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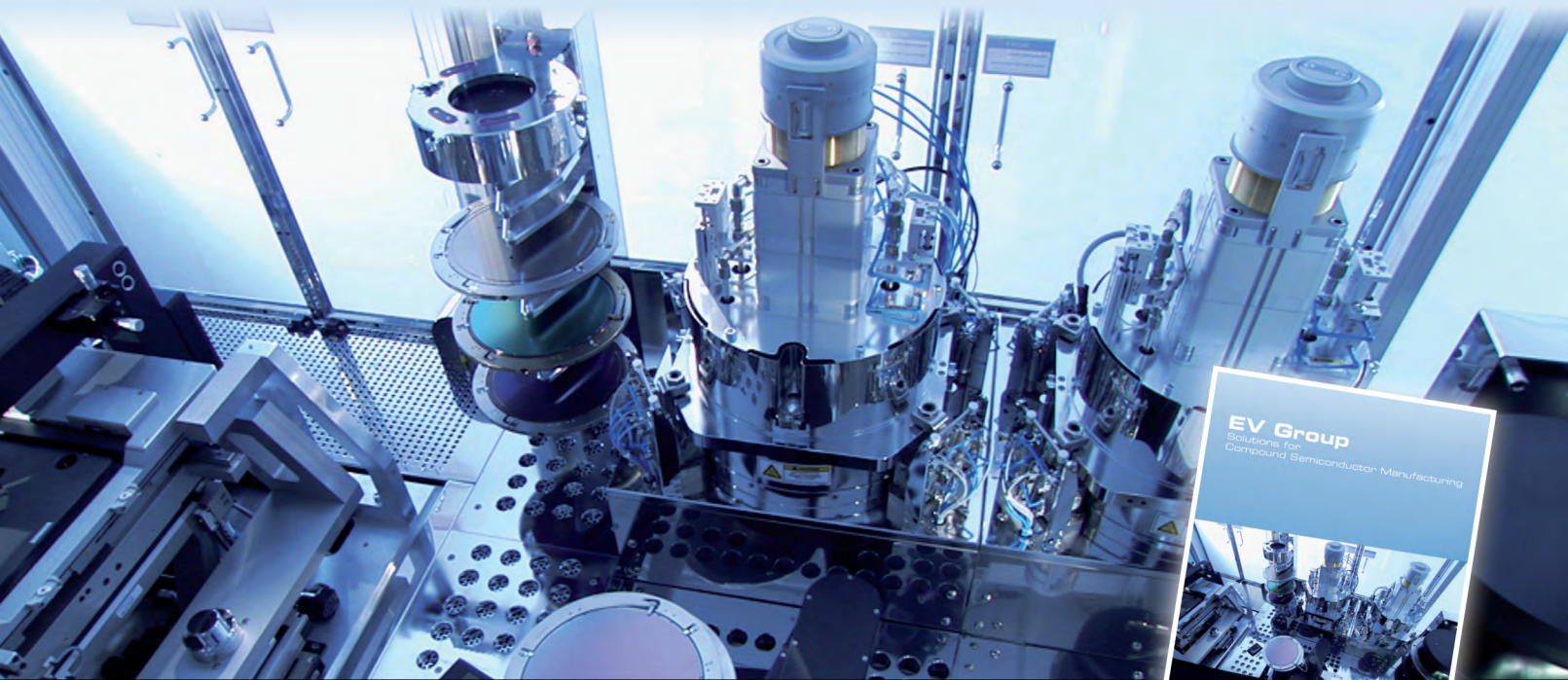

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semiconductorTODAY

COMPOUNDS & ADVANCED SILICON

Vol. 9 • Issue 3 • April/May 2014

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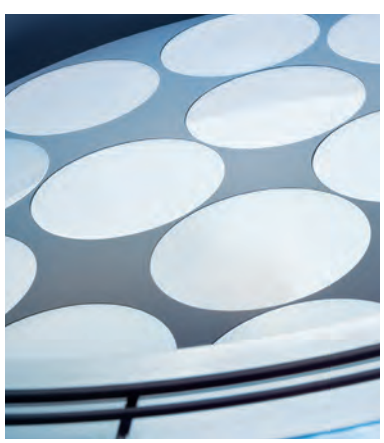
Skyworks & Panasonic form filter JV • First flush-mountable IRED • Solar Frontier sets thin-film PV cell record of 20.9%

Light Up a Brighter World

MaxBright MHP MOCVD System



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contents

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COMPOUNDS & ADVANCED SILICON

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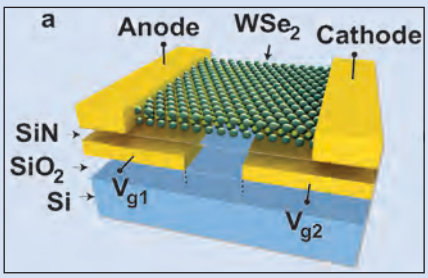
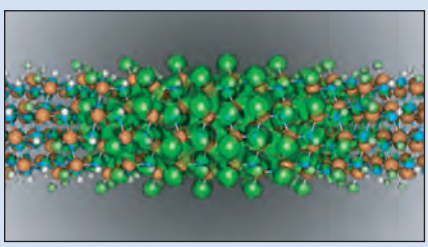
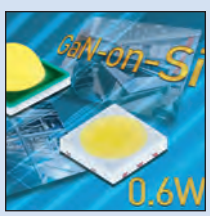
p58 Solar Frontier and Chopro are to construct and operate a 29.1MW solar power plant (the largest in Nagasaki Prefecture) adjoining Nagasaki Airport.



p60 Schematic of the structure of a tungsten diselenide monolayer device with split gate electrodes.



p72 Simulations conducted by the US National Energy Research Scientific Computing Center show that nanostructures could enhance the efficiency of LEDs, particularly in the 'green gap' part of the spectrum.



Cover: Toshiba has launched GaN-on-Si-based ultra-small (0.65mm x 0.65mm) chip-scale packaged white LEDs with a CCT of 5000K and a minimum CRI of 80 for lighting applications that can reduce the mounting area by 90% compared with conventional 3.0mm x 1.4mm packaged products. **p42**

editorial

MOCVD upturn driven by LEDs but GaN-on-Si electronics chips in

Despite coming too late to be included in the news pages of this issue, at www.semiconductor-today.com/news_items/2014/MAY/AIXTRON_010514.shtml we report the Q1/2014 results for metal-organic chemical vapor deposition (MOCVD) system maker Aixtron, which show revenue up 9% and orders up 26% year-on-year (a fourth consecutive quarter of growth, to the highest order level in more than two years). The firm is seeing "a slight pick-up in demand for equipment from LED manufacturers... it is starting to feel as if another tipping point for LED adoption within general lighting is imminent". Meanwhile, for MOCVD in Q1 compared with Q4/2013, Veeco has reported rises of 28% in revenue and 59% in orders (the highest since Q3/2011) — see www.semiconductor-today.com/news_items/2014/MAY/VEECO_060514.shtml. "LED fab utilization rates have improved to high levels at most key accounts and LED adoption is happening faster than many had expected," notes CEO John Peeler, adding that Veeco is currently discussing MOCVD capacity expansion plans with customers. "After a long downturn in MOCVD, it appears that the worst is behind us."

On page 6, market research data from Strategies Unlimited forecasts a compound annual growth rate (CAGR) of 27% for LEDs in lighting applications, driven by "increased consumer confidence and continuously increasing sales of replacement lamps, downlights, industrial, commercial, and outdoor products". Consequently, despite slowing demand from display applications, increasing adoption by the lighting sector will maintain high-brightness LEDs as the main driver of growth in the MOCVD market (a CAGR of over 14% over 2013–2018).

Indeed, on page 80 Yole Développement says that, after a 18–24 month digestion period, the LED frond-end equipment market has begun its next investment cycle (over 2014–2016), driven by demand for general lighting applications. The market will peak in 2015 at nearly $580m (80% of which will be from MOCVD systems, with the main suppliers Aixtron and Veeco continuing to dominate through the strength of their finances and expertise). Trade organization SEMI notes that, after 2 years of decline, LED epi/chip equipment spending is stabilizing in 2014 and will grow in 2015, driven by LED lighting adoption growing more than 50% annually over the next three years (see page 78). In particular, leading LED chip makers in China and Taiwan will show the strongest new investment and capacity additions. Also, although leading LED chip makers are in mass production on 4" and 6" substrates, the LED industry is now moving towards 6" and 8" GaN-on-silicon production, for which investment is occurring worldwide, with companies in Japan, Korea and China the most aggressive in adoption, adds SEMI.

Despite this, Yole says that GaN-on-Si will not become the industry standard, capturing less than 5% of LED manufacturing by 2020 (see page 88). Nevertheless, Yole forecasts that, in GaN-based power electronics, GaN-on-Si will come to dominate, because of its lower cost and CMOS compatibility (making GaN devices for some applications less costly than silicon devices three years from now, according to some manufacturers). A report from MarketsandMarkets forecasts that the total GaN device and substrate market will grow to as much as $15.6bn in 2022 (see page 7).

