkdogan.

While this first proof-of-concept is important, significant obstacles remain to make such white lasers applicable for real-life lighting or display applications, says the researchers. One of crucial next steps is to achieve similar white lasers under the drive of a battery. For the present demonstration, the researchers had to use a laser light to pump electrons to emit light. This experimental effort demonstrates the key first material requirement and is expected to lay the groundwork ultimately for white lasers under electrical operation.

www.nature.com/nnano/journal/vaop/ncurrent/full/nnano.2015.149.html

http://nanophotonics.asu.edu

Increasing the power and efficiency of 265nm-wavelength LEDs

Researchers in Japan have improved the light extraction from deep UV LEDs by using photonic crystal and subwavelength structures.

Researchers based in Japan claim the highest output power and external quantum efficiency (EQE) so far for deep ultraviolet (DUV) sub-270nm-wavelength light-emitting diodes (LEDs) during DC operation [Shin-ichiro Inoue et al, Appl. Phys. Lett., vol106, p131104, 2015]. One 265nm device achieved 90mW output power and 6.3% peak EQE. The team from Japan's National Institute of Information and Communications Technology (NICT) and Tokuyama Corp used photonic crystal and subwavelength structures to enhance light extraction, giving improved EQE performance over previous devices.

Potential applications for DUV LEDs include air/water purification, surface disinfection, bio-agent detection, lithographic microfabrication, and medicine. To replace mercury lamps, high-power, efficient operation is required, particularly in the sub-270nm region needed for efficient destruction of DNA and RNA for microbial sterilization. However, existing DUV devices have low EQEs – in the 270-300nm range a value of 10% has been achieved, but moving to shorter wavelengths yields a dramatic drop off in efficiency. For comparison, blue LEDs have reached more than 80% EQE.

DUV LEDs are generally constructed from aluminium gallium nitride (AlGaN) materials, which suffer from high defect densities in active layers and poor light extraction efficiency. Defect densities can be reduced by growing AlGaN epitaxial layers on AlN rather than sapphire substrates.

AlGaN DUV LEDs use p-GaN contacts to give a reasonable electrical contact. Unfortunately this means that the device must be flipped so that the light is emitted from the back-side/substrate of the device, since GaN strongly absorbs DUV radiation. Devices on sapphire already suffer from poor light extraction due to total internal reflection at the sapphire–air interfaces as a result of the difference in refractive index at 265nm (1.8:1). This contrast is made worse with AlN substrates (2.29:1).

The NICT/Tokuyama team produced a 100μm transparent AlN substrate by hydride vapor phase epitaxy (HVPE) on c-plane single-crystal AlN, grown by physical vapor transport (PVT). The HVPE AlN was separated from the PVT AlN since the latter absorbs DUV. The PVT AlN was removed using polishing techniques.

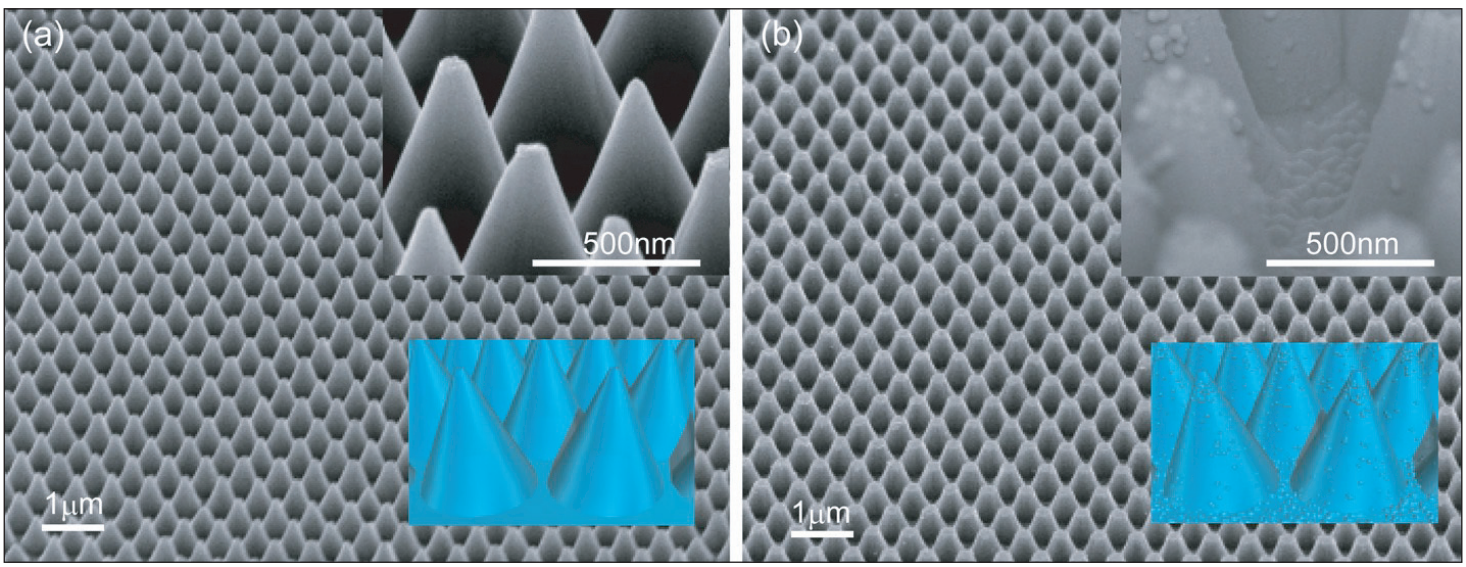


Figure 1. SEM micrographs of fabricated light extraction structures on AlN substrate surfaces: two-dimensional photonic crystals with triangular lattice of circular AlN cones, (a) without subwavelength nanostructures and (b) with subwavelength nanostructures. Insets show enlarged SEM images and schematics.

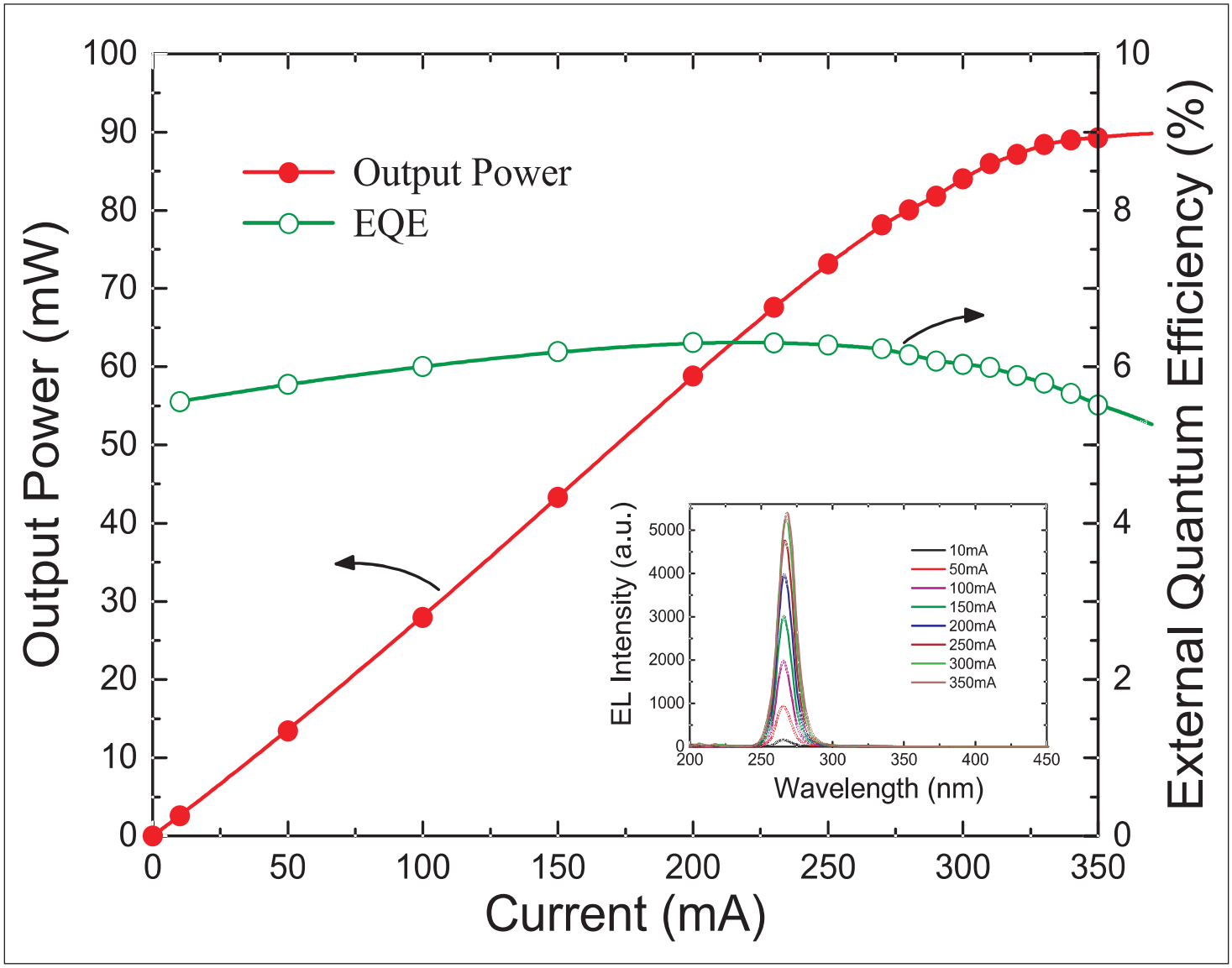


Figure 2. Output power and EQE as function of injection current for 265nm DUV-LED during DC operation. Inset shows EL spectra.

The epitaxial layers for the DUV LED were grown by metal-organic chemical vapor deposition (MOCVD) on the free-standing HVPE AlN: 100nm AlN, 1μm silicon-doped n-$Al_{0.75}Ga_{0.25}N$, three-period multiple quantum well (MQW) active region, magnesium-doped p-AlN electron-blocking layer, p-$Al_{0.8}Ga_{0.2}N$ cladding layer, and p-GaN contact. The contact layer was chosen so that good ohmic electrical contact could be made with the metal electrode and for current spreading, despite the strong DUV absorption of p-GaN.

The fabricated LEDs had ~0.001cm^2 mesa regions and, respectively, nickel/gold and titanium/aluminium/gold p- and n-type electrodes.

The majority of light was designed to be emitted via two-dimensional photonic crystals on the AlN surface to improve light coupling between the semiconductor and air. The triangular-lattice photonic crystal (Figure 1) was formed using inductively coupled plasma etch. The elements of the lattice consisted of circular cones of AlN. The lattice spacing was in the range 250–1000nm. Experiment and simulation gave an optimal spacing of ~600nm, giving 144% light extraction enhancement over a flat surface.

Light extraction was further enhanced with self-organized subwavelength 30nm-diameter hemisphere nanostructures produced through wet etching with hydrochloric acid. A hybrid structure of photonic crystal and subwavelength structures achieved 196% light extraction enhancement with 300nm lattice spacing.

Electroluminescence was measured up to 350mA injection current with the device encapsulated on an AlN submount (Figure 2). The maximum output power was 90mW with external quantum efficiency of 5%. At 200mA, the output power was 59mW with 6.3% EQE. The researchers write: "This is the highest output power and EQE published to date for DUV-LEDs with a peak emission wavelength shorter than 270nm during DC operation." ■

http://dx.doi.org/10.1063/1.4915255

Author: Mike Cooke

Long-wavelength N-polar indium gallium nitride LEDs

MOVPE process achieves red emission with 633.4nm wavelength, longer than other –c-plane InGaN LEDs, according to researchers.

Researchers in Japan have been developing long-wavelength N-polar indium gallium nitride (InGaN) light-emitting diodes (LEDs) [Kanako Shojiki et al, Appl. Phys. Express, vol8, p061005, 2015]. By varying the metal-organic vapor phase epitaxy (MOVPE) growth temperature between 880°C and 790°C, the emission wavelength was changed from 444nm to 633nm.

In making longer-wavelength devices, InGaN with high indium content is needed. The researchers from Tohoku University and the CREST funding program of the Japan Science and Technology Agency studied –c-plane/N-polar MOVPE since indium incorporation is more efficient than for +c-plane/Ga-polar growth. However, –c-plane MOVPE growth is more difficult to achieve and growth conditions need more strict optimization.

One problem with high-indium-content InGaN alloy is that that the InN and GaN components do not mix uniformly (phase separation).

The team used a horizontal reactor for metal-organic vapor phase epitaxy on c-plane sapphire. The substrate was off-cut at 0.8° around the a-axis, a smaller angle than previous research on –c growth by University of California Santa Barbara (UCSB) in the USA. The researchers believed that the smaller angle would reduce step-bunching in the growth.

N-polar growth was initiated with a nitridation step. A buffer of –c-plane 1μm GaN was followed by 1.8μm of n-type GaN. Both these layers were grown at 1100°C.

Five InGaN wells were grown in GaN barriers. The wells and barriers were grown with different gas mixture ratios (Figure 1). Hydrogen carrier gas was not used in the InGaN growth steps. Hydrogen inhibits indium incorporation.

The structure was capped off with p-GaN grown at 930°C. For the LEDs, the n- and p-type electrodes were titanium/aluminium/titanium/gold and nickel/gold, respectively. The current injection area was 67,600μm^2.

The growth of the multiple quantum well (MQW) active region was carried out at six different temperatures between 790 and 880°C. X-ray analysis of the wells showed no strain relaxation, in contrast to long-wavelength LED materials produced in the +c-direction by Tokyo University of Science.

The electroluminescence (EL) spectra blue-shifted to

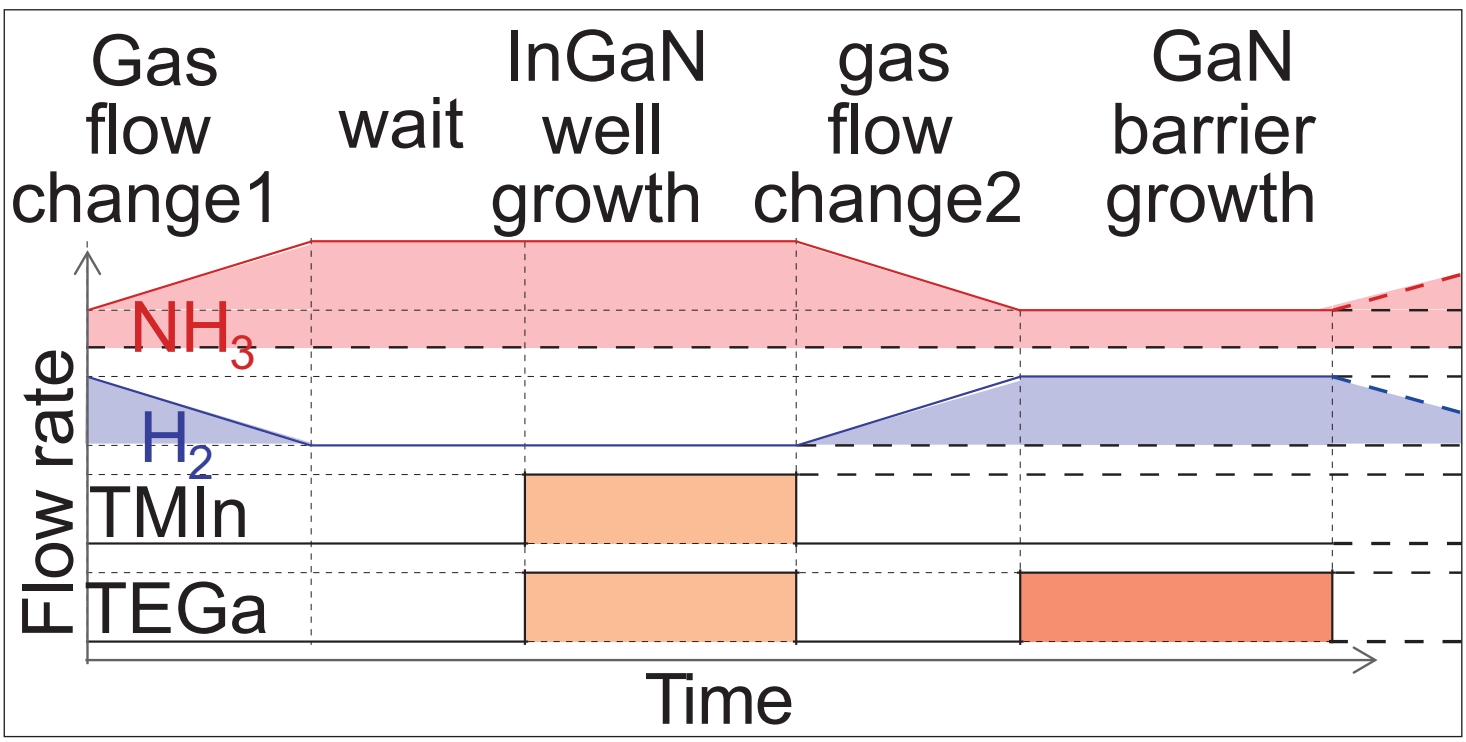


Figure 1. Schematic for one-period sequences of gas flow of InGaN/GaN MQW.

Table 1. EL characterization of –c-plane InGaN LEDs with MQW temperatures ranging from 790°C to 880°C.

$T_{g,MQW}$	790°C	810°C	820°C	830°C	850°C	880°C
Injection current	20mA (29A/cm^2)	20mA (29A/cm^2)	20mA (29A/cm^2)	20mA (29A/cm^2)	20mA (29A/cm^2)	80mA
EL peak wavelength	633.4nm	600.5nm	551.0nm	506.8nm	488.6nm	444.4nm
EL intensity	0.7mW/cm^2	1.9mW/cm^2	14.0mW/cm^2	32.5mW/cm^2	10.7mW/cm^2	0.3mW/cm^2

shorter wavelengths with increased current — an effect attributed to screening of the quantum-confined Stark effect and band filling, as seen in +c-plane devices. For an LED with 810°C MQW, the shift was 47nm between 5.3A/cm^2 and 137.6A/cm^2. The peak was around 600nm (orange). Self-heating effects reduced the efficiency at high current injection, associated with the low hole concentration in the p-GaN layer and increased non-radiative recombination.

Transmission electron microscopy (TEM) and x-ray diffraction (XRD) analysis gave estimates for the InGaN well thickness of 2.8nm and GaN barrier thickness of 8.7nm. The indium composition of the wells was 21%. For +c-plane wells with the same indium composition, the peak wavelength is generally around 100nm shorter. The researchers comment: "This means that –c-plane LEDs have a higher density of localized emission centers associated with a high-indium-content and/or a thick region, which cannot be detected by XRD."

One expects in both –c-plane and +c-plane growth similar amounts of phase separation, leading to high-indium-content regions. However, at the present stage, the thickness uniformity of –c-plane deposition is inferior to the more established +c-plane processes.

The effect of increasing MQW growth temperature was to shorten the peak EL wavelength (Table 1). The researchers claim that their 633.4nm LED with 790°C MQW had a longer wavelength than previously reported –c-plane devices. In particular, this wavelength was 85nm longer than a reported –c-plane LED produced using plasma-assisted molecular beam epitaxy (PAMBE).

The researchers comment: "A comparison among the LEDs on sapphire substrates grown by the same growth method of MOVPE reveals that the output power and maximum EL peak wavelength of our LEDs far exceeded those previously reported for –c-plane LEDs." ■

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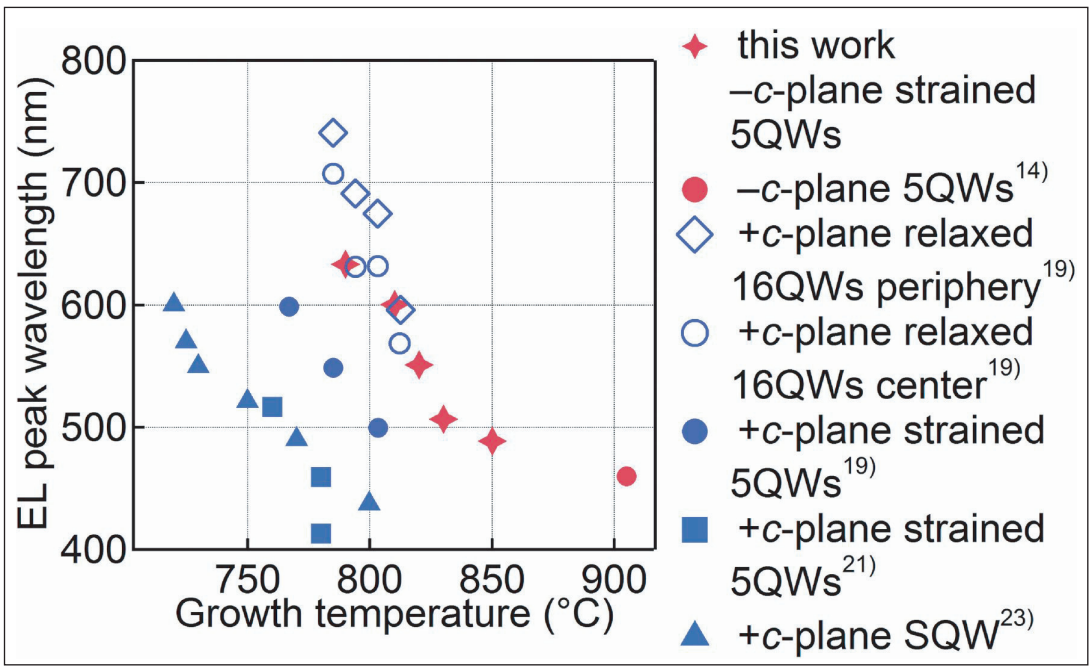

Figure 2. Dependence of EL peak wavelength and $T_{g,MQW}$ of +c-plane and –c-plane LEDs under driving current of 20mA.

Indium surfactant for higher hole concentration in gallium nitride

Ammonia-based MBE process suppresses compensating donor effects.

University of California Santa Barbara (UCSB) in the USA has improved hole concentrations in p-type gallium nitride (p-GaN) by using indium as a surfactant in ammonia-based molecular beam epitaxy (NH_3MBE) [Erin C. H. Kyle et al, Appl. Phys. Lett., vol106, p222103, 2015].

The difficulties in producing p-type magnesium (Mg) doping of GaN have hampered the production of efficient light-emitting devices. The Mg acceptors have an activation energy of ~200meV, which means that most of the acceptor atoms are not ionized at room temperature (300K ~ 26meV). In addition there are donor states (even in undoped GaN) that partially compensate for the holes released from the ionized acceptors. Nitrogen vacancy defects are thought to be one source of these compensating donor states. Hydrogen can also play a role in reducing p-GaN doping efficiency [see www.semiconductor-today.com/news_items/2015/jun/kopti_100615.shtml].

The 200nm-thick p-GaN layers were grown on Lumilog semi-insulating iron-doped GaN-on-sapphire templates. The MBE was performed in a Veeco 930 system with effusion cells as Ga, In and Mg sources. The nitrogen source was ammonia delivered through an unheated showerhead injector. Extreme nitrogen-rich conditions were used, with the ammonia/III ratio being more than 3700.

First the researchers studied the effect of increasing the indium surfactant flux on the hole concentration in $4.5x10^{19}/cm^3$ Mg-doped GaN, created using 700°C MBE. The highest hole concentration came with an indium flux of $5x10^{-8}$Torr beam equivalent pressure (BEP). The Ga flux was the same. The residual indium concentration in the grown material was between $6.0x10^{19}/cm^3$ and $1.3x10^{20}/cm^3$.

The effect of temperature was analyzed in growth with $5x10^{-8}$Torr In flux and $6x10^{19}/cm^3$ Mg doping. The resistivity and hole concentration for 700°C growth

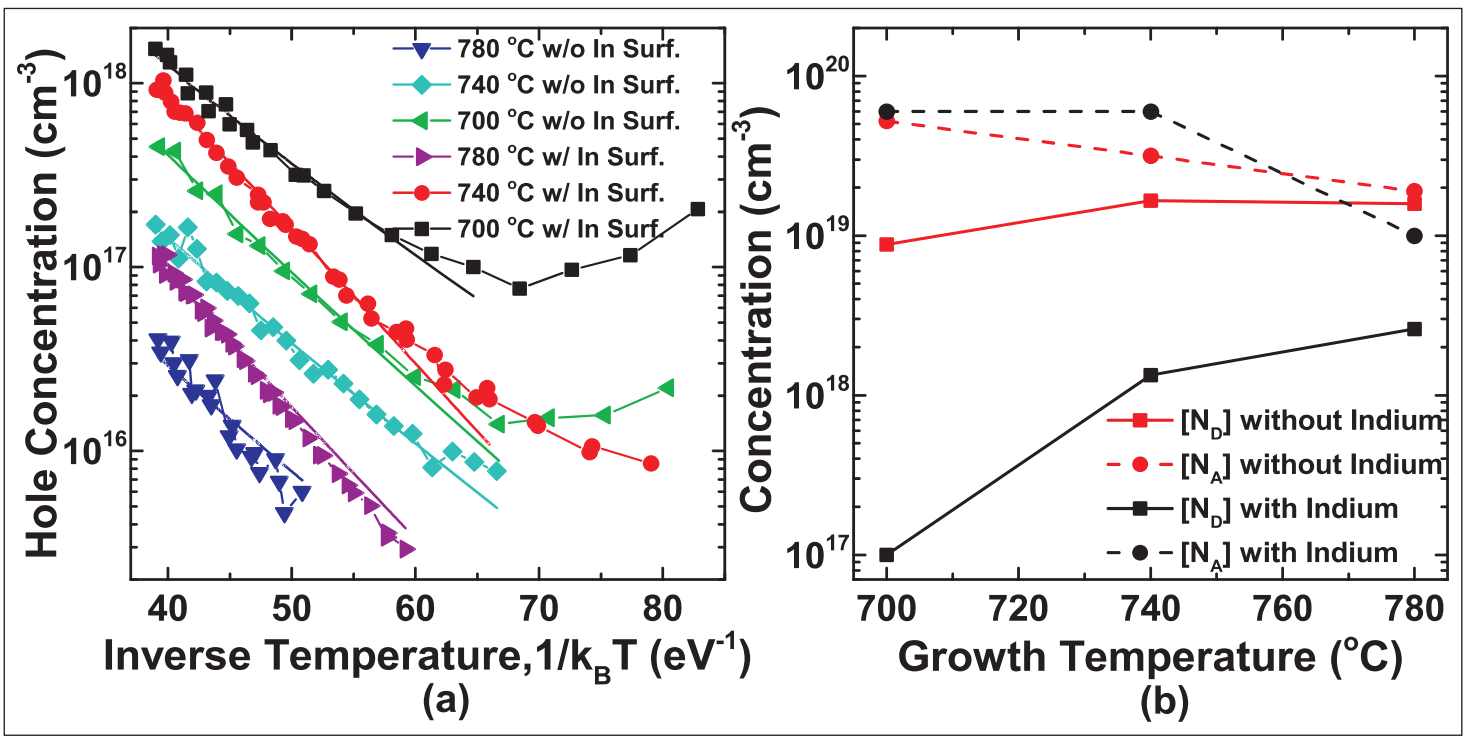

Figure 1. (a) Fit of temperature-dependent hole data for growth temperature series using charge balance equation. E_{a0} fitted globally for all data sets; E_a calculated for each data set at each temperature. Data below 170K not included in fit. (b) Fitted acceptor (N_A) and donor (N_D) concentrations for temperature-dependent data.

were 0.59Ω-cm and $1.6x10^{18}/cm^3$, respectively. The residual indium concentration was $1x10^{20}/cm^3$.