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

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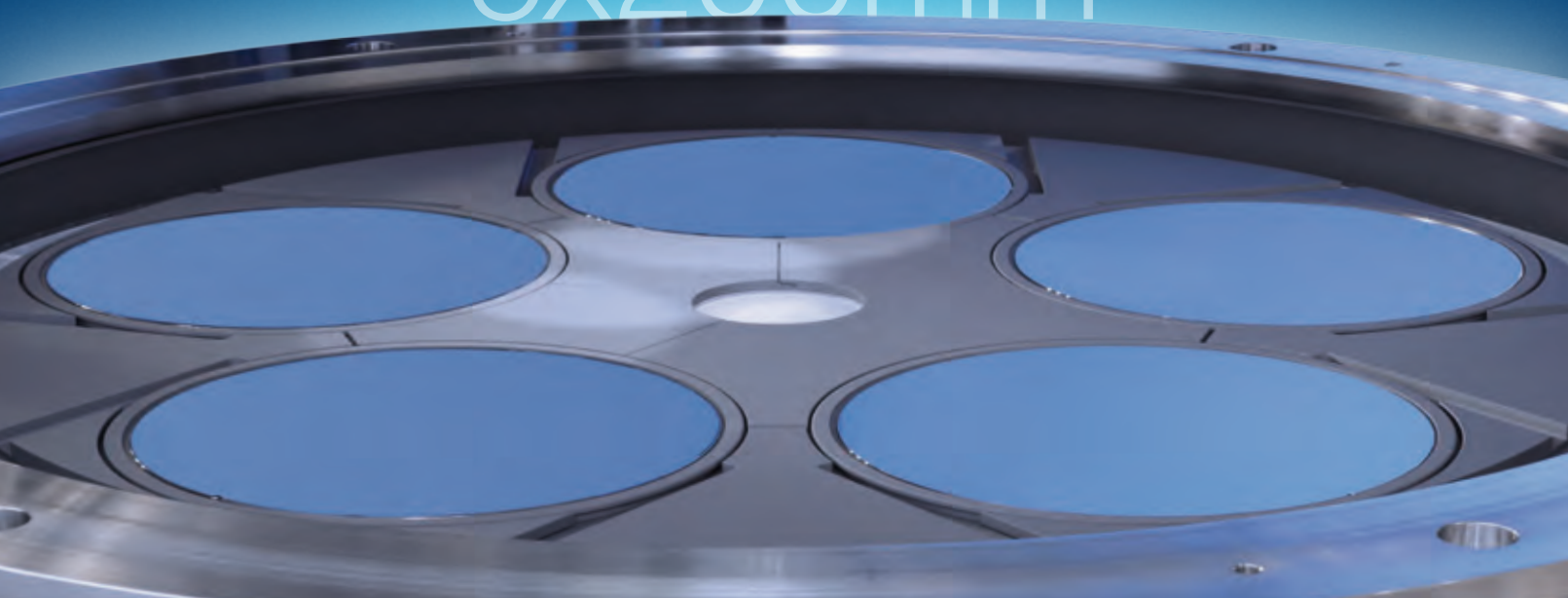

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news

Packaged HB-LED market to grow at 12.9% to over $26bn in 2018

General lighting LEDs to grow at CAGR of 27%

The total market for packaged LEDs is forecast to increase in revenue at a compound annual growth rate (CAGR) of 12.9% from 2013 to 2018, according to Strategies Unlimited's annual report 'The Worldwide Market for LEDs: Market Review and Forecast 2014', which covers display backlighting, mobile device, automotive, signage, and general lighting applications.

The packaged LED industry grew from $1.2bn in 2000 to $14.2bn in 2013. Back in 2009, illumination accounted for just $665m in revenue. In 2013, the general lighting segment was worth $4.4bn.

"We forecast the growth for LEDs in lighting to be 27% of CAGR from 2013 to 2018, driven mostly by an increased consumer confidence and continuously increasing sales of replacement lamps, downlights, industrial, commercial, and outdoor products," says analyst Katya Evstratyeva.

Of total revenue, the top 15 firms in the LED space account for about 81% and the top 25 firms account for 93%. Strategies Unlimited says it is clear that quite a few manufacturers continue to struggle to find their identity in this fast-changing environment as the packaged LED industry is becoming increasingly complex. "As a result, we anticipate consolidation of the market in the coming years," the firm concludes.

www.strategies-u.com

Japan to keep largest share of global LED lighting in 2014

Japan will remain the largest LED lighting market with a global share of 25.6% in 2014, down 3.4 percentage points on 2013, according to Digitimes Research.

North America will be second largest, at 23.1%, followed by Europe at 20.3% and China at 16%.

However, Japan will see the lowest growth, at 22%, since its LED penetration of lighting is expected to rise to 65.5%, while growth will be 46% for North America, 40% for Europe and 47% for China.

www.digitimes.com

MOCVD equipment market growing at 14.13% CAGR from $519.86m in 2013 to $1006.65m in 2018

HB-LEDs for lighting to remain main driver, but installations rising for GaN-on-Si power electronics

The global MOCVD equipment market will increase at a compound annual growth rate (CAGR) of 14.13% from $519.86m in 2013 to $1006.65m in 2018, with year-on-year growth slowing from 16.56% in 2013 to 9.1% in 2018, forecasts a new report from market analyst firm TechNavio.

According to the report 'Global Metal Organic Chemical Vapor Deposition (MOCVD) Equipment Market 2014–2018' (which cites system suppliers Aixtron SE, Veeco Instruments Inc and Taiyo Nippon Sanso Corp), the main driver is the increasing demand for high-brightness LEDs in the lighting market, as the rapid decline in the average selling price (ASP) of LEDs has led to an increase in the adoption of LEDs for lighting applications.

Consequently, the geographic split of the market is 95.8% Asia-Pacific and just 2.2% Americas and 2% EMEA (Europe, Middle East, and Africa). More specifically, the leading purchasers by country are China (62.9%), South Korea (15.01%), and Taiwan (13.1%).

In addition, power semiconductors form an emerging market for MOCVD equipment. In recent years, gallium nitride (GaN) has replaced the existing silicon technology in many power semiconductor applications due to its various properties such as a wider bandgap, high breakdown voltage, larger critical electric field, and higher thermal conductivity. This has in turn increased the demand for GaN power semiconductors. To satisfy the demand for high-performance electronic devices, semiconductor manufacturers are expected to increase the installation of GaN processing equipment such as MOCVD systems. GaN-on-Si-based power electronics developed on MOCVD equipment can potentially deliver higher performance, higher efficiency, and switching speed, notes the report.

www.technavio.com

GaN device & substrate market to rise to $15.6bn by 2022

GaN power semi market to be worth billions as silicon devices replaced

According to the report 'Gallium Nitride (GaN) Semiconductor Devices (Discrete & IC) and Substrate Wafer Market by Technology, Application, Product, Device, & by Geography — Forecast & Analysis to 2013–2022' from MarketsandMarkets, the market is forecasted to reach $15.6bn by 2022.

In particular, the specific sub-sector where GaN has an edge over established silicon-based counterparts is 'Power Semiconductors & Electronics'. In terms of end-user applications, the two major upcoming sectors driving demand for GaN devices are the Industrial & Power sector and Communication Infrastructure sector. The Communication Infrastructure sector has found use for GaN power discretes, particularly transistors in power amplification, rectification, and high-frequency switching.

GaN has turned out to be the technology of choice for most power semiconductor applications and is quickly replacing the existing silicon technology, reckons the report. Compared with pure silicon devices, the various properties of GaN such as a wider bandgap energy, high breakdown voltage, larger critical electric field, and higher thermal conductivity allow GaN devices to operate at higher voltages and high switching frequencies, and to handle higher power density, offering enhanced power efficiency.

Such properties allow GaN discretes such as Schottky diodes, FETs, HEMTs and the other advanced transistors to operate efficiently at much higher voltage levels, exceeding the limits of their counterpart silicon devices.

GaN power semiconductors also help to reduce conduction and switching losses, offering higher efficiency in electronic systems. Currently, the major application segments of GaN power semiconductors are inverters (& converters), RF devices, power supply modules, and motor drives, used across all end-user sectors.

The GaN power semiconductor device market is growing primarily due to penetration into the medium-voltage power electronics market and applications across all major end-user verticals. It is obvious that most revenue comes from the rising number of advanced power applications in the industrial, power, solar and wind sector and the sector's developing globally. GaN power devices draw most of their revenue from the Communication Infrastructure sector, focusing solely on replacing their silicon counterparts in various RF power devices, particularly in RF communication applications over the past few years.

Regarding their features, GaN devices are smaller and lighter but tougher and more efficient than silicon devices, and can serve as replacements for their silicon counterparts, which have hit maturity.

GaN devices and wafers also feature low sensitivity to ionizing radiation, and better stability in some radiation environments. They also have a future in solar cell arrays, satellites and high-end power appliances in the Military, Defense & Aerospace sector.

These devices also have huge revenue potential in the automotive and transportation sector, mainly in electric vehicles & hybrid electric vehicles (EV/HEV).

Since GaN power semiconductors have the potential to operate at higher temperatures, higher power levels and voltages, and high frequencies (microwave ranges), the number of applications is increasing continuously in various industries, including telecommunications, consumer electronics, automotive, industrial, power and clean-tech applications.