Temperature-dependent Hall measurements were used to disentangle the concentration of acceptor and donor impurities in the Mg-doped GaN with and without In surfactant (Figure 1). It was found that the surfactant mainly suppressed the compensating donor concentration. The analysis assumed that the ionization energy of the acceptors was 0.183eV (183meV) in the absence of ionized acceptors (E_{a0}). The lowest-temperature growth at 700°C gave the highest acceptor and lowest donor concentrations

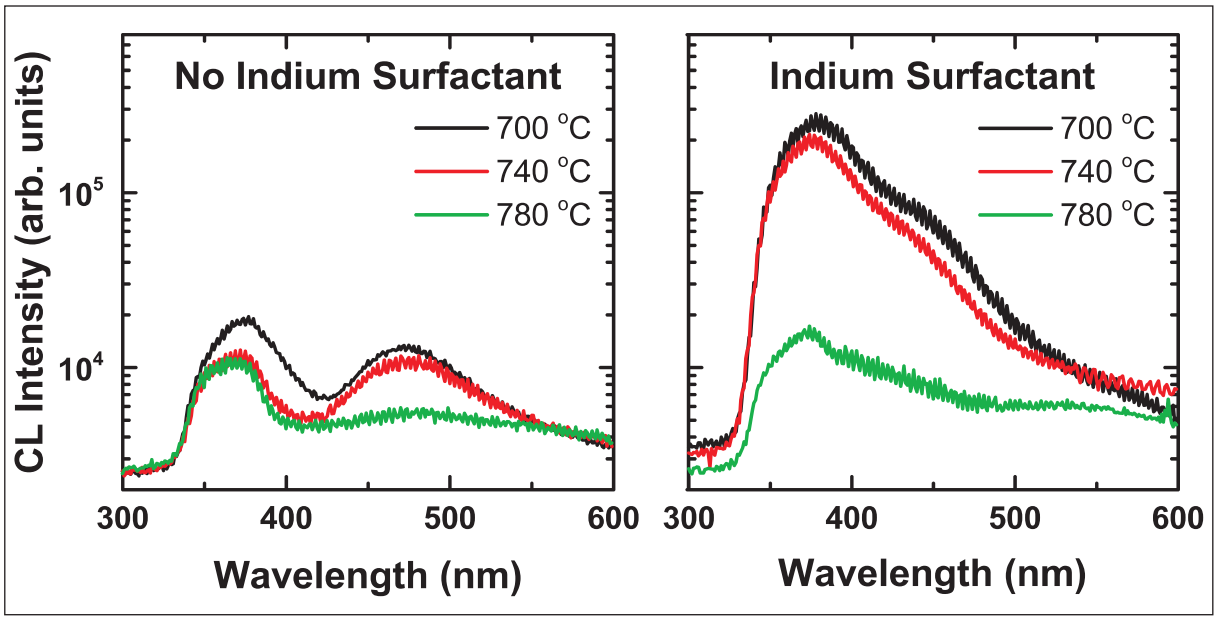

Figure 2. Cathodoluminescence spectra for growth temperature series.

The use of indium surfactant also improved band-edge cathodoluminescence (CL) by about an order of magnitude for 700°C and 740°C p-GaN (Figure 2). The electron excitation voltage was 7kV with estimated 275nm penetration. Most of the luminescence was expected from the p-GaN since the iron-doped GaN template layer should give negligible intensity. Both samples showed similar levels of blue luminescence associated with optical transitions involving the Mg acceptor.

The researchers comment: "The nitrogen vacancy is believed to contribute to the reduction in p-type conductivity in NH_3MBE-grown films and may be the defect suppressed in this study. The nitrogen vacancy may also be forming complexes with Mg at higher growth temperatures, causing the ~6x reduction in acceptor concentration observed in our films. Hydrogen may also be forming complexes with Mg, but the decrease in acceptor concentration was greater than the total hydrogen concentration observed in the films." ■

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Author: Mike Cooke

Nanoscale optoelectronic heterogeneity in monolayer MoS_2 accompanied by 300nm-wide, energetically disordered edge region

Sulfur deficiency in disordered edge region has implications for optoelectronics.

The US Department of Energy (DOE)'s Lawrence Berkeley National Laboratory (Berkeley Lab) has used its unique 'Campanile' nano-optical probe in the Molecular Foundry (a DOE Office of Science User Facility) to study the effects of illumination — at the molecular level — on two-dimensional semiconductors, specifically MoS_2, a member of the transition-metal dichalcogenide (TMDC) family of semiconductors, whose optoelectronic properties hold great promise for future nanoelectronic and photonic devices ('Visualizing nanoscale excitonic relaxation properties of disordered edges and grain boundaries in monolayer molybdenum disulfide', Nature Communications, 6, no 7993).

"The Campanile probe's remarkable resolution enabled us to identify significant nanoscale opto-electronic heterogeneity in the interior regions of monolayer crystals of molybdenum disulfide, and an unexpected, about 300nm-wide, energetically disordered edge region," says James Schuck, a staff scientist in Berkeley Lab's Materials Sciences Division who led the study as well as the team that created the Campanile probe (which combines the advantages of scan/probe microscopy and optical spectroscopy).

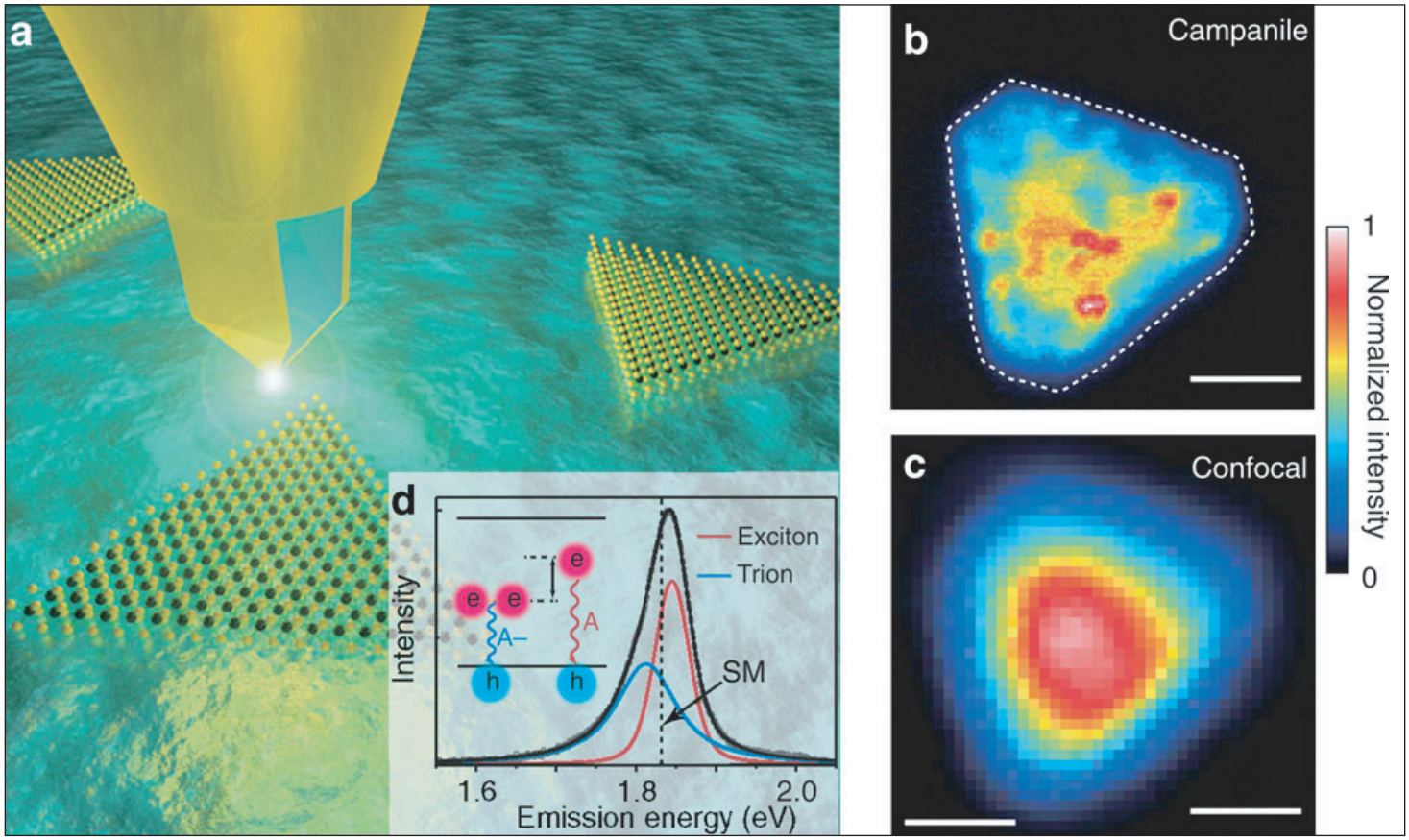
"This disordered edge region, which has never been seen before, could be extremely important for any devices in which one wants to make electrical contacts," Schuck says. "It might also prove critical to photo-catalytic and nonlinear optical conversion applications." Schuck, who directs the Imaging and Manipulation of Nanostructures Facility at the Molecular Foundry, is the corresponding author of the paper. Co-lead authors are Wei Bao and Nicholas Borys.

2D-TMDCs rival graphene as potential successors to silicon for the next generation of high-speed electronics. However, since their experimental discovery in 2010, their performance has lagged far behind theoretical expectations, primarily because of a lack of under-standing of 2D-TMDC properties at the nanoscale, particularly regarding excitons (bound pairs of excited electrons and holes that enable semiconductors to function in devices).

Our study revealed significant nanoscale optoelectronic heterogeneity and allowed us to quantify exciton-quenching phenomena at crystal grain boundaries. The discovery of the disordered edge region constitutes a paradigm shift from the idea that only a 1D metallic edge state is responsible for all the edge-related physics and photochemistry being observed in 2D-TMDCs. What's happening at the edges of 2D-TMDC crystals is clearly more complicated than that. There's a mesoscopic disordered region that likely dominates most transport, nonlinear optical, and photocatalytic behavior near the edges of CVD-grown 2D-TMDCs

"The poor under-standing of 2D-TMDC excitonic and other properties at the nanoscale is rooted in large part to the existing constraints on nanospectroscopic imaging," Schuck says. "With our Campanile probe, we overcome nearly all previous limitations of near-field microscopy and are able to map critical chemical and optical properties and processes at their native length scales," he claims.

The Campanile probe features a tapered, four-sided microscopic tip that is mounted on the end of an optical fiber. Two of the probe's sides are coated with



(a) Near-field excitation and collection of photoluminescence from monolayer (ML)-MoS_2 using Campanile probe where the optical laser excitation (2.33eV) and collection of sample emission are confined to tip apex to produce high-resolution optical maps. (b) Map of PL emission intensity of a triangular ML-MoS_2 flake using Campanile probe. White dashed line indicates flake boundary as determined from the shear-force topography. (c) Image acquired with scanning confocal microscopy using x100, 0.7NA air objective. Scale bars, 1μm. (d) Near-field nano-PL spectrum averaged over spatial extent of the ML-MoS_2 flake.

gold and the two gold layers are separated by just a few nanometers at the tip. The tapered design enables the probe to channel light of all wavelengths down into an enhanced field at the apex of the tip. The size of the gap between the gold layers determines the resolution, which can be below the diffraction optical limit.

The researchers used the Campanile probe to spectroscopically map nanoscale excited-state/relaxation processes in monolayer crystals of molybdenum disulfide that were grown by chemical vapor deposition (CVD). MoS_2 is a 2D semiconductor that features high electrical conductance comparable to that of graphene but, unlike graphene, has natural energy bandgaps (so its conductance can be switched off).

"Our study revealed significant nanoscale optoelectronic heterogeneity and allowed us to quantify exciton-quenching phenomena at crystal grain boundaries," Schuck says. "The discovery of the disordered edge region constitutes a paradigm shift from the idea that only a 1D metallic edge state is responsible for all the edge-related physics and photochemistry being observed in 2D-TMDCs," he adds. "What's happening at the edges of 2D-TMDC crystals is clearly more complicated than that. There's a mesoscopic disordered region that likely dominates most transport, nonlinear optical, and photocatalytic behavior near the edges of CVD-grown 2D-TMDCs."

The researchers also discovered that the disordered edge region in MoS_2 crystals harbors a sulfur deficiency that has implications for future optoelectronic applications of this 2D-TMDC. "Less sulfur means more free electrons are present in that edge region, which could lead to enhanced non-radiative recombination," Schuck says. "Excitons created near a sulfur vacancy would live for a much shorter period of time."

The researchers plan to next study the excitonic and electronic properties that may arise, as well as the creation of p–n junctions and quantum wells, when two disparate types of TMDCs are connected.

"We are also combining 2D-TMDC materials with so-called meta surfaces for controlling and manipulating the valley states and circular emitters that exist within these systems, as well as exploring localized quantum states that could act as near-ideal single-photon emitters and quantum-entangled Qubit states," Schuck says. ■

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http://foundry.lbl.gov/schuckgroup

2D transistor made from dual-phase transition-metal dichalcogenide crystal

Laser-induced phase patterning has been used to yield an ohmic homojunction in molybdenum ditelluride.

A multi-disciplinary research team led by Young Hee Lee, director of South Korea's Institute for Basic Science (IBS) Center for Integrated Nanostructure Physics at Sungkyunkwan University (SKKU), has devised a fabrication method for the creation of pure molybdenum ditelluride (Suyeon Cho et al, 'Phase patterning for ohmic homojunction contact in $MoTe_2$', Science (2015) vol. 349, no. 6248, p625).

Molybdenum ditelluride ($MoTe_2$) is a crystalline compound that, if pure enough, can be used as a transistor. Its molecular structure is a sandwich made up of one molybdenum atom for every two tellurium atoms. It was first made in the 1960s via several different fabrication methods, but had never been made in a pure enough form to be suitable for electronics.

Not only did the IBS-led team succeed in making $MoTe_2$ in pure form, they were also able to make two types of it — the semiconducting variety 2H (hexagonal) and the metallic variety monoclinic 1T' (octahedral) of $MoTe_2$ — which are both stable at room temperature.