Currently, gallium nitride accounts for less than 1% of the total power semiconductor market

Currently, GaN accounts for less than 1% of the total power semiconductor market (which currently amounts to $34bn, including power discrete and power ICs). However, over the next ten years, the entire base for power semiconductors & electronics players is expected to penetrate into this new value chain, rapidly increasing the percentage share.

In particular, the GaN market's total competitive landscape had only a handful of players at the beginning of the last decade but quickly emerged into a significant network of key players for both power and optoelectronic semiconductor devices. Companies cited in the report include Aixtron SE, Azzurro Semiconductors AG, Cree Inc, Epigan NV, Fujitsu Ltd, IQE plc, Philips, Mitsubishi Chemical Corp, Nippon Telegraph & Telephone, RF Micro Devices Inc, Texas Instruments Inc, Toshiba Corp.

Today's world includes many suitable power applications for GaN in several segments, such as power distribution systems, industrial systems, heavy electrical systems, turbines, heavy machinery, advanced industrial control systems, electro-mechanical computing systems etc, as well as several new power applications (clean-tech) including high-voltage direct current (HVDC), smart grid power systems, wind turbines, wind power systems, solar power systems, and electric & hybrid electric vehicles. Another application sector is ICT, with several communication application segments such as RF, radar, and satellite communications offering huge revenue potential due to the unbeatable ability of GaN to operate at high-frequency ranges (including microwave frequencies). The potential size of these markets is currently in the trillions, it is reckoned, making the total addressable market for GaN power semiconductors worth billions.

www.marketsandmarkets.com

Thin-film material market to reach $10.25bn by 2018

The thin-film material market is expected to increease at a significant compound annual growth rate (CAGR) to $10.25bn by 2018, according to the report 'Thin Film Material Market, By Type (CdTe, CIGS, a-Si, Others), End-User Industry [Photovoltaic Solar Cells, MEMS, Semiconductors and Electrical (Circuit Boards), Optical Coating, Others], and Deposition Processes – Global Trends & Forecast to 2018' from the firm MarketsandMarkets.

Covering materials including amorphous silicon (a-Si), cadmium telluride (CdTe), and copper indium gallium selenide (CIGS), the advantages offered by thin-film material in industrial as well as domestic operations — coupled with the rising demand for efficiency and miniaturization — will continue to drive the thin-film material market, says the report. Rising demand from end-user industries will be responsible for rapid growth of the thin-film material market in the future, it adds.

Globally, thin-film material manufacturing companies are dependent on government funding and subsidies. During the global economic crisis, the USA and European countries were affected the most. Many countries such as the USA and Germany stopped the funding subsidies provided to thin-film material manufacturing companies, resulting in their bankruptcy, closure or acquisition by Chinese counterparts. It also affected the thin-film material market adversely, causing revenues to decline in 2013. However, the recovering global economy — combined with the stringent government regulation and funding from venture capitalists — is estimated to be providing the market with a necessary boost.

The thin-film material market is growing steadily in Europe, but will continue to grow rapidly in the Asia-Pacific, driven by countries such as China and Japan. The North American market for thin-film material will also continue to grow at a significant rate. The African and Latin American markets have still not realized their full potential.

The thin-film material market is highly competitive and most companies do not offer all types of material, notes the report. First Solar Inc of Tempe, AZ, USA is a major player that has dominated the CdTe market, accounting for nearly 90% of that market in 2012. China's Hanergy dominates the CIS/CIGS market, occupying about a third of the market by acquiring bankrupt firms in 2012. Ascent Solar in the USA and Kaneka Solar Energy and Solar Frontier in Japan are the other major companies offering CIS/CIGS technology. Amorphous silicon (a-Si) technology is used mainly by Asian firms such as Anwell Solar (Hong Kong), Suntech Power Co Ltd (China), and Moser Baer (India).

Thin-film materials are appropriate for high-density and high-frequency applications, notes the report. Applications include several industries such as photovoltaic solar cells, micro-electro-mechanical system (MEMS), semiconductor, electrical and optical coating. One of the key factors contributing to market growth is the increasing use of solar energy. The market has also witnessed growth due to various governments investing increasingly in the solar industry globally. However, the shortage of raw material used for the production of thin films could pose a challenge for the growth of this market, cautions the report.

www.marketsandmarkets.com/Market-Reports/thin-film-material-market-232915487.html

LED usage in NVIS-compatible lighting to grow from $62.6m to $170.5m in 2020

Global consumption of LEDs used in night-vision imaging system (NVIS)-compatible illumination (lighting) in non-civilian applications, such as military, law enforcement, emergency medical services (EMS) etc, will rise from $62.61m in 2013 to $170.52m in 2020, according to ElectroniCast Consultants.

The use of LEDs in NVIS-compatible lighting (night-vision-goggle-friendly lighting) will continue to be dominated by the Military market sector. In 2013, the use of LEDs in Military category night vision goggle (NVG) friendly lighting reach $60.14m.

"The increase use of LEDs in night vision compatibility (NVC) devices is driven by the following market dynamics: technological advances, size, weight and durability in harsh environments (e.g.military/warfare), lower-maintenance and ecological/energy-saving concerns," says Stephen Montgomery, director of the LED Lighting market research group at ElectroniCast.

"Military and law enforcement personnel using night vision goggles (NVG) must be able to read illuminated displays without those displays interfering with the performance of the goggles," he adds. "The displays also must be readable to those not using night vision."

The Naval/Military sector is aggressively increasing the use of night vision compatible (NVC) lighting, notes the report. This sector is upgrading the NVIS lighting as it addresses the requirement to provide convert aviation capable ships. The NVC ship/watercraft lighting provides the benefit and safety of on-board personnel without affecting aviators' abilities to land safely while using night vision goggles.

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Anadigics begins production shipments of AWT6530 quad-band ProVantage 3G/4G PA

Anadigics Inc of Warren, NJ, USA has begun high-volume production shipments of its AWT6530 quad-band ProVantage power amplifier (PA), which is compatible with chipsets from leading suppliers including MediaTek, HiSilicon and Qualcomm.

ProVantage solutions offer high power mode efficiency, linearity and reduced system costs, says the firm. By leveraging Anadigics' unique quad-band architecture, the new AWT6530 PA also delivers integration that minimizes space requirements in mobile devices, it adds.

"Smartphone, tablet and datacard manufacturers increasingly value power amplifier solutions that integrate innovative features and excellent performance into compact packages," says Jerry Miller, senior VP of cellular products. "Our new AWT6530 quad-band ProVantage power amplifier is optimized to answer this challenge by providing an industry-leading blend of value, performance and space-saving integration," he adds. "The AWT6530 has broad applicability, validated by design wins at multiple OEMs, and is a key element of our growth strategy in China and emerging markets."

ProVantage power amplifiers leverage the firm's patented InGaP-Plus technology to achieve high performance and integration. The power amplifiers help to extend battery life by offering two selectable bias modes that optimize efficiency for low and high output power levels, as well as a shutdown mode with low leakage current. The AWT6530 quad-band power amplifier delivers 40% power-added efficiency (PAE) operating in UMTS bands 1, 5 and 8 and 42% PAE in band 2. Two independent amplification chains provide high performance for each band.

The AWT6530 has broad applicability and is a key element of our growth strategy in China and emerging markets

ProVantage solutions are also designed for use with an external switch mode power supply (SMPS) to support average power tracking (APT), which further increases efficiency and reduces current consumption at low and medium operating powers. The ProVantage power amplifiers also provide high linearity to maintain stable, high-throughput 3G and 4G cellular connectivity and high data throughput.

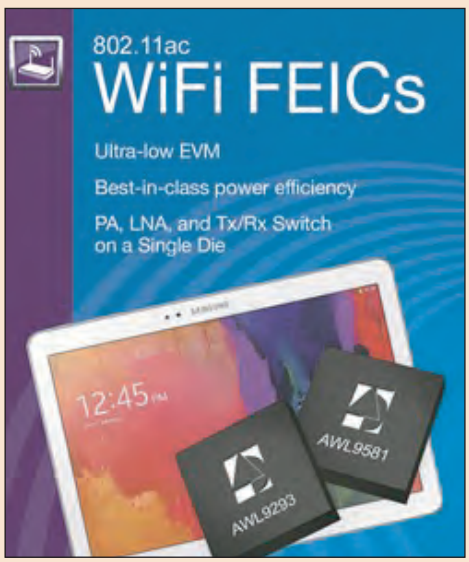
ProVantage solutions are offered in compact 3mm x 4mm x 0.9mm packages with internal voltage regulation and integrated DC blocks on the RF ports to reduce PCB space requirements. RF matching is optimized for output power, efficiency, and linearity in a 50Ω system.

www.anadigics.com

Samsung selects Anadigics' FEICs for WiFi in GALAXY Tab Pro

Broadband wireless and wireline communications component maker Anadigics Inc of Warren, NJ, USA says that its AWL9293 and AWL9581 802.11ac front-end integrated circuits (FEICs) are enabling WiFi connectivity in Samsung Electronics' new GALAXY Tab Pro, powering both the 2.4GHz and 5GHz 802.11ac WiFi bands.

"Our FEICs deliver differentiated performance and integration to help reduce time-to-market, extend battery life and increase data rates," says Jonathan Griffith, VP of WiFi Products at Anadigics. "By collaborating with Samsung, we continue to leverage these advantages in the latest generation of tablets."



Anadigics' WiFi FEICs in Samsung's GALAXY Tab Pro.

Anadigics' AWL9293 2.4GHz and AWL9581 5GHz FEICs leverage the firm's patented InGaP-Plus technology and uniquely designed architectures to combine a high-performance power amplifier (PA), low-noise amplifier (LNA) with bypass option, and Tx/Rx RF switch on a single die, simplifying RF design and reducing time-to-market. The compact 2.5mm x 2.5mm x 0.4mm QFN package also incorporates a high-accuracy integrated power detector and RF ports internally matched to 50Ω. This level of integration greatly improves manufacturability and reliability, while reducing PCB space requirements, says Anadigics. The FEICs also deliver low current consumption, extending battery-life in mobile applications. What is claimed to be best-in-class power efficiency improves thermal characteristics to support MIMO applications.

Anadigics claims that its complete family of 802.11ac FEICs provides outstanding error vector magnitude (EVM) and noise figure performance in the toughest 802.11ac modulation formats, enabling ultra-high data throughput.

SEC filing details RFMD–TriQuint merger timeline

Following the merger agreement in February between RF Micro Devices Inc of Greensboro, NC, USA and RF front-end component maker and foundry services provider TriQuint Semiconductor Inc of Hillsboro, OR, USA, on 14 April the newly formed Rocky Holding Inc filed a Registration Statement on Form S-4 (containing a preliminary joint proxy statement/prospectus) with the US Securities and Exchange Commission (SEC). Rocky Holding was incorporated in Delaware in December as a subsidiary of RFMD solely to effect the mergers. The deal is projected to close in second-half 2014 (subject to shareholder and regulatory approval).

Prior to the closing, Rocky Holding will form two direct subsidiaries, Trident Merger Sub and Rocky Merger Sub. Trident Merger Sub will merge with and into TriQuint, and Rocky Merger Sub will merge with and into RFMD. TriQuint and RFMD will hence each become a subsidiary of Rocky Holding. Former shareholders of TriQuint and RFMD will own common stock in Rocky Holding, which will be listed for public trading on the NASDAQ Global Select Market.

Prior to completion of the mergers, Rocky Holding will change its name, adopt a NASDAQ symbol for its common stock, and register a new trade name and logo reflecting key attributes of the combined company. The merged firm will execute a one-for-four reverse stock split, yielding 145 million shares outstanding.

TriQuint's total revenue in Q4/2013 was $267.7m, and full-year 2013 revenue was $892.9m. RFMD's December-quarter revenue was $288.5m, while its revenue for full calendar 2013 was $1.17bn. The merged firm is projected to have about $2bn in total revenue.

Involving closing a fabrication facility (which could take up to two years to accomplish), the merger is expected to achieve at least $150m in synergies across manufacturing costs and operating expenses ($75m in annualized synergies exiting the first year after closing and an additional $75m exiting the second year). "We will benefit in terms of scale and manufacturing, sharing manufacturing strengths and eliminating overlapping public-trading expenses," says Quinsey.

The merger is expected to be accretive to non-GAAP earnings per share (EPS) in the first full fiscal year after close of the transaction.

Rocky Holding's SEC filing details the timeline up to the merger agreement as follows:

- On 25 February 2013 TriQuint's stock price was near its lowest in years ($4.87) when, at the 2013 Mobile World Congress in Barcelona, Spain, CEO Ralph Quinsey and RFMD's CEO Bob Bruggeworth reopened earlier talks, suggesting a merger creating two new businesses – one focused on mobile, another on networks and defense. Quinsey later met with the CEO of a 'Company B' (based on a pre-existing general business relationship) and proposed a similar deal.
- On 3 April, RFMD proposed a deal to give TriQuint a slightly larger share of the merged firm (swapping 0.9226 RFMD shares for each TriQuint share), reflecting their relative market values. TriQuint's board rejected the offer, for not adequately valuing its infrastructure and defense businesses.
- On 5 June, Company B offered to buy TriQuint for $8.25 per share, an 18% premium on its share price of $6.93 at the time. A week later, TriQuint rejected the offer.
- On 22 August, Quinsey and Bruggeworth discussed a 'merger of equals', with shareholders of each firm controling 50% of the business.
- TriQuint shares rose during 2013 to $8.94 but then plunged 26% to $7.09 during 23–24 October after poor quarterly results from RFMD (signaling a weaker market) and then TriQuint's own results.
- On 29 October, New York-based activist investment fund Starboard Value, which holds 8% of TriQuint's stock, requested that TriQuint outsource or sell part of its business.
- On 17 November, RFMD delivered a proposed 'term sheet' to TriQuint, outlining specifics of a deal. On 19 November, Company B offered to buy TriQuint for $10 per share (a 33% premium on the share price of $7.29 at the time).
- On 13 December, TriQuint's board rejected a deal with RFMD, based partly on concerns regarding the potential reaction on Wall Street in light of both RFMD's and TriQuint's expected near-term financial results.
- On 15 December, Company B raised its offer by $0.10 per share, to $10.10.
- On 28 January 2014 (when TriQuint's share price was $8.36), a 'Company C' expressed interest in buying part of TriQuint's business.
- On 31 January, Starboard proposed a merger to RFMD (which was subject to a written non-disclosure agreement with TriQuint).
- On 18 February (when TriQuint's share price was $9.33), Company B withdrew its offer.
- On 19 February, TriQuint expressed its willingness to move forward in a deal with RFMD, and RFMD accepted TriQuint's terms.
- On 22 February, TriQuint and RFMD agreed a merger. TriQuint's stock price of $9.23 then rose by 26%.

For each TriQuint or RFMD share held, TriQuint shareholders will receive 1.675 shares of the new firm and RFMD shareholders will receive 1 share, giving each 50% post-merger. The transaction represents an implied price of $9.73 for each TriQuint share (a 5.4% premium based on the closing price of $9.23 for TriQuint on 21 February).

www.sec.gov/Archives/edgar/data/1604778/000119312514140867/d708439ds4.htm#rom708439_77

TriQuint's Q1 revenue hit by inventory correction

Improved product mix and cost management yield better-than-expected margins and earnings

For first-quarter 2014, RF front-end component maker and foundry services provider TriQuint Semiconductor Inc of Hillsboro, OR, USA has reported revenue of $177.6m, down 34% on $267.7m last quarter (due to seasonality plus channel inventory burn in the mobile devices market) and down 4% on $184.2m a year ago (due mainly to program timing in the defense market). However, this was towards the high end of the $170–180m guidance.

Subcontract assembly firm Foxconn Technology Group accounted for 26% of revenue (although TriQuint notes that end-customers may use multiple sub-contractors, and the mix of these firms can vary over time).

End-market revenue split was 58% Mobile Devices (down on 71% last quarter), 29% Network Infrastructure (up on 18%), and 13% Defense & Aerospace (down on 11%).

"In Infrastructure, we continue to see healthy demand for base-station products [doubling year-on-year, excluding commercial foundry revenue] and support of the TD LTE build-out in China," notes president & CEO Ralph Quinsey. "In optical, last year's Q3 inventory correction is behind us and demand for high-performance optical drivers remain strong," he adds. "Defense revenue was seasonally down in Q1 following a very strong 2013 and the cyclical nature of a large defense program."

Mobile Devices saw a sequential drop in revenue of 45% following a very strong last quarter. "First-quarter seasonality plus a temporary inventory correction at a significant customer contributed to the larger-than-normal revenue decline," notes Quinsey. "2G and 3G revenues declined year-over-year as we transitioned away from the legacy products, with significant growth in 4G LTE revenue across a broad set of customers," he adds.

Much of the gross margin headwinds that typically come with such a large seasonal decline were offset by better product mix, efficient factory management, and cost reduction, says Quinsey. On a non-GAAP basis, gross margin was 35.3%, down from 37.2% last quarter but up sharply from 22.8% a year ago, and well above the guidance of 28–30%. Operating expenses of $70.9m were up on $68m a year ago but down slightly on $71.1m last quarter, as expenses are managed closely.

Compared with net income of $26.4m ($0.16 per diluted share) last quarter, Q1/2014 saw a net loss of $9.4m ($0.06 per diluted share). However, this is a big improvement on a loss of $27.2m ($0.17 per share) a year ago, and much better than the expected $0.11–0.13 per share.

After dropping from $20.8m in Q3 to just $9m in Q4, capital expenditure returned to $21.7m (again, primarily for premium filter capacity).

Despite the net loss and increased CapEx, during the quarter, cash and investments rose by $84.5m, from $79m to $163.5m, driven by a reduction in accounts receivable and significant cash proceeds from employee stock option exercises.