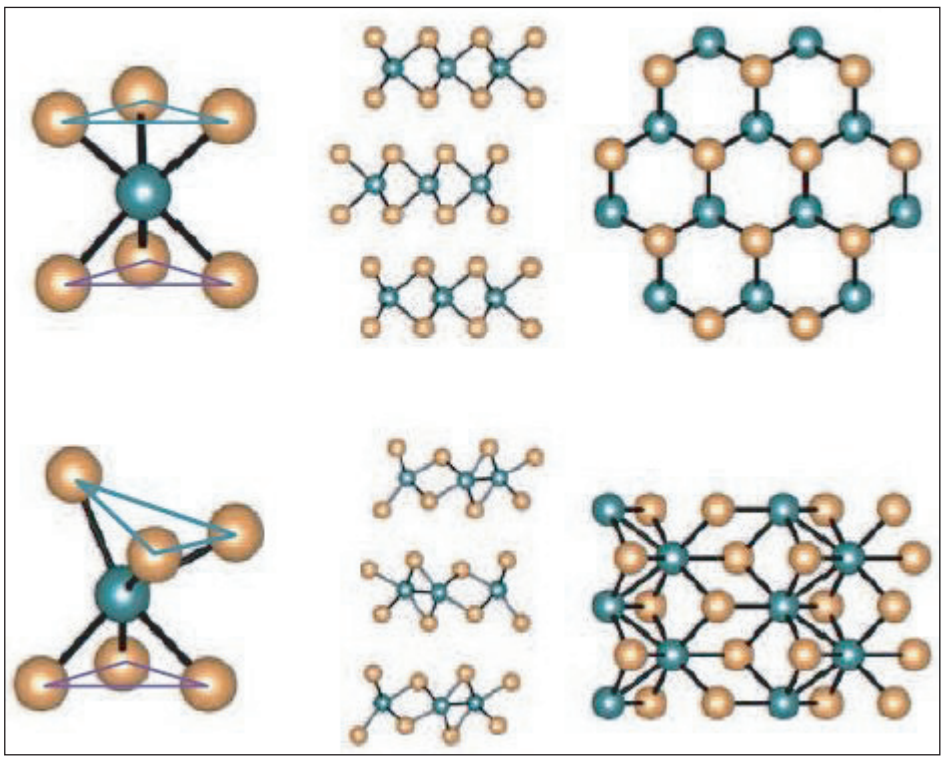

Figure 1. Top, 2H-$MoTe_2$ Bottom, 1T'-$MoTe_2$.

Making $MoTe_2$ in a pure form was very difficult and was seen by some as a black sheep of the transition metal dichalcogenides (TMD) family and hence ignored. TMDs are molecules that can be made very thin (just several atomic layers thick) and have an energy bandgap that makes them ideal for making electrical components, especially transistors.

A TMD crystal follows an MX_2 format: there is one transition metal (where M can be tungsten, molybdenum, etc) and two chalcogenides (where X_2 is sulfur, selenium or tellurium). These atoms form a thin, molecular sandwich with the one metal and two chalcogenides, and (depending on their fabrication method) can exist in several slightly differently shaped atomic arrangements.

As electronic devices get smaller there is increasing demand to shrink the size of their logic chips. As the chips approach single or several atom thickness (i.e. two-dimensional), silicon no longer works as well as it does in a larger, three-dimensional scale. As the scale approaches two dimensions (2D), the bandgap of silicon changes (to a higher bandgap than that in its 3D form) and the contact points with metal connections on silicon are no longer smooth enough to be used efficiently in electrical circuits.

This is the perfect opportunity to employ new TMD materials. The IBS research team was able to exploit the two versions of $MoTe_2$ and make one 2D crystal that was composed of the semiconducting 2H-$MoTe_2$ and the metallic 1T'-$MoTe_2$. This configuration is superior to using silicon as well as other 2D semiconductors because the boundary where the semiconducting (2H) and metallic (1T') $MoTe_2$ meet forms an ohmic homo-

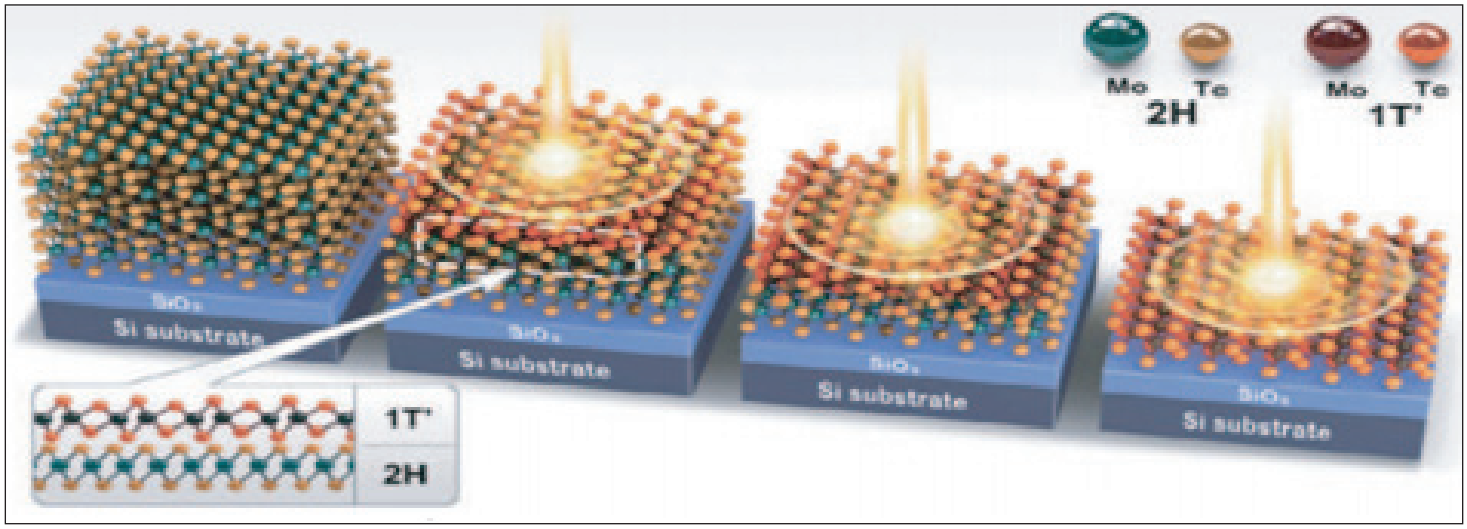

Figure 2. Simulation of the process of converting the 2H-$MoTe_2$ into 1T'-$MoTe_2$ with laser-irradiation.

junction (a connection formed at the boundary between two different structural phases in a single material). Despite one $MoTe_2$ state being a semiconductor and one being metallic, the team was able to create an ohmic homojunction between them, making an extremely efficient connection.

To do this, the team started with a piece of their pure 2H-$MoTe_2$ that was several atoms thick. They directed a 1μm-wide laser at it, which locally heated the sample and changed the affected area into 1T'-$MoTe_2$. The team was hence able to create a 2D transistor that utilized an amalgamation of both the semiconducting properties of 2H-$MoTe_2$ and the high conductivity of 1T'-$MoTe_2$.

This presents a solution to several problems that have been a hindrance in the past. By using only one material in the device channel and the metal-semiconductor junction, it is more energy efficient since the joints between the two phases of the $MoTe_2$ are fused seamlessly, realizing an ohmic contact at the joints. Because 1T'-$MoTe_2$ is such a good conductor, metal electrodes can be applied to it directly, saving any additional work of finding a way to attach metal leads. This new fabrication technique is a very efficient way of utilizing the available $MoTe_2$ without any wasted or extraneous parts.

$MoTe_2$ has a bandgap of around 1eV, which is similar to silicon's bandgap and it allows an ohmic homojunction at the semiconductor–metal junctions. So, $MoTe_2$ can replace silicon without much change in the current voltage configurations used with today's silicon technologies

"There are many candidates for 2D semiconductors, but $MoTe_2$ has a bandgap of around 1eV, which is similar to silicon's bandgap and it allows an ohmic homojunction at the semiconductor–metal junctions," says SKKU professor Heejun Yang. So, $MoTe_2$ can replace silicon without much change in the current voltage configurations used with today's silicon technologies. The dual-phase $MoTe_2$ transistor looks promising for use in new electronic devices as demand for components increases for materials that are small, light and extremely energy efficient. ■

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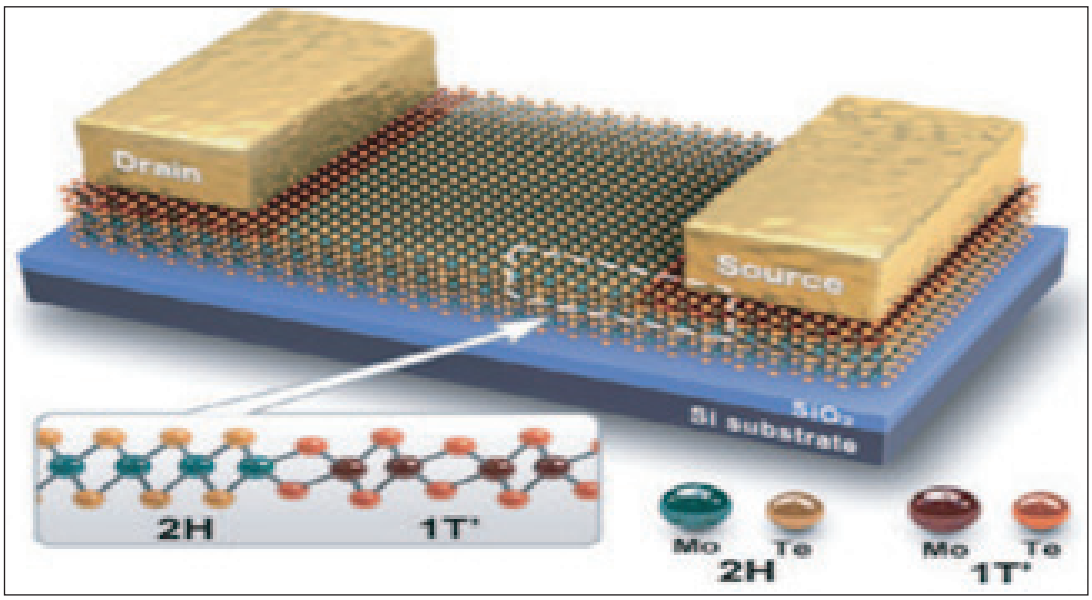


Figure 3. 2H-$MoTe_2$ and 1T'-$MoTe_2$ transition line and metal electrodes attached to the 1T'-$MoTe_2$.

Getting ready for indium gallium arsenide high-mobility channels

Mike Cooke reports on the VLSI Symposium, highlighting the development of compound semiconductor channels in field-effect transistors on silicon for CMOS.

Researchers across the world are readying the implementation of indium gallium arsenide (InGaAs) and other III-V compound semiconductors as high-mobility channel materials in field-effect transistors (FETs) on silicon (Si) for mainstream complementary metal-oxide-semiconductor (CMOS) electronics applications. The latest Symposia on VLSI Technology and Circuits in Kyoto, Japan in June featured a number of presentations from leading companies and university research groups directed towards this end.

In addition, Intel is proposing gallium nitride (GaN) for mobile applications such as voltage regulators or radio-frequency power amplifiers, which require low power consumption and low-voltage operation. Away from III-V semiconductors, much interest has been attracted around two-dimensional semiconductors such as graphene and, more recently, transition-metal dichalcogenides (TMDs) such as molybdenum disulfide. Massachusetts Institute of Technology (MIT) presented a number of developments, including a design flow, with possible future application of molybdenum disulfide in flat-panel display manufacturing.

InGaAs-OI

IBM has been working on two approaches to integrating InGaAs-on-insulator (InGaAs-OI) — confined epitaxial lateral overgrowth (CELO) and direct wafer bonding (DWB) — to achieve high-mobility channel devices on silicon.

The first demonstration of the CELO concept was presented by IBM Research's Zürich Laboratory in conjunction with the Swiss Federal Laboratories for Materials Science and Technology (EMPA) Electron Microscopy Center [L. Czornomaz et al, session 13-3]. Gate-first (GF) self-aligned fin-FETs were produced with electrical performance comparable to state-of-the-art InGaAs MOSFETs on silicon, according to the researchers.

The CELO process (Figure 1) starts by defining a seed area in a thermal oxide. The InGaAs is grown in a cavity. The cavity constrains the geometry, thickness and morphology of the InGaAs regions. By contrast, traditional techniques to reduce defects — e.g. epitaxial layer overgrowth or aspect-ratio trapping (ART) — are free in the vertical direction, and thickness and surface smoothness are determined post-growth by lithography or chemical mechanical polishing (CMP). The CELO process filters out defects by the abrupt change in growth direction from vertical to lateral, as constrained by the cavity. The researchers believe their technique avoids the main problems of alternative methods of integrating InGaAs into CMOS in terms of limited wafer size, high cost, roughness, or background doping.

The cap of the cavity was removed to access the InGaAs for device fabrication. Also the InGaAs material was removed from the seed region to electrically isolate the resulting devices from the underlying silicon substrate. At the same time, the 25nm-thick fins for the fin-FETs were etched. After this, a GF process flow was adopted. The gate stack consisted of aluminium oxide/hafnium dioxide (Al_2O_3/HfO_2) bilayer and tungsten (W) electrode. Devices were produced with and without raised source-drain structures.

For 150nm gate-length fin-FETs without raised source–drain structures, the subthreshold swing (SS) was 130mV/decade and the on/off ratio was 10^4, limited by gate leakage. The on-current (I_{on}) was improved to 0.4mA/μm for 80μm wide devices with raised source–drain contacts. Unfortunately, the off-current (I_{off}) was also increased through more gate leakage.

The researchers comment: "A transconductance benchmark against GF, replacement-gate (RMG) and gate-last (GL) InGaAs MOSFETs integrated on silicon reveals that the performance of CELO-integrated GF devices exceeds the one of similarly sized ART-integrated GF MOSFETs and compares to ART-integrated RMG devices."

The IBM Research Zürich Laboratory also led the work on DWB, which created ultra-thin-body InGaAs-OI structures [V Djara et al, session 13-5]. Also involved in this presentation were Université Grenoble Alpes and CEA, LETI MINATEC Campus, in France, and IBM T.J.Watson Research Center and IQE in the USA.

The researchers claim this as the first demonstration of ultra-thin-body (50nm), low-defectivity 200mm InGaAs-OI fabricated by DWB.

The InGaAs was first grown on a 200mm silicon donor substrate using molecular beam epitaxy (MBE) with a series of metamorphic layers bridging the lattice mis-match between the materials. The insulator consisted of an Al_2O_3 atomic layer deposited on the InGaAs and target silicon substrate. After bonding of the Al_2O_3 surfaces, the donor wafer and metamorphic buffer layers were removed with wet and dry etching, leaving a 250nm layer of InGaAs. The channel layer was further thinned to 50nm by CMP.

The researchers fabricated planar and fin-FET devices using GF and replacement metal gate (RMG) processes. The capacitive equivalent thickness (CET) of the gate insulator was as low as 1.2nm. Capacitance–voltage measurements suggested that the interface trap density (D_{it}) of the RMG process ($1.5x10^{12}/cm^2$-eV) was almost a factor of three lower than for GF ($4x10^{12}/cm^2$-eV). The researchers comment: "These results are among the best D_{it} versus CET reported for high-k/InGaAs."

In general, the RMG performed better than GF in terms of I_{on}, subthreshold swing and drain-induced barrier lowering (DIBL). A hydrogen/argon anneal improved SS and DIBL for both device types, although there was a slight degradation of I_{on} for GF transistors due to a shift in threshold voltage.

Noting that the RMG device type has a 'very competitive' trade-off between transconductance and SS, the researchers claim a record I_{on} against other InGaAs devices integrated on silicon of 118μA/μm at 0.5V operation with the I_{off} pegged at 100nA/μm. The team also claims that there was no evidence of short-channel effects down to 50nm gate length.

The researchers have also worked on scalability of the devices to small overall dimensions, rather than just the channel length, achieving a contact-to-contact pitch of 120nm. With a contact length of 70nm, the drain current was 261μA/μm at 0.5V drain and 1V gate. The contact resistance for 90nm length was 83Ω-μm.

Tunneling and quantum wells

Pennsylvania State University (PSU) presented results claiming record performance for complimentary all III-V heterojunction vertical tunnel FETs (HVTFETs) and a demonstration of InAs single and dual quantum well (QW) heterostructure fin-FETs (FF).

The HVTFET work was carried out with University of California Santa Barbara (UCSB) and the US National Institute of Standards and Technology (NIST) [R. Pandey et al, session 15-3].

Tunnel devices can achieve steep switching with low SS values. However, I_{on} and I_{on}/I_{off} ratios can be hit by the device structure. Performance improvement has been achieved by using antimonide (Sb) and arsenide (As) materials.

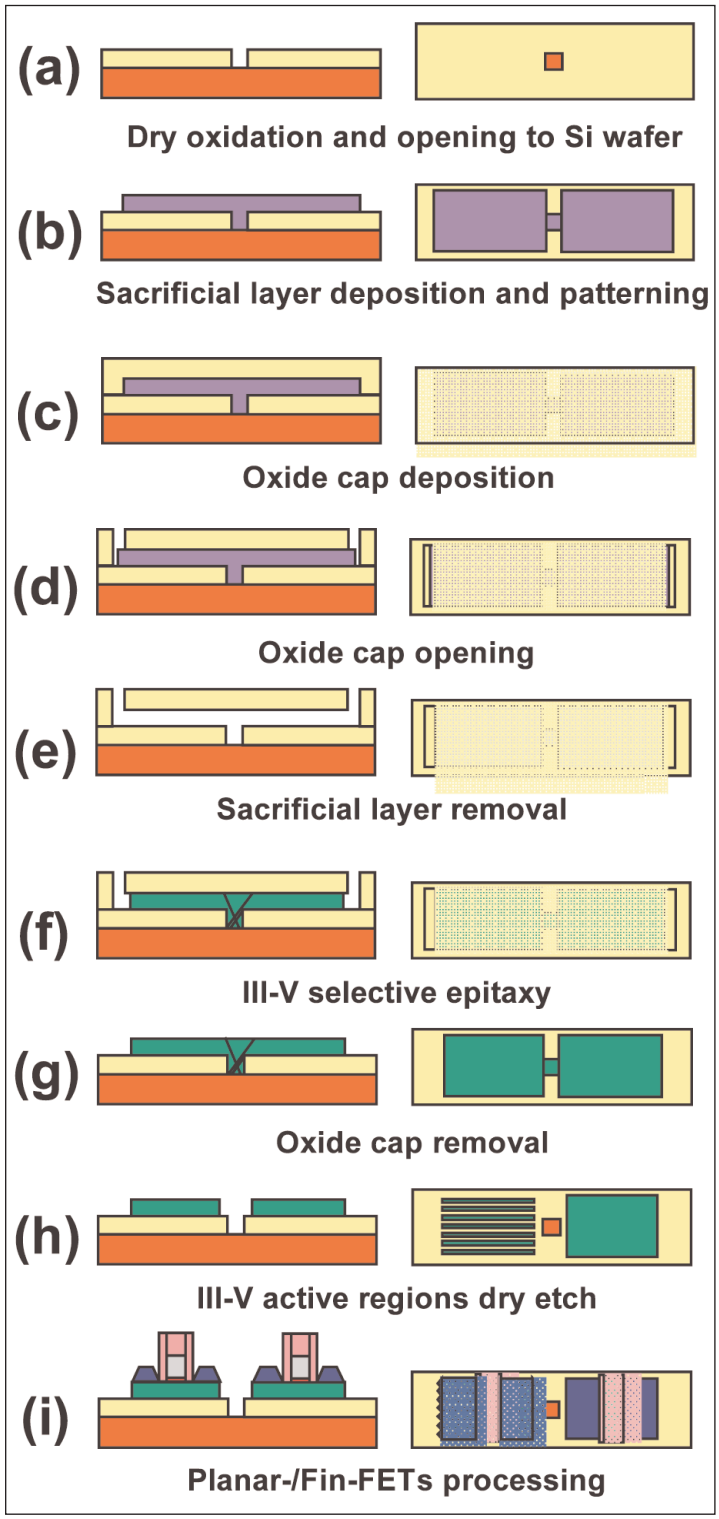


Figure 1. Process flow for integration of lattice-mismatched materials on insulator on Si by CELO method. Process only requires standard Si substrates and typical CMOS modules.

The researchers comment: "To implement energy-efficient complementary logic, both NTFETs and PTFETs need to be realized preferably in the same material system. Here, for the first time, we demonstrate complementary TFETs with high I_{on}, high I_{on}/I_{off} in

arsenide–antimonide material sharing the same metamorphic buffer layer."

The heterostructure material for the devices (Figure 2) was grown on a common metamorphic buffer on indium phosphide. However, the gate insulators for the n- and p-type TFETs differed, being zirconium dioxide and HfO_2, respectively, to match the different material contents of the channels.

The processing of the high-k dielectrics for the gate insulators had to be optimized. The PTFET needed a 150ºC hydrogen plasma clean to remove native oxide before applying 3.5nm HfO_2 to give a CET of 1.2nm and reduced mid-gap D_{it}. The NTFET insulator consisted of 4nm ZrO_2, giving a CET of 1.1nm and low mid-gap D_{it}.

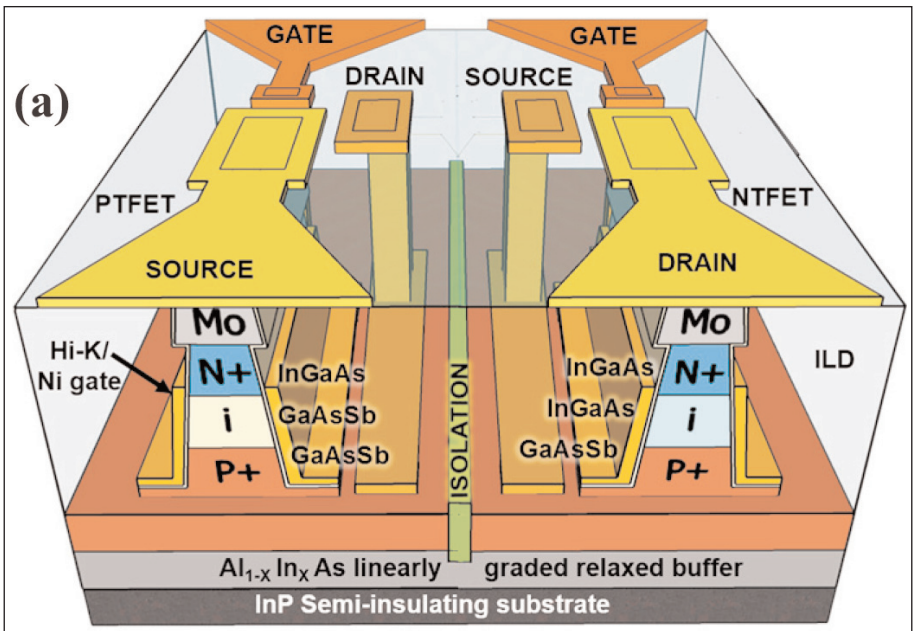
The PTFETs achieved an I_{on} of 30μA/μm and I_{on}/I_{off} ratio of 10^5 with drain bias of 0.5V. The corresponding results for the NTFET were 275μA/μm and $3x10^5$. The SS values were above the 60mV/decade limit value (kT/q) for planar devices at room temperature.

Pulsed operation reduced the swing by suppressing the response of slow mid-gap traps. The researchers report: "We achieve SS=55mV/decade for NTFET and SS=115mV/decade for PTFET at room temperature. The high I_{on} with sub-kT/q SS demonstration for NTFET and high I_{on} with improved SS demonstration in case of PTFET, is a direct consequence of engineering high-quality scaled gate dielectrics and tunnel barriers in the As–Sb system."

Comparing with TFETs produced with silicon, silicon-on-insulator or silicon germanium, the researchers note that they achieve higher I_{on}.

For the InAs QW fin-FETs, PSU teamed up with Samsung Electronics Co Ltd of the Republic of Korea [Arun V. Thathachary, session 15-4]. The aim of the research was to produce n-channel devices with superior performance compared with InGaAs fin-FETs.

InGaAs has higher mobility at higher indium concentration — hence InAs would theoretically offer the best high-mobility channels. However, strain considerations limit InAs to layers less than 5nm



(b)

PTFET	NTFET
400nm $In_{0.7}Ga_{0.3}As$ N+ (Si-5X10^{19} cm^{-3})	200nm $In_{0.65}Ga_{0.35}As$ N+ (Si-10^{18} cm^{-3})
200nm $GaAs_{0.35}Sb_{0.65}$ Intrinsic	150nm $In_{0.65}Ga_{0.35}As$ Intrinsic
500nm $GaAs_{0.35}Sb_{0.65}$ P+ (C-10^{19} cm^{-3})	10nm $GaAs_{0.4}Sb_{0.6}$ P++ (C-10^{20} cm^{-3})
100nm $Al_{0.3}In_{0.7}As$ Buffer	300nm $GaAs_{0.4}Sb_{0.6}$ P+ (C-5X10^{19} cm^{-3})
$Al_{1-X}In_XAs$ linear grade relaxed buffer	$Al_{1-X}In_XAs$ linear grade relaxed buffer
InP Substrate	InP Substrate

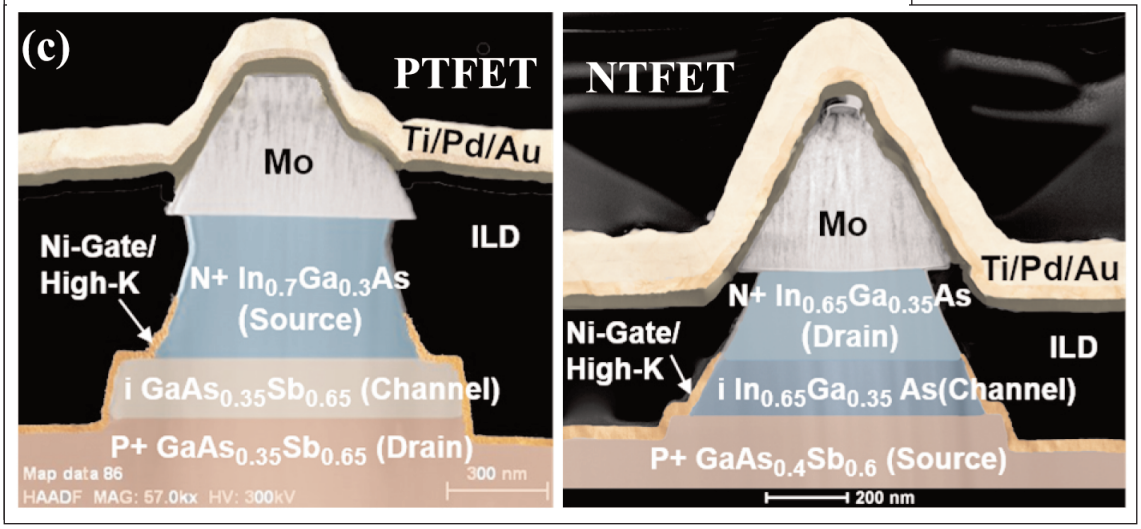


Figure 2. (a) Schematic of complimentary PTFET and NTFET on common metamorphic buffer technology; (b) starting heterostructures, and (c) cross-sectional TEMs.

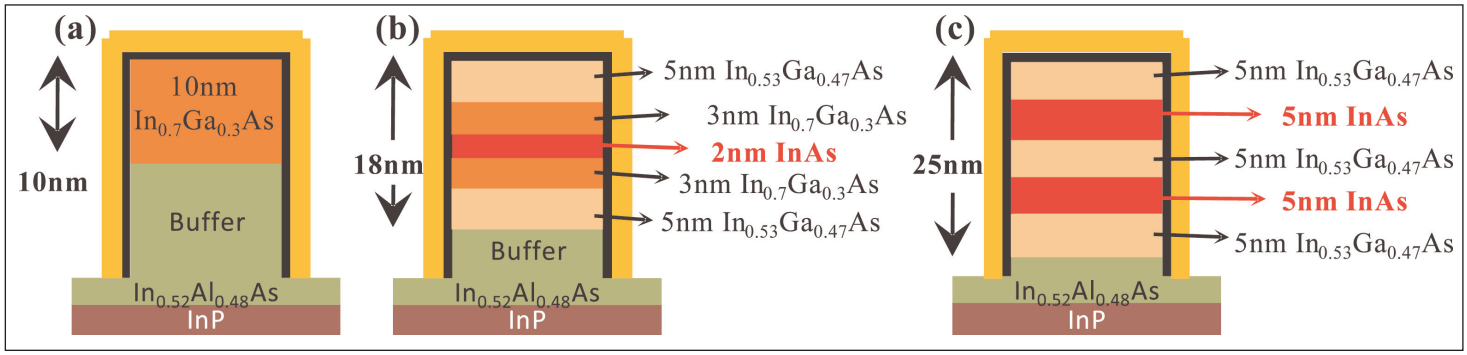


Figure 3. Cross-sectional schematic of (a) InGaAs QW, (b) InAs QW, (c) InAs dual QW fin-FETs.

thick when grown on indium phosphide (InP) substrates.