"Demand for Q2 remains healthy [specifically seeing a significant step up for mobile] as we transition into our seasonally stronger quarters," says Quinsey. The book-to-bill ratio of 1.22 the firm's highest in over two years (boosted by 1.74 specifically for discrete premium filters). TriQuint is hence fully booked to second-quarter 2014 revenue expectation of $215–225m, led by a strong recovery in the mobile market. Gross margin should rebound to 37–38%. Operating expenses are expected to fall to $68–70m. Net income should be $0.06–0.08. Both revenue and earnings guidance are well above current analyst estimates.

"Our goals this year include transitioning our mix from legacy to premium-level products [with LTE expansion representing the firm's single largest growth driver over the next several years], improvements in operation efficiency, and continued growth in the output of new products, with emphasis on Infrastructure and Defence markets," says Quinsey. For example, after receiving orders for a fourth S-band radar system in Q1, TriQuint introduced a 130 Watt Spatium solid-state power amplifier for Ka-band satellite communications.

"I expect gross margins to improve with healthy year-over-year comparisons, each quarter of 2014," Quinsey says. "The combination of cost-reduction initiatives and improved product mix is expected to drive gross margins above 40% on average over the next three quarters," he adds. "Finally, we continue to execute on key development projects and have maintained a high level of new product output, with 36 new product introductions in Q1," Quinsey continues. During the quarter, new multi-mode multi-band power amplifiers (MMPAs) with envelope tracking captured design wins in Korea and China.

"The proposed merger between TriQuint and RFMD [announced on 24 February] will create a capability-rich new company, with growth opportunities across Mobile, Infrastructure and Defense applications," believes Quinsey. "The combination creates a compelling line of product to serve the growing demand for dense RF integration… Customers will benefit from high-value cost-effective products," he adds. "The combined manufacturing scale of the new company will lead to improved levels of financial performance, not achievable by either company on a standalone basis… We expect this merger to unlock significant value for shareholders." Merger preparation and integration planning with RFMD has ramped up in anticipation of a second-half 2014 close.

www.triquint.com

RFMD's quarterly revenue falls 11% to $256m

Cost management yields higher-than-expected rise in margins

For its fiscal fourth-quarter 2014 (ended 29 March), RF Micro Devices Inc of Greensboro, NC, USA has reported revenue of $256m, down 11.3% on $288.5m last quarter and 8.8% on $280.6m a year ago.

Multi-Market Products Group (MPG) revenue was $53m, up 6.4% on $49.8m last quarter but down 3.5% on $54.9m a year ago.

Cellular Products Group (CPG) revenue was $203m, down 15% on $238.7m last quarter and 10% on $225.7m a year ago. China comprised 20–25% of CPG revenues. During the quarter, CPG supported the launch of a new flagship Android smartphone with multiple high-performance 3G/4G components, including antenna control solutions and envelope tracking (ET)-enabled power amplifiers. CPG revenue is now 85% 3G/4G and only under 15% 2G, versus 80% 3G/4G and under 20% 2G last quarter.

Despite the seasonal decline in revenue, on a non-GAAP basis, gross margin has risen from 34.4% a year ago and 39.7% last quarter to 42% (exceeding guidance of 40%). "One year ago, we highlighted our goal to expand RFMD's gross margin by 300-400 basis points in four quarters," notes president & CEO Bob Bruggeworth. "Four quarters later, we've nearly doubled that goal, expanding gross margin by 760 basis points," he adds.

Operating expenses have fallen slightly from $74.6m last quarter to $74m. Net income was $33.4m ($0.12 per diluted share), down from $36.4m ($0.13 per diluted share) last quarter but nearly double the $17.1m ($0.06 per diluted share) a year ago, and exceeding the $0.09–0.10 guidance on the strength of robust margin expansion and operating leverage.

Cash flow from operations was $31.7m. After capital expenditure of $7.3m (less than half last quarter's $15.6m), free cash flow was $24.4m. During the quarter, cash, cash equivalents and short-term investments rose from $205.5m to $244m.

Subsequent to the close of the quarter, on 15 April RFMD retired the remaining principal balance of $87.5m of convertible subordinated notes. The firm is now debt free.

"RFMD is executing on multiple long-term structural initiatives that are enhancing our operating model and delivering robust improvements in gross margin, operating income, and earnings per share," says Bruggeworth. "We have greater than 75 initiatives underway that roll up into one comprehensive effort, spanning our entire organization," he adds. "We are reducing our costs, in our fab, in our packaging and test facilities, across our supply chain, and in how we design our products, and we're confident we can drive margins even higher."

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For fiscal first-quarter 2014 (to end-June), RFMD expects revenue to rise about 19% sequentially to $305m, with CPG growing a little faster than MPG. Gross margin should expand further by 150–200 basis points, as operating expenses will be roughly flat, driving earnings per share (EPS) up to about $0.17.

"In the June quarter and beyond, RFMD anticipates revenue growth ahead of the growth rate of our underlying markets, supported by distinct long-term growth drivers, like the deployment of TD-LTE in China, 2x2 MIMO Wi-Fi connectivity in smartphones, additional 3G bands in entry-level smartphones, additional 4G bands in feature phones, and the advent of new technologies, like envelope tracking, carrier aggregation, and transmit MIMO," says Bruggeworth. "RFMD's diversified growth strategy is also driving additional growth opportunities in new categories, like antenna tuning, impedance tuning, diversity switches, power management circuits, highly integrated receive modules and, soon, our RF Fusion [introduced by CPG during the quarter], which is a complete RF front-end solution for 4G world phones and tablets," he adds.

"RFMD is capturing broad opportunities in Smart Energy and home-area networks with our ZigBee and WiFi solutions, and we're at the forefront of new standards in development, like the sub-1GHz standards enabling long-range mesh networks and the 802.11p standard for automotive networks," Bruggeworth continues. "We are enjoying broad-based design win activity in WiFi for both mobile and non-mobile applications like routers, access points, set-top boxes and televisions. We see double-digit growth opportunities in WiFi, especially where device requirements favor RFMD's performance leadership." During the quarter, MPG won the CableFAX Tech Award for green technology for its gallium nitride (GaN) amplifiers for DOCSIS 3.1. MPG was also awarded a $9.7m contract from the US Air Force Research Laboratory (AFRL) to produce millimeter-wave GaN integrated circuits.

"RFMD is executing on a diversified growth strategy, expanding gross margin, and managing expenses to our financial model, and we are projecting robust operating leverage and EPS growth," says chief financial officer Dean Priddy. "We continue to expect capital expenditures of 4–5% of annual revenue and strong free cash flow," he adds. RFMD still expects revenue growth of 10% year-on-year for fiscal 2015.

www.rfmd.com

Skyworks reports above-target 13% year-on-year growth to $481m quarterly revenue

Growth of 11% next quarter to $535m; earnings per share approach long-term target

For fiscal second-quarter 2014 (ending 28 March), analog semiconductor maker Skyworks Solutions Inc of Woburn, MA, USA has reported revenue of $481m, down 4.8% on $505.2m last quarter but up 13% on $425.2m a year ago (better than guidance of 11% growth to $470m), outpacing normal seasonality. The 10%-customers were again Foxconn and Samsung.

Highlights during the quarter include:

- enabling NetGear's newest 802.11ac MU-MIMO routers and residential gateways;
- supporting Audi's Homelink programmable car system;
- capturing high-reliability sockets with several aerospace & defense suppliers (including Cobham, EADS, Herley and Teledyne);
- securing power management design wins with Samsung;
- ramping connected home solutions supporting security sensors, motion detectors, lighting controls and meters at Centralite and Landis+Gyr;
- leveraging the firm's infrastructure portfolio for macro base-station and remote and multi-standard radio applications across Alcatel–Lucent, Ericsson, Nokia Solutions and Networks, and ZTE;
- delivering analog control ICs to Medtronics for implantable heart monitors;
- developing a dual flash driver utilizing proprietary TrueFlash capability (enabling LED flash management features);
- powering Microsoft, Nintendo and Sony gaming platforms with analog and connectivity solutions;
- expanding the firm's footprint in multiple 4G TD-LTE architectures at leading smartphone OEMs including Coolpad, HTC, Lenovo and ZTE;
- launching next-generation SkyOne platforms with carrier aggregation, additional frequency bands and MIPI baseband interfaces; and
- enabling the Moto G smartphone with five front-end devices.

"Skyworks is executing to our strategy of gaining semiconductor content through system-level integration, diversifying into adjacent vertical applications and relentlessly pursuing operational excellence," says VP & chief financial officer Donald W. Palette.

On a non-GAAP basis, gross margin has risen further, from 42.2% a year ago and 44.5% last quarter to 44.7% (better than the 44–44.5% guidance), driven by strong adoption of the firm's integrated system solutions, margin-accretive new-product introductions, and strength in key vertical markets.

Operating expenses rose further, from $82.9m last quarter to $84.8m, but this is due to R&D expense rising from $50.8m to $53.1m (to support organic growth initiatives) counteracting selling, general & administrative (SG&A) expense falling slightly from $32.1m to $31.7m.

Operating income was $130.4m, up from $99.7m a year ago but down on $141.8m last quarter. Nevertheless, operating margin has continued to rise, from 23.4% of revenue a year ago and 25.3% last quarter to 27.1%, "highlighting the continued strength of our business model in our execution," says Palette.