PSU and Samsung produced single and double InAs QWs by molecular beam epitaxy on InP for fabrication into fin-FETs (Figure 3). The fins were produced using a 'new side-wall image transfer (SIT) process'. The resulting fin pitch was 105nm. The high-k gate insulation was produced using alternate pulses of nitrogen plasma and trimethyl-aluminium to passivate the fin surface, followed by atomic layer deposition (ALD) of 3.25nm HfO_2. The gate metal was nickel.

The subthreshold swing for 2μm gate length was 87mV/decade for single QW fin-FETs and 94mV/decade for dual QWs — these values are described as 'excellent' by the researchers. The effective mobilities and carrier densities for 5μm devices were 3531cm^2/V-sec, 2x10^{11}/cm^2, and 3950cm^2/V-sec, 3.2x10^{11}/cm^2, respectively.

Projections to 26nm gate length suggest that the dual QW fin-FET would achieve an I_{on} 478μA/μm at an I_{off} of 100nA/μm and 0.5V drain bias, compared with 417μA/μm for a silicon fin-FET.

TSMC reported on $In_{0.53}Ga_{0.47}As$-channel metal-oxide-semiconductor (MOS) FETs fabricated on 300mm silicon [M. L. Huang et al, session 15-2]. The researchers claim Hall electron mobility values comparable to those achieved on InP. Devices with 150nm gate length achieved subthreshold swing of ~95 mV/decade, I_{on}/I_{off} ratio ~10^5, DIBL ~51 mV/V at 0.5V drain. "The extracted high field-effect mobility (μ_{EF} = 1837cm^2/V-s with equivalent oxide thickness (EOT) ~0.9nm) is among the highest values reported for surface-channel $In_{0.53}Ga_{0.47}As$ MOSFETs," the researchers write.

Mobile gallium nitride

Intel Corp researchers have been exploring "for the first time" the potential of gallium nitride transistors for low-power-consumption mobile system-on-chip (SoC) electronics [H.W. Then et al, session 15-1]. The researchers see their GaN MOS-HEMTs as being competitive against transistors used in voltage regulator (VR) and power amplifier (PA) applications.

Up to now, much of the focus in GaN transistor development has been toward high-voltage power switching and radio-frequency amplification. Intel's devices are normally-off 'enhancement-mode' metal-oxide-semiconductor high-electron-mobility transistors (MOS-HEMTs) rather than the normally-on depletion-mode Schottky gate HEMTs mostly used in the high-voltage applications.

The Intel transistors (Figure 4) used a barrier of aluminium indium nitride ($Al_{0.83}In_{0.17}N$) polarization layer on aluminium nitride (AlN) spacer to create two-dimensional electron gas (2DEG) source–drain access regions in the underlying GaN. The carrier density in the 2DEG was 2x10^{13}/cm^2 with mobility of 1200cm^2/V-s and sheet resistance of 250Ω/square.

The AlInN was etched away in the gate region. The gate insulation consisted of a high-k composite of 4.5nm HfO_2 and 1.5nm Al_2O_3 deposited on the AlN spacer, which was used to avoid mobility degradation in the gate region. The equivalent oxide thickness of the high-k stack was 23Å. The source–drain contacts

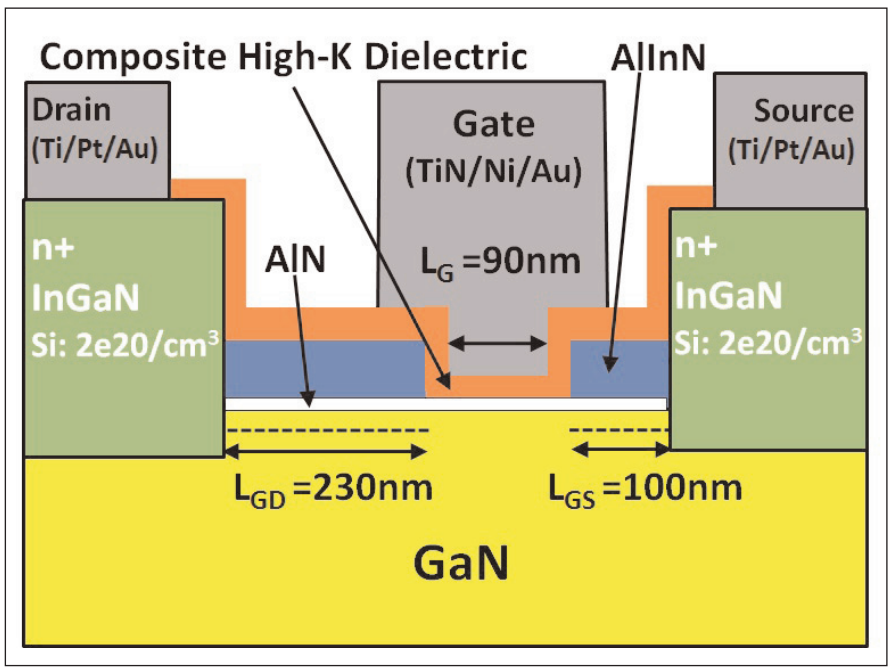


Figure 4. Schematic of enhancement-mode high-k GaN MOS-HEMT.

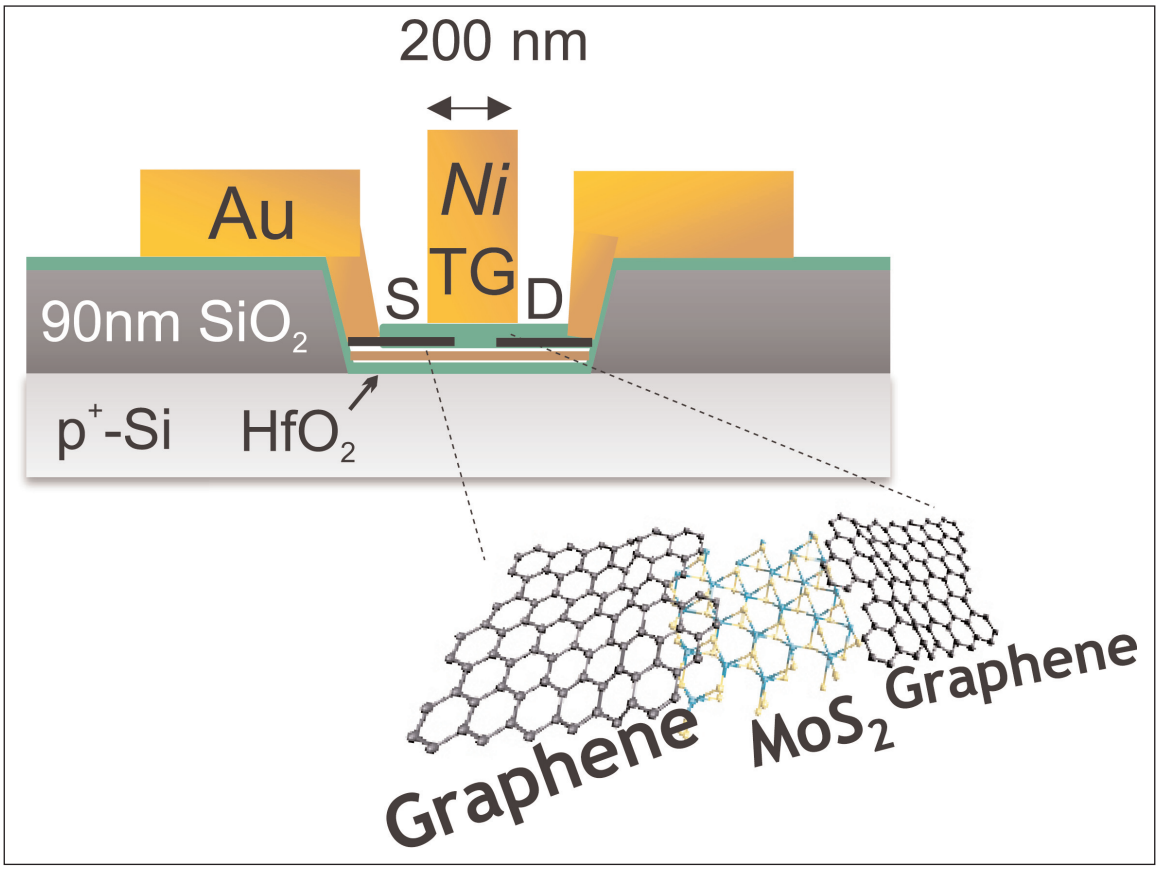


Figure 5. Schematic cross-section of short-channel single- and dual-gate-MoS_2 FETs with graphene source–drain contacts.

consisted of re-grown n^+-$In_{0.1}Ga_{0.9}N$.

Intel claims the best enhancement-mode GaN MOS-HEMT characteristics ever reported. These include a low I_{off} of 70nA/μm with 3.5V drain bias and 0V gate for a 90nm gate-length device. The drain-induced barrier lowering was 45mV/V. The maximum drain current was 1.4mA/μm with a knee voltage less than 1V. The on-resistance was 490Ω-μm.

The off-state breakdown (1μA/μm) for a 90nm-gate device and 230nm gate-drain distance was 8V. Comparing this with industry-standard silicon VR transistors with the same breakdown, the researchers comment that their GaN device has 3.6x lower on-resistance.

In frequency measurements, a 90nm-gate GaN transistor achieved a cut-off (f_T) of 100GHz and maximum oscillation (f_{MAX}) of 150GHz, "which exceed the requirements (f_T, f_{MAX}>20GHz) for 2G/3G/4G cellular applications at mobile SoC voltages," according to the Intel team.

For RF amplification, the researchers measured an 'excellent' power-added efficiency (PAE) of 80% with 0.55W/mm power density at typical mobile SoC voltages (3.5V drain bias).

The researchers comment: "Our GaN data show >10% better PAE at matched RF P_{out} or >50% higher RF P_{out} at matched PAE than industry-standard GaAs RF PA transistors at mobile SoC voltages."

Molybdenum disulfide

Massachusetts Institute of Technology (MIT) presented two papers on molybdenum disulfide (MoS_2) devices. The first detailed work with imec and KULeuven in Belgium on single- and double-gate FETs down to 15nm channel length [A.Nourbakhsh et al, session 3-4]. The second paper described efforts towards fabrication and modeling of large-scale flexible electronics circuits [Lili Yu et al, session 10-4].

MoS_2 is one of a range of transition metal (e.g. molybdenum or tungsten) dichalcogenides (e.g. sulfur or selenium) or 'TMDCs' that crystallize in layered structures. These layers can be separated rather like graphene from graphite using Scotch tape, allowing structures with two-dimensional electron transport to be created. As with graphene, there are alternative growth processes such as chemical vapor deposition (CVD) that could lead to mass production.

The MIT/imec/KULeuven single-/double-gate devices (Figure 5) were based on CVD monolayer or Scotch tape mechanical exfoliation of 4-layer MoS_2. The MoS_2 was transferred onto 10nm HfO_2 dielectric on p^+-Si on silicon dioxide (SiO_2) substrates. This gave a back-gate structure. The source–drain electrodes consisted of patterned monolayer graphene.

A top gate stack was fabricated by depositing 1nm Al_2O_3 in an air oxidation process, followed by atomic layer deposition of 10nm HfO_2. The gate electrode was 50nm nickel.

The MoS_2 was found to have n-type conduction in capacitance–voltage measurements. The FET operation was therefore accumulation-mode. A monolayer FET with 1μm channel length achieved an I_{on}/I_{off} ratio of 10^7 and a minimum SS of 75mV/decade. Four-layer devices had smaller I_{on}/I_{off} ratios and high SS (105mV/dec). Use of a top gate reduced the SS for the 4-layer MOSFET to 66mV/decade.

The team did not produce monolayer double-gate devices because the high-k dielectric deposition process

'drastically' shifts the threshold voltage and I_{off}. The 4-layer devices were less affected by the gate-stack fabrication.

Monolayer devices with channel lengths less than 30nm were affected by short-channel effects, giving high values of I_{off}.

A 4-layer MoS_2 double-gate FET with 15nm channel length at 0.5V drain bias achieved ~10^6 I_{on}/I_{off} ratio, 90mV/decade SS, and an I_{on} of 50μA/μm.

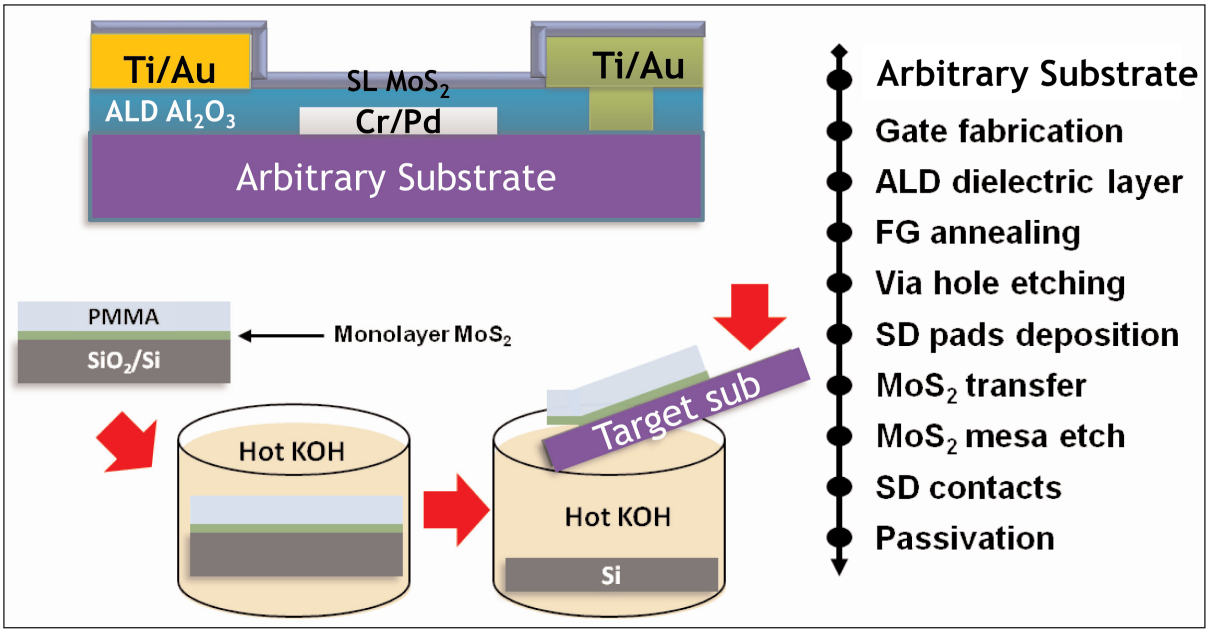


Figure 6. Fabrication technology for large-scale MoS_2 electronics.

The researchers comment: "This transistor has the shortest operating channel length of any MoS_2 transistor to date. The device performance indicates further scaling to sub $L_{S/D}$ = 10nm is possible."

The second MIT presentation of large-scale MoS_2 circuits used CVD growth and a GF fabrication technique to overcome the problems with producing the gate stack. The researchers point to flat-panel drive circuits as a possible application based on higher carrier mobility, compared with amorphous silicon or organic semiconductors, and a 1.8eV bandgap, which should give higher I_{on}/I_{off} ratios.

The team summarizes the challenges: "Despite its promising characteristics, applications up to date have been limited to single or a few devices scale system. The challenges in large-scale system design with a newly introduced material mainly remain in three issues: material growth and transfer, device integration, and circuit simulations."

The CVD process used sulfur and molybdenum trioxide (MoO_3) as precursors in a quartz tube furnace. A seed promoter of perylene-3,4,9,10-tetracarboxylic acid tetrapotassium salt (PTAS) was used to start the process. The substrate was SiO_2 on silicon.

The resulting monolayer MoS_2 demonstrated good uniformity and coverage approaching 100%, according to the researchers. The domain size was around 30μm on average.

Devices (Figure 6) were fabricated by first depositing the gate electrode on a SiO_2 layer on a silicon substrate. The gate electrode was covered with 20nm of Al_2O_3 by atom layer deposition. After annealing, a via hole was etched to give access to the gate electrode.

The MoS_2 monolayer was coated with poly(methyl methacrylate) (PMMA) thermoplastic before being released by soaking in 85ºC potassium hydroxide solution to etch away the SiO_2. The MoS_2 was then transferred to the device substrate and annealed to clean away the polymer residue. Mesa isolation was achieved with oxygen plasma etch to form the MoS_2 channel. Ohmic contacts were formed with 5nm titanium and 90nm of gold. Contact pads were created with 90nm gold.

The researchers say that they used the GF method to avoid fixed charge and trapped states inside the dielectric or at the interface with the MoS_2, which degrade mobility and shift threshold voltages. The problem with GL techniques is the low temperature or seeding processes needed to avoid damaging the underlying structure. "Using the gate-first process instead, the critical components are fabricated before the MoS_2 transfer step, achieving high gate dielectric and interface quality and the potential for low effective oxide thickness scaling," the team comments.

GF transistors had 10x larger I_{on} and 100x smaller I_{off} than GL devices, along with a higher threshold voltage – 0.54V (enhancement-mode, 0.12V standard deviation) rather than –4.20V (depletion-mode, 1.75V standard deviation) for GF. The subthreshold swing was 115mV/decade for the GF transistors, compared with 300mV/decade for a GL device.

The researchers have also developed a computer-aided design flow along with circuit simulation based on a Verilog-A compact model for the transistors. The flow was used to create a switched capacitor DC–DC converter from two MoS_2 transistors and a charge transfer capacitor. The simulation predicted the performance of the circuit well with switching frequencies up to 100kHz. ■

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

Metal-insulator-semiconductor gated hybrid anode GaN-on-silicon diode

A reverse breakdown voltage of more than 1.1kV has been achieved with current leakage as low as 10μA/mm.

University of Electronic Science and Technology of China has developed a gallium nitride-on-silicon (GaN-on-Si) metal-insulator-semiconductor gated hybrid anode diode (MG-HAD) with low onset voltage, on-resistance and reverse current leakage [Qi Zhou et al, IEEE Electron Device Letters, published online 12 May 2015]. Breakdown voltages of more than 1.1kV were achieved with a 10μA/mm criterion.

The MG-HAD consisted of a hybrid anode with electrically shorted ohmic and recessed metal/aluminium oxide/III-nitride MIS gate. The threshold voltage was determined by the degree of depletion of the two-dimensional electron gas (2DEG) channel beneath the gate region – this could be modulated by modifying the recess depth.

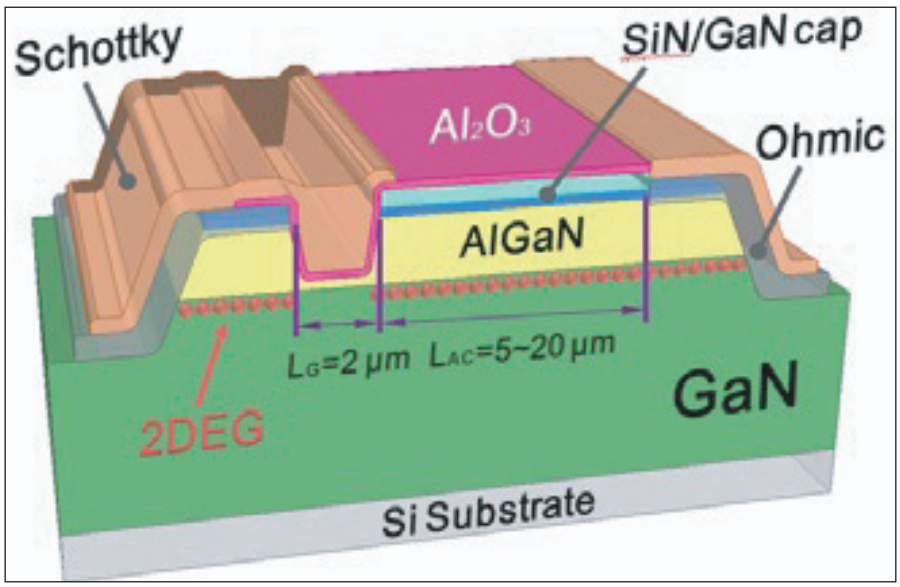


Figure 1. Schematic three-dimensional device structure of MG-HAD. Gate length and overhanging extension were 2μm and 0.5μm, respectively. Gate width was 50μm.

Although better performance has been achieved with GaN diode devices, this has been at the cost of using more expensive, smaller-diameter substrates such as free-standing GaN, silicon carbide, or sapphire. A further attraction of GaN-on-Si is the potential for integration with conventional silicon CMOS electronics.

The researchers used a commercial heterostructure material from Enkris Semiconductor (www.enkris.com) that consisted of 4-inch silicon (111) substrate, 3.5μm GaN buffer, 1nm AlN spacer, 23nm $Al_{0.23}Ga_{0.77}N$ barrier, and 2nm GaN cap. The carrier density and mobility in the 2DEG were $9.5x10^{12}/cm^2$ and $1500cm^2/V\text{-}s$, respectively.

Device fabrication (Figure 1) began with 100nm silicon nitride passivation, reactive ion etch to open the ohmic regions, native oxide removal, and titanium/aluminium/nickel/gold ohmic metal deposition.

Further etching removed silicon nitride in the gated region, created mesa isolation, and cut through the GaN cap and 16nm of the AlGaN barrier. The etching was completed with a low-damage digital oxygen plasma etch process and hydrochloric acid rinse to remove native oxide. The 10-cycle digital etch removed some 5nm of material creating a recessed 2nm AlGaN barrier. The 2DEG under the recessed region was completely depleted.

The device was completed with 10nm aluminium oxide from atomic layer deposition (ALD) and annealing, and evaporation of nickel/gold Schottky metal.

Devices with 5μm anode-cathode distance (L_{AC}) had a 1mA/mm forward current threshold of 0.6V, a 0.3V reduction compared with reference Schottky barrier diodes (SBDs) produced on the same substrate. The specific on-resistance of MG-HAD and SBD were $0.6m\Omega\text{-}cm^2$ and $1.24m\Omega\text{-}cm^2$, respectively. The researchers attribute the lower MG-HAD resistance to the current flow through the ohmic part of the anode contact.

The reverse current leakage was two orders of magnitude (1/100) lower for the MG-HAD, compared with the SBD reference. The team says this is due to the insertion of aluminium oxide insulation between the AlGaN barrier and recessed gate.

Varying L_{AC} between 5μm and 20μm had little effect on the threshold, which had an average value of 0.66V

with 0.07V standard deviation for 189 devices. This was due to the low-damage, controllable recessing, according to the researchers.

The researchers also compared the reverse current leakage and breakdown of the MG-HADs and SBDs. The team applied a more rigorous breakdown criterion for the MG-HAD of 10μA/mm, compared with the more usual 1mA/mm for the SBD. A 20μm L_{AC} MG-HAD broke down at more than 1100V. The reverse voltage for 1μA/mm leakage was 790V, giving an on/off current ratio for the device of five orders of magnitude. Similarly dimensioned SBDs had 1mA/mm breakdowns at around 500V.

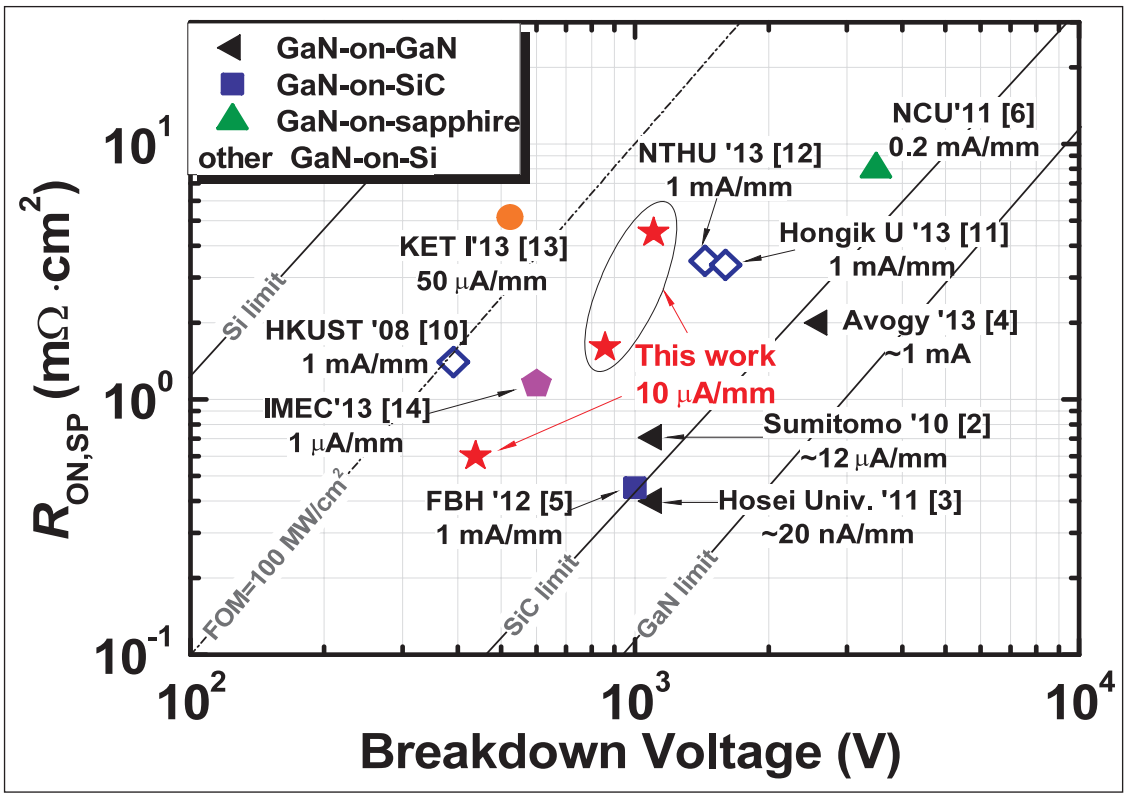


Figure 2. Benchmark of $R_{ON,SP}$ versus BV of GaN power diode on GaN/SiC/sapphire/Si substrates.

The MG-HAD breakdown was attributed to buffer leakage bypassing the 2DEG path between the ohmic cathode and anode. The researchers suggest that AlGaN back barriers or thicker low-dislocation-density buffers should increase the breakdown voltage.

Thermal measurements showed an increase of on-resistance with temperature by a factor of 1.9 between 25°C and 150°C. The breakdown voltage was 615V at 150°C.

A 10μm L_{AC} MG-HAD had 10μA/mm breakdown (BV) at 857V with corresponding specific on-resistance ($R_{ON,SP}$) of 1.6mΩ-cm^2. The $BV^2/R_{ON,SP}$ figure of merit was 459MV/cm^2.