Although down on $127.7m ($0.67 per diluted share) last quarter, Skyworks' net income was $118.6m ($0.62 per diluted share, above the guidance of $0.59), up on $91.9m ($0.48 per diluted share) a year ago (the fourth consecutive quarter of above-20% year-on-year earnings growth).

We see integrated mobile systems and broad markets revenue continuing to grow as an overall percentage of our mix

Cash flow from operations rose from $159m last quarter to a record $214m. After falling from $38m the prior quarter to $16m last quarter, capital expenditure jumped to $41.8m, invested in support of upcoming program ramps. Depreciation was steady at $21.7m. Cash reserves hence rose from $648.6m to $798m.

During the quarter, Skyworks repurchased 2 million shares of common stock (representing a $61.5m investment). "With the confidence we have in our business outlook, we continue to believe that repurchasing common stock represent a highly accretive use of our cash," says Palette.

Also, the board of directors has declared its first cash dividend of $0.11 per share (implying roughly a 1.2% dividend yield), payable on 22 May to stockholders of record at the close of business on 13 May.

"With the combination of the newly initiated dividend and our ongoing share repurchase activity, we are returning roughly 40% of free cash flow to shareholders, a pace which we believe strikes the appropriate balance between internal investment for growth initiatives and shareholders returns," says Palette.

"Skyworks exceeded guidance across all key metrics last quarter and is set to substantially outpace the broader semiconductor industry as we capitalize on increasing analog system complexity driven by the Internet of Things," says president & CEO David J. Aldrich. "By providing custom solutions that help our customers solve increasingly complex design challenges, we are

enabling connectivity across a number of new and previously unimagined end-markets and applications," he adds. "Our expanding market footprint, customer relationships and design-win pipeline are translating into accelerating growth and improving financial returns."

"Looking forward, we are on track to deliver strong, sustainable top-line growth with continued operating leverage," reckons Palette. For fiscal third-quarter 2014 (to end-June), Skyworks expects revenue of $535m, up 11% sequentially and 23% year-on-year, driven by strength in emerging markets, content gains in key programs, and 802.11ac deployments in an expanding set of opportunities within the Internet of Things. Gross margin should be in the 45% range despite operating expenses rising slightly to about $86m. Diluted earnings per share should be $0.73, up 18% sequentially and 35% year-on-year (representing the fifth consecutive quarter of year-on-year earnings growth of about 20%), "reflecting the strength of demand for our products, our differentiation in the market place, and the consistency of our execution," says Palette. This is also close to the firm's $0.75 long-term target.

For fiscal first-half 2014, power amplifiers represented 40% of revenue, integrated mobile systems 33%, and broad markets 27%. Skyworks expects these percentages to stay relatively consistent throughout the remainder of the fiscal year. "In fiscal 2015 and beyond, we see integrated mobile systems and broad markets revenue continuing to grow as an overall percentage of our mix, which should support improved returns based on the high differentiation and better margins associated with these products," notes Palette.

www.skyworksinc.com

Skyworks and Panasonic form 66:34 joint venture

Panasonic's SAW filters complement Skyworks' BAW filters

Skyworks has announced the creation of a joint venture with Japan's Panasonic Corp, one of the world's largest electronic product manufacturers, to design, develop and deliver high-performance filters, including surface acoustic wave (SAW) and temperature-compensated (TC) SAW devices.

At the core of the joint venture is Panasonic Filter Division's engineering and process talent, expertise in filter design, and products, as well as 412 fundamental filter patents and patent applications.

"This new venture leverages the core strengths of both companies to better serve the high-volume filter market and positions us to substantially grow the business," believes Shigeru Ono, director of Panasonics' Circuit Components business division.

The insatiable demand for always-on connectivity and ever increasing user data demands have driven a proliferation of bands and the addition of 4G/LTE capabilities, says Skyworks. In fact, 3GPP now has more than 45 sanctioned bands. This is significantly increasing the demand for filters and especially for high-performance TC SAW filters that enable the dense packing of bands. The need for sensitivity and the increasing co-existence issues (due to simultaneous operation of GPS, WiFi, Bluetooth, and cellular radios) necessitate the extremely high-quality filtering enabled by Panasonics technology, says Skyworks. Panasonic's high-performance filter portfolio is said to offer advantages including: reduced size and weight; higher selectivity; excellent Q and low insertion loss; reliability and stability under harsh environments; lower distortion; and field-proven, high-volume production.

"Panasonic has a long heritage in SAW filter products and is the clear performance leader and largest volume producer of rapidly emerging TC SAW filters, with shipments already approaching a quarter of a billion units," comments Skyworks' president & CEO David J. Aldrich. "Our joint venture structure capitalizes on Panasonic's acoustic filtering and piezoelectric leadership while further augmenting Skyworks product breadth and integration capabilities," he adds. "Together, we intend to deliver the worlds highest-performance, lowest-cost and shortest-cycletime solutions.

Skyworks' joint venture with Panasonic is complementary to its strategic investments in high-frequency bulk acoustic filters. "As a result, we can now develop customized solutions for any band configuration where filter technology is applicable, spanning high-, mid- and low-band frequencies," says Aldrich. "In short, Skyworks has covered the RF spectrum with best-in-class filter products, by targeted band, allowing us to offer differentiated architectures for the most demanding customer applications."

At closing, Skyworks will hold 66% of the newly created entity, with Panasonic retaining 34%. The transaction encompasses the products, working capital, manufacturing equipment and intellectual property of Panasonics' Filter Division. Headquartered in Osaka, Japan with design centers and operations at facilities in Japan and Singapore, the joint venture will comprise about 590 staff.

In exchange, Skyworks will make a cash payment of $148.5m to Panasonic for its share of the new venture. This investment is expected to be immediately accretive to Skyworks margins and earnings per share. Skyworks and Panasonic expect the transaction to close by the end of third-quarter 2014 (subject to customary closing conditions).

http://panasonic.net

GigOptix delivers $1.5m order for E-band radio chipsets

GigOptix Inc of San Jose, CA, USA (a fabless supplier of analog semiconductor and optical communications components for fiber-optic and wireless networks) has claimed a leadership position in point-to-point (PtP) wireless backhaul with volume delivery and continuous revenue growth in E-band radio chipsets.

GigOptix's Wireless Product Line was launched in June 2012 when GigOptix augmented its internal gallium arsenide (GaAs) power amplifier program by licensing silicon germanium (SiGe) millimeter-wave technology from IBM for E-band chipsets, for both 71–76GHz and 81–86GHz frequency bands.

"We have received a substantial purchase order of $1.5m of our leading E-band devices from one Tier 1 customer," says Dr Raluca Dinu, VP & general manager of GigOptix's High-Speed Communications division. "Total fiscal 2013 revenue from the Wireless Product Line was $1.7m," he adds. "With the strong demand that we have seen so far this year, and considering our current GaAs power amplifier backlog, the Wireless Product Line is in an excellent position to about double the revenue of E-band devices in 2014 compared to the previous year."

GigOptix says its EXP7602-DNT and EXP8603-DNT devices were the first GaAs E-band high-performance power amplifiers with general availability (from September 2013) and include integrated power detectors specifically designed to meet ANSI and ETSI requirements. Among other best-in-class RF performance metrics, the amplifiers are claimed to have exceptionally good linearity, output intercept points (OIP3s) better than 31dBm, and typical power dissipation lower than 2.2W.

The E-band radio market, which was still in its early stages just two years ago, is entering the maturity stage with significant volume deployment, says GigOptix. Market estimates are that about 3000 E-band radios per month are currently being shipped. Based on strong demand from Tier 1 customers, the number of deployed radios is expected to grow to 6000 per month, with total shipments in 2014 in excess of 50,000. Demand for E-band radios in the first few months of 2014 has been very strong, driven by the deployment of LTE cellular infrastructure in support of ever growing demand for mobile data for smartphones. If the current trend continues, it is expected that in 2015 the E-band radio will become one of the most deployed solutions for wireless back-hauling, with volumes in the range of 200,000 radios in 2015 and doubling in 2017, adds GigOptix.

The deployment of small cells will be part of the second wave of LTE deployment, with volume installation from 2015, and will be addressed by V-band devices, in the 60GHz band. With small-cell density expected to be one order of magnitude greater than regular cells in urban areas, demand for V-band radios should boom in the next two years, with volumes much higher than E-band. GigOptix reckons it is also uniquely positioned to be a dominant supplier in V-band chipsets based on the firm's specialized core skills, RF performance, and roadmap.

According to EJL Wireless Research's 9th Edition (May 2013) of the report 'Global Digital PTP Radio Market Analysis and Forecast, 2013–2017', a shift towards high-capacity radios will continue to drive more value-added products in the market, based on 4G networks launched in 2010 and continuing deployments through 2015. The market report accounts for the impact of micro-cells, as well as demand for new sites and capacity upgrades within the mobile infrastructure market. At 60GHz, Gigabit Ethernet unit shipments are forecasted to grow from 20,000 in 2014 to 200,000 in 2017. At 70/80GHz, Gigabit Ethernet unit shipments are forecasted to grow from 18,000 in 2014 to 120,000 in 2017. Gigabit Ethernet is expected to dominate the 60GHz and 70/80GHz frequency bands in the forecast period.

www.gigoptix.com

Senior director of IC development added for Wireless Product Line

Due to the rapid business growth and customer demand, GigOptix has appointed industry-veteran Sushil Kumar to the newly created role of senior director of IC development for the Wireless Product Line, based in San Jose, to lead the engineering teams for the line.