The researchers comment on the comparison with other state-of-the-art devices (Figure 2) that "[the MG-HAD] value is among the best results reported for GaN-on-Si power diode at reverse leakage as low as 10μA/mm." ■

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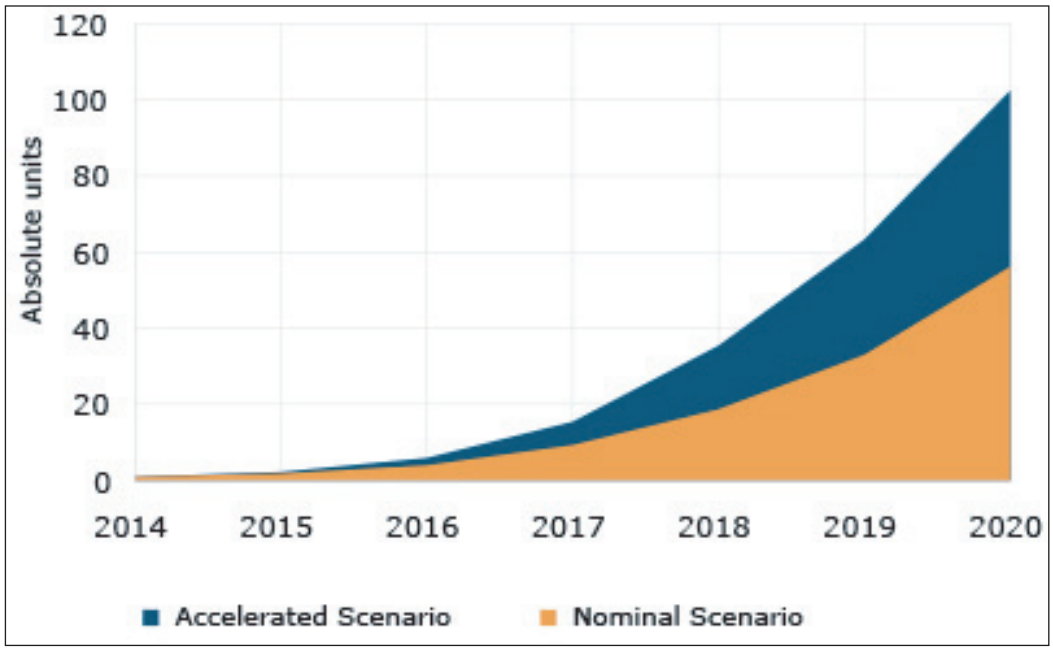
Author: Mike Cooke

SiC market to treble and GaN to explode — if challenges are overcome

SiC and GaN will compete with silicon from low to high power, says Yole.

According to the report 'GaN and SiC for power electronics applications' from Yole Développement, in 2014 the silicon carbide (SiC) chip business was worth more than $133m, with power factor correction (PFC) and photovoltaics (PV) still the leading applications (as in previous years).

More than 80% of this market consists of SiC diodes, which in 2020 will remain the main contributor across various applications, including electric vehicles and hybrid electric vehicles (EV/HEV), PV, PFC, wind, uninterruptible power supplies (UPS) and motor drives, reckons Yole.



GaN device market size: nominal versus accelerated scenario.

SiC transistors will grow in parallel with diodes, driven by PV inverters, forecasts the report. However, challenges must be overcome prior to the adoption of pure SiC solutions for EV power train inverters, which is nevertheless expected by 2020.

Including the growth in both diodes and transistors, Yole expects the total SiC market to more than treble $436m by 2020.

Gallium nitride (GaN) potentially has a huge total accessible market (TAM), and its adoption would therefore be significant, says Yole. However, the starting point and the growth rate are directly linked to two important questions:

- How will the emerging applications of low-voltage GaN expand, and how will GaN be adopted by these applications?
- Will 600V devices make their way to market?

Yole has integrated these variables in developing two scenarios for the GaN device market up to 2020. The analysis is based on the penetration rate of GaN in different applications including DC–DC conversion, Lidar, envelope tracking, wireless power, and PFC. The firm hence estimates that by 2020 the GaN device market will grow to $303m in the nominal scenario, or $560m in the accelerated scenario (where low-voltage GaN and 600V GaN are rapidly adopted). Emerging applications (namely envelope tracking, wireless power and Lidar) will collectively consume one third of GaN transistors, it is forecast. In both scenarios, low-voltage applications below 200V are expected to be the major contributors to the market.

Companies moving in right direction to overcome remaining technical challenges to accelerate adoption of WBG devices

Designing a totally new product with these semiconductor materials will induce R&D expenses that must be compensated by adding value at the system level, says Yole. This could include improving cost, size, and operating conditions compared with regular silicon solutions. To capture this added value, an integrator must get the full benefit from the increased operating frequency and temperature of wide-bandgap (WBG) devices.

So far, the WBG market has not grown as fast as hoped. The four barriers to device adoption remain: high cost

at the device level; reliability; multi-sourcing; and integration.

Many R&D programs have been launched in recent years. Some prototypes have demonstrated that the bill of materials (BOM) cost can be lower at the system level when using WBG devices.

To overcome reliability challenges, Rohm and Cree have announced new SiC device generations or platforms with enhanced, more stable specifications. SiC and GaN devices are also going through reliability tests to reduce the risk involved in adoption.

Many companies — including Cree, Rohm, ST Microelectronics, Mitsubishi and GE — have now developed SiC MOSFETs. So, end-users are more able to multi-source these devices. By contrast, there is a limited number of suppliers in the GaN market. In the coming years, new entrants such as ExaGaN and TSMC should provide extra sourcing options. Also, Infineon and Panasonic have announced this year that they will establish a dual-sourcing relationship for normally-off 600V GaN power devices.

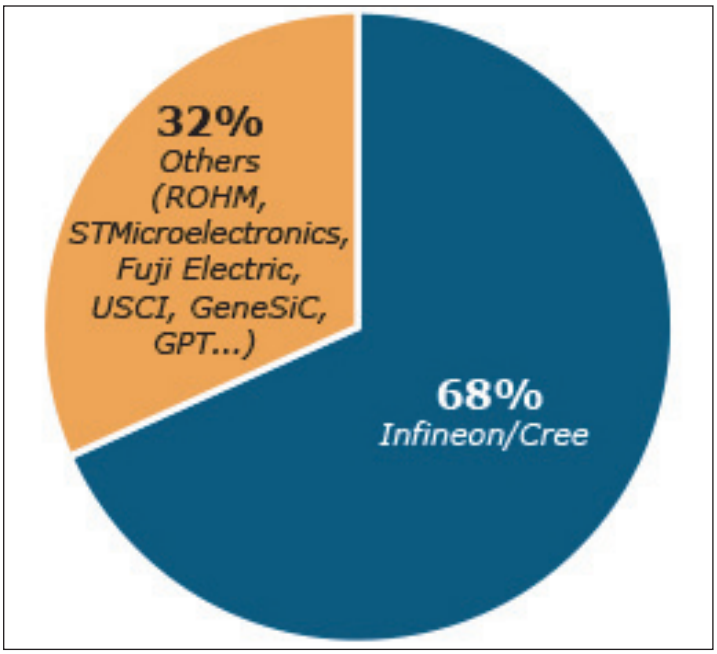
Integrating these fast-switching, high-operating-temperature devices remains one of the major challenges. WBG suppliers and end-users need to reconsider many factors, including device packaging, module packaging, gate driver integration and topology design.

Packaging is becoming a particular bottleneck, but the good news is that companies are moving in the right direction, says Yole. GaN device makers EPC and GaN Systems have both adopted advanced packaging, which seems to be more suitable than traditional power device packages. The recent acquisition of APEI by Cree should likewise accelerate the development of SiC module packaging.

Recent financial moves indicate market confidence in WBG devices

There have recently been several pieces of good news for the WBG sector, says Yole. The existing SiC device market leader Cree has decided to spin off its Power and RF division as a separate company, and will issue shares in a new IPO. Yole interprets this as a positive sign of the continuing growth in the SiC power device market.

At the same time, about $100m in investment has been made in various GaN startups. Two of them are in the top four commercial GaN companies. In May, GaN Systems raised $20m in venture funding. In June, Exagan raised €5.7m ($6.5m) in first-round financing to produce high-efficiency GaN-on-silicon power-switching devices on 200mm wafers. Also, Transphorm announced a new $70m funding round led by investment firm KKR. These investments reflect the confidence in the GaN device market and investors' willingness to provide funds to accelerate production capabilities, says Yole.



Market share of SiC device makers (2014).

Will GaN and SiC compete for the same power electronics applications?

After years of discussion about whether it would be GaN or SiC, the answer is now clearer than ever, states Yole.

SiC diodes have been on the market for over 14 years, and are becoming a mature technology, leaving no room for GaN diodes.

GaN transistors have made their way into low-voltage applications, which SiC will find difficult to challenge.

Commercial SiC transistors exist in the 600–3300V range. Compared to GaN lateral devices, their advantages at voltages over 1200V are now widely recognized. In early 2015, SiC device leader Cree launched its 900V platform. This is considered by the market as a significant move for SiC, signaling its intention to address 900V and lower voltage applications.

GaN is also trying to enter the 600V market. Applications such as PFC, on-board chargers, and low-voltage/high-voltage DC–DC converters for automotive applications will therefore be the main battlefields for GaN and SiC in the coming years, reckons Yole.

In the end, integrators do not care what the chips they buy are made of, notes the market research firm. They want suitable devices at reasonable prices to make a system desired by the market. The real competition is not between GaN and SiC, but WBG versus incumbent silicon-based technology. Silicon insulated-gate bipolar transistor (IGBT) technology is progressing, becoming better and cheaper. However, in the future, the market will not be as dominated by silicon-based devices as it is today, but more diversified. A variety of devices — including silicon, GaN, SiC and others that are yet to be developed — will find their own niches, concludes Yole. ■

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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
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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

2–3 September 2015
EPRSC Centre for Power Electronics - Post-Graduate Summer School 2015
Newcastle University, UK
E-mail: nh416@cam.ac.uk
www.powerelectronics.ac.uk/power-electronics/events

2–4 September 2015
SEMICON Taiwan 2015
Taipei World Trade Center (TWTC), Taiwan
E-mail: staiwan2@semi.org
www.semicontaiwan.org

6–10 September 2015
16th conference on Defects Recognition, Imaging and Physics in Semiconductors (DRIP XVI)
Suzhou, China
E-mail: drip16@163.com
http://dripxvi.csp.escience.cn

8–10 September 2015
European Microwave Week (EuMW2015), incorporating:
45th European Microwave Conference (EuMC)
10th European Microwave Integrated Circuits Conference (EuMIC)
12th European Radar Conference (EuRAD)
Palais des Congrès, Paris, France
E-mail: aubert@laas.fr
www.eumweek.com

13–18 September 2015
II-VI 2015: 17th International Conference on II-VI Compounds and Related Materials
Campus des Cordeliers, Paris, France
http://ii-vi-2015.sciencesconf.org

15–18 September 2015
Process Certification and Defect Recognition: Hybrids, Microcircuits and RF/MMIC Modules
Pasadena, CA, USA
E-mail: tgreen@tjgreenllc.com
www.tjgreenllc.com/course/process-certification

16–19 September 2015
11th LED China and LED Lighting China 2015
Shanghai New International Expo Center (SNIEC), China
E-mail: led-trust@ubm.com
www.ledchina-sh.com/en-us/

20–24 September 2015
Seventh Annual IEEE Energy Conversion Congress & Exposition (ECCE 2015)
Palais des congrès de Montréal, Canada
E-mail: ecce@courtesyassoc.com
www.2015.ecceconferences.org

21–24 September 2015
SPIE Remote Sensing 2015
Centre de Congrès Pierre Baudis, Toulouse, France
E-mail: info@spieeurope.org
http://spie.org/spieremotesensing

advertisers' index

27 September – 1 October 2015
ECOC 2015: European Conference on Optical Communication
Feria Valencia, Spain
E-mail: ecoc2015@viajeseci.es
www.ecoc2015.org

4–8 October 2015
IPC 2015: 28th IEEE Photonics Conference
Reston, VI, USA
E-mail: c.c.scott@ieee.org
www.ipc-ieee.org

4–9 October 2015
16th International Conference on Silicon Carbide and Related Materials (ICSCRM 2015)
Congress Center Atahotel Naxos Beach, Giardini Naxos, Sicily, Italy
E-mail: webmaster@icscrm2015.org
http://icscrm2015.imm.cnr.it

6–8 October 2015
SEMICON Europa 2015
Dresden, Germany
E-mail: semiconeuropa@semi.org
www.semiconeuropa.org

12–14 October 2015
International Semiconductor Conference (CAS 2015)
Sinaia, Romania
E-mail: cas@imt.ro
www.imt.ro/cas

12–15 October 2015
SPIE Optifab 2015
Joseph A. Floreano Rochester Convention Center, Rochester, NY, USA
E-mail: customerservice@spie.org
http://spie.org/spieoptifab

13–16 October 2015
SCTE Cable-Tec Expo 2015
New Orleans Ernest N. Morial Convention Center, Louisiana, USA
E-mail: expo@scte.org
http://expo.scte.org

14–15 October 2015
High Power Diode Lasers & Systems (HPDLS 2015), co-located at PHOTONEX 2015
Ricoh Arena, Coventry, UK
E-mail: brenda@xmarkmedia.com
www.hpdls.org

26–29 October 2015
IMAPS 2015: 48th International Symposium on Microelectronics
Orlando, FL, USA
E-mail: blamm@imaps.org
www.imaps.org

26–29 October 2015
2015 IEEE International Topical Meeting on Microwave Photonics
Paphos, Cyprus
E-mail: info@cyprusconferences.org
www.mwp2015.org

28–29 October 2015
UV LED 2015
Troy, N.Y, USA
E-mail: mickey@radtech.org
www.uvled2015.com

2–4 November 2015
ChinaSSL 2015 (12th China International Forum on Solid-State Lighting)
Shenzhen Exhibition Center, China
E-mail: liuh@china-led.net
www.sslchina.org

3–5 November 2015
Global Summit on Electronics and Electrical Engineering
Valencia, Spain
E-mail: electricalengineering@conferenceseries.net
http://electricalengineering.global-summit.com

4–6 November 2015
Successful Semiconductor Fabless 2015: Technology & supply chain challenges for fabless semiconductor companies
Paris, France
E-mail: veyrier@yole.fr
www.i-micronews.com/trade-shows-conferences.html

8–13 November 2015
ISGN-6 (6th International Symposium on Growth of III-Nitrides)
Act City Hamamatsu, Hamamatsu, Japan
E-mail: secretary@isgn6.jp
www.isgn6.jp

10–12 November 2015
12th Avionics Fiber-Optics & Photonics Conference (AVFOP)
Santa Barbara, CA, USA
E-mail: m.figueroa@ieee.org
www.avfop-ieee.org

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