"Now that significant GigOptix product shipments have started to ramp, we hired Sushil Kumar to take the next generation of the E-band and other wireless-band products to the next level," says senior VP & chief technical officer Andrea Betti-Berutto. "Sushil has more than 25 years of high-speed RFIC and MMIC transceiver development experience," he adds. "Sushil will lead our advanced RF and E-band initiatives and will help us accelerate our development of the next-generation mmWave IC transceivers."

Previously, Kumar was director of engineering at RFMD, leading GaN and GaAs MMIC development in its San Jose design center. He participated in over 100 MMIC designs, from near base-band up to E-band. He has also worked in engineering and research roles for over 20 years, including senior RFIC/MMIC design engineer at Avago Technologies in San Jose, senior RFIC/MMIC design engineer at Agilent in San Jose, design engineer at Hewlett Packard in Santa Clara, and senior scientist at the Defense Research and Development Organization in India. Kumar has been awarded three patents and is involved in activities of the IEEE International Microwave Symposium.

Hittite's margins rebound as sales reach record $70.6m

For first-quarter 2014, Hittite Microwave Corp of Chelmsford, MA, USA (which designs and supplies analog, digital and mixed-signal RF, microwave and millimeter-wave ICs, modules and subsystems as well as instrumentation) has reported record revenue of $70.6m, up 2.7% on $68.8m last quarter and 4.3% on $67.7m a year ago, and above the guidance of $67.5–69.5m.

Three of the firm's eight markets (military, microwave and millimeter-wave communications, and cellular infrastructure) accounted for about 78% of total revenue. The remaining markets (test & measurement, automotive, broadband, fiber optic and space) accounted for the other 22%.

Cellular infrastructure, microwave communications, test & measurement and automotive revenues grew sequentially. "We continue to see strong growth in the infrastructure market, driven by LTE spending in China and the USA," says CEO & president Richard D. Hess. "The microwave communications market was solid and the test & measurement market was stronger than in the previous quarter," he adds. Fiber optic, broadband and military were essentially flat. Space was down sequentially due to the cyclical nature of that business.

Of total Q1 sales, 39.4% ($27.8m) came from US customers (down for a fourth consecutive quarter, from 41.3% or $28.4m last quarter, and 44.7% or $30.2m a year ago) and 60.6% ($42.8m) was non-US (up from 58.7% or $40.4m last quarter, and 55.3% or $37.5m a year ago). Specifically, domestic revenue was down 1.9% sequentially and 7.9% year-on-year, while international revenue was up 5.9% sequentially and 14.2% year-on-year.

After falling quarter-on-quarter from 73.7% a year ago, gross margin recovered slightly from 67.3% last quarter to 67.4%, remaining at the lower end of the firm's operating range (as forecasted), due to the product and market mix and, to a lesser extent, the impact of several lower-margin and primarily military development contracts. "These development contracts are new projects we choose to participate in," notes VP & chief financial officer William W. Boecke. "In the past these development programs have grown into production contracts, with greater revenues and higher margins. We expect similar results from these current programs."

Although down from $13.2m a year ago, R&D expense has risen slightly from $11.8m last quarter to $11.9m (16.8% of revenue). "R&D costs represent a continued investment in the development of new products and product lines, which is the principle long-term growth driver of the firm," says Boecke. Sales & marketing expenses have risen from $5.8m a year ago and $6.1m last quarter to $6.9m (9.8% of revenue) due to travel as well as other marketing costs related to the incrementally higher revenue. General & administrative expenses were $3.7m (5.3% of revenue), compared with $3.4m last quarter and $3.8m a year ago. Total operating expenses have risen from $21.3m last quarter to $22.6m (though still down on $22.8m a year ago).

Net income was $16.4m, down from $17.6m a year ago but up from $15.6m last quarter, and at the high end of the $15.3–16.5m guidance range.

Operating cash flow of $27.2m was offset by $1.8m of capital expenditures, $4.7m in dividends paid and $0.9m in net tax payments related to equity compensation. This hence yielded free cash flow of $19.8m, driving total cash and marketable securities up during the quarter from $472.5m to $492.4m.

Hittite also announced that its board of directors has declared a further $0.15 per share dividend, payable on 27 June, to shareholders of record on 4 June.

During Q1, Hittite agreed to buy the assets of Keragis Corp of San Diego, CA, which provides high-power wideband amplifier modules. "This acquisition fits well with our strategy of leveraging our IC capability in both gallium arsenide and gallium nitride into a higher level of assemblies," says Hess. "Keragis has developed a unique power combining capability allowing them to build devices that replace tube amplifier technology with solid-state devices," he adds. "This offers customers the opportunity to both replace existing tube amplifiers as well as design solid-state amplifiers into new systems. These devices provide a substantial reliability and lifetime improvement to the existing technology used." Applications include military radar, weather radar, air-traffic radar, as well as other high-powered opportunities. "In addition, we delivered multi-channel up- and down-converter modules for ship or navy demonstrator program," notes Hess. "These devices achieve significant performance improvement and offer the possibility to be used across multiple future platforms on military programs."

"The increase in our R&D spending over the last three years is starting to pay benefits that will drive our growth," says Hess. Based on new products and design-ins, coupled with record order bookings in Q1, for Q2/2014 Hittite expects revenue to rise to a record $74–76m, driven by continuing strength in cellular infrastructure business, a growing microwave backhaul market, and modest growth in test & measurement, as well as signs that the military business is now picking up. Net income should hit $17.6–18.4m, based on (1) estimated gross margin rising to 68% (approaching the firm's normal range of 68–73%); (2) operating expenses rising slightly due to continued R&D and sales & marketing investments; and (3) a tax rate of about 34%.

"We will continue to invest in our new product development and expanding our penetration into new products and markets," says Hess.

www.hittite.com

IN BRIEF

TowerJazz receives Supplier Excellence Award from MACOM

Specialty foundry TowerJazz (which has fabs at Tower Semiconductor Ltd in Migdal Haemek, Israel, and at its subsidiaries Jazz Semiconductor Inc in Newport Beach, CA, USA and TowerJazz Japan Ltd) has received the 2013 Supplier Excellence Award from M/A-COM Technology Holdings Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog, RF, microwave and millimeter-wave applications).

In 2013, MACOM acquired Mindspeed Technologies Inc of Newport Beach, CA, USA (which designs network infrastructure semiconductors for communications applications), which has been a TowerJazz customer for over 10 years. The award recognizes the foundry's continued support, partnership commitment and delivery performance to Mindspeed and now MACOM.

MACOM uses TowerJazz processes such as mixed-signal/CMOS, RF CMOS, BiCMOS and SiGe BiCMOS, including SBC18H2 and SBC18H3 advanced nodes, to develop products like cross-point switches, transimpedance amplifiers (TIAs), laser drivers, clock data recovery (CDR) chip-sets, power amplifiers (PAs) and equalizers.

"This award demonstrates our commitment to partnering with our customers and providing leading-edge technology to enable their new products and consistently support their on-time delivery needs," says Todd Mahlen, TowerJazz's VP of North American sales. "This is confirmation of our worldwide manufacturing excellence while providing the best technical and design solutions for our customers' specific needs."

www.macom.com
www.towerjazz.com

Peregrine names VP of marketing

Peregrine Semiconductor Corp of San Diego, CA, USA, a fabless provider of radio-frequency integrated circuits (RFICs) based on silicon-on-sapphire (SOS) and silicon-on-insulator (SOI), has promoted Duncan Pilgrim to VP of marketing, driving all its product marketing and marketing communication initiatives.

"Coming on the heels of a very successful UltraCMOS Global 1 launch at Mobile World Congress, we believe Duncan has the skills and expertise to continue to drive this momentum in the marketplace," says CEO Jim Cable. "Duncan's strong technical background, extensive industry experience and understanding of go-to-market strategies make him an ideal fit to lead the future Peregrine marketing initiatives," he adds.

Pilgrim, a 17-year semiconductor industry veteran, joined Peregrine in 2010. Previously, he was VP of marketing for Sequoia Communications and held product, strategic and technical marketing roles at RF Micro Devices. His technical background comes from engineering positions at RFMD, GEC Plessey Semiconductor and Marconi.

Pilgrim earned a master's degree in business administration from Wake Forest University and a bachelor's degree in electronic engineering from University of Birmingham in the UK.

www.psemi.com

MACOM launches highest-power, full E-band MMIC power amplifier

M/A-COM Technology Solutions Inc of Lowell, MA, USA has launched what it claims is the industry's highest-power, full E-band power amplifier, delivering typical saturated power output of 25.5dBm for the 71–76GHz and 81–86GHz frequency ranges in a single product.

Optimized to enable fiber-caliber data rates over long distances across 10GHz of available E-band spectrum, the new power amplifiers equip designers of point-to-point transceivers to maximize design flexibility by eliminating the need for two different amplifiers to cover the full 71–86GHz E-band range.

The MAAP-011106 E-band power amplifier is suitable for small-cell wireless backhaul infrastructure, enabling data rates of 1Gbps and higher to accommodate surging data demand, particularly in densely populated metro environments. Providing what is claimed to be the highest output power for high-frequency E-band operation, the new amplifier offers a broad bandwidth and can reduce transceiver design and manufacturing costs via the consolidation of PAs within compact, multi-band systems, claims MACOM.

The E-band power amplifier includes an integrated power detector and supports 20dB of small-signal gain with variable gain control for flexible performance tuning. The output 3rd-order intercept point (OIP3) is 30dBm, and the output and input match is 15dB. Each device is RF tested to ensure performance compliance, and is fabricated using an efficient pHEMT process.

"MACOM's MMIC design expertise and decades-long innovation in point-to-point wireless backhaul technology has distinguished us as a leading supplier of power amplifiers across every frequency band," says David Richardson, product line director Wireless, MACOM. "With the introduction of our E-band power amplifier, we're making it easier for transceiver designers to achieve high linear power and gain control over the full E-band spectrum, while including the convenience and performance of an integrated output power detector."

www.macom.com

Quantum Semiconductor and Silvaco collaborate on modeling Si-Ge-C superlattices

TCAD tools to gain Si-based superlattice band-structure models for combining opto functions with CMOS

Quantum Semiconductor LLC of San Jose, CA, USA (which develops devices that expand what silicon can do with light) and Santa Clara-based Silvaco Inc, a provider of technology computer-aided design (TCAD), circuit simulation and IC CAD electronic design automation (EDA) software tools, are collaborating to develop TCAD models for Si-based superlattices. The TCAD tools and engineering support provided by Silvaco led to the US National Science Foundation last year awarding Quantum $180,000 in follow-on Small Business Innovation Research (SBIR) Phase 1B funding ('SiGeC Superlattices with Direct Bandgaps for Light Emission and Absorption at 1.55 Micron').

Quantum says that its technology platform addresses the most challenging problems currently facing CMOS. Si-Ge-C superlattice films, which have radically improved optoelectronic properties, enable highly efficient light absorption and emission across an extended wavelength range, from ultraviolet (UV) to mid-wavelength infrared (MWIR). Through their collaboration, Quantum and Silvaco aim to incorporate new electronic band-structure models of the Si-based superlattices into Silvaco's TCAD tools, which will be used to perform device simulations.

"Our vision is to bring new functionality to CMOS by incorporating Si-Ge-C superlattices which allow the efficient absorption and emission of light from UV to visible to infrared, enabling new products for image sensing, optical communications, silicon photonics, wide-spectrum photovoltaic cells and even advanced tunnel MOSFETS," says Quantum's chief technology officer Carlos Augusto. "To enable the adoption of these new superlattices into CMOS design and manufacturing, new models must be developed to describe their properties. With Silvaco, we can accelerate the investigation and verification of modeling and optimization for Si-Ge-C superlattices combined with CMOS."

"We are excited to collaborate with Quantum Semiconductor and develop new physical models allowing the use of Si-Ge-C superlattice films in our TCAD flow," says Eric Guichard, VP of Silvaco's TCAD Division. "This partnership will enable Silvaco to provide additional unique solutions to our customers working on the next generation of optoelectronic devices which incorporate these novel superlattice materials."

www.silvaco.com
www.quantumsemi.com

Peregrine launches first monolithic alternative to discrete PIN-diode limiters

At EDI CON 2014 Electronic Design Innovations Conference in Beijing China (8–10 April), Peregrine Semiconductor Corp of San Diego, CA, USA, a fabless provider of radio-frequency integrated circuits (RFICs) based on silicon-on-sapphire (SOS) and silicon-on-insulator (SOI), debuted its new line of UltraCMOS RF power limiters.

Peregrine claims that its power limiters represent the first turnkey, monolithic solutions to provide an alternative to discrete, PIN-diode limiters based on gallium arsenide, adding that the UltraCMOS power limiters deliver simple, repeatable and reliable protection suitable for test & measurement, land mobile radio (LMR), wireless infrastructure, military and radar systems.

"Customers continuously find that incumbent GaAs-based RF solutions do not rise to the challenge of new complexity in the market, and they are investing in Peregrine's SOI technology as fast as we can develop new options like this," says director of marketing Duncan Pilgrim.

Turnkey monolithic architecture delivers benefits

On a chip eight times smaller than the board space required by discrete PIN-diode solutions, Peregrine reckons that its new power limiters provide a 10-100x improvement in response and recovery time; deliver greater than 40dB improvement in linearity (IP3); and offer a 20x improvement in ESD (electrostatic discharge) protection.

The power limiters save PCB space with a small form factor; reduce BoM (bill of materials) by eliminating the need for extra components; and improve time to market by reducing in-design time and costs, claims Peregrine. They also beat existing solutions in RF performance, including higher linearity to eliminate signal distortion, high ESD to ensure high reliability, wide bandwidth to enable design flexibility, and fast response and recovery times to ensure robust protection of power-sensitive components, the firm adds. Finally, because the power limiters are based on UltraCMOS instead of GaAs, they can be closely integrated with other UltraCMOS RF components.

Peregrine Semiconductor claims that its power limiters represent the first turnkey, monolithic solutions to provide an alternative to discrete, PIN-diode limiters based on gallium arsenide

Several industries require repeatable and reliable power protection

Peregrine says that its UltraCMOS power limiters can protect:

- RF ports in test & measurement equipment;
- RF front ends and low-noise amplifiers (LNAs) in LMRs;
- RF receivers in wireless infrastructure equipment;
- tactical radio receivers from intentional jammers in military warfare; and
- transceiver (TRX) modules in radar systems.

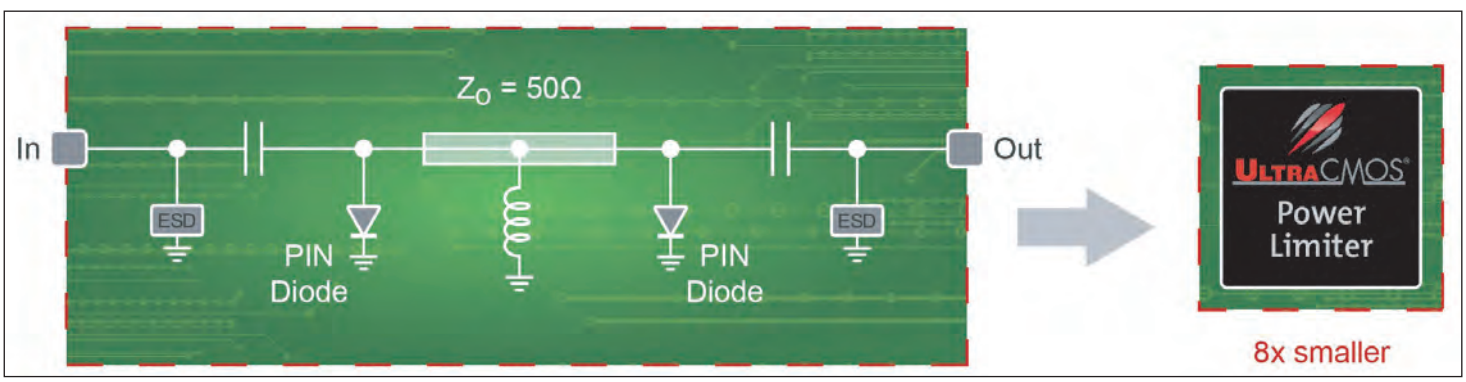
The firm says that, in order to achieve repeatable and reliable power protection, customers currently face challenges because it takes so long to design and validate PIN-diode power-limiter circuits and the multiple external components that this architecture requires. With the new, all-in-one architecture, both time to market and cost can be reduced significantly, it adds.

Exhibited at EDI CON, the first two UltraCMOS power limiters (to be released in May) are:

- the PE45140, a 20MHz–2GHz, 50W power limiter designed for professional portable and mobile radios, such as tactical radios and LMRs, as well as HF, VHF, UHF, L-band radar transceivers; and
- the PE45450 is a 9kHz–6GHz, 50W power limiter designed for test-and-measurement systems, L/S/C-band radar transceivers, counter-measure receivers and wireless receivers.

Both power limiters feature an adjustable limiting threshold, unbiased power limiting, and operation in two modes (power limiting or power reflecting).

www.psemi.com



Discrete GaAs PIN-diode circuits (left) vs Peregrine's UltraCMOS power limiter (right) as turnkey, monolithic solution.

Anvil awarded grant to grow high-quality GaN on 3C-SiC on large-diameter silicon

Migration to 150mm wafers and non-polar GaN LEDs targeted

Anvil Semiconductors Ltd of Coventry, UK has been awarded a grant by the UK's Technology Strategy Board (TSB) to evaluate the feasibility of using its unique stress relief technology to enable the production of low-cost, high-brightness LEDs on large-diameter silicon substrates.

Anvil was spun off in August 2010 from the University of Warwick's School of Engineering by its technology commercialization subsidiary Warwick Ventures Ltd in order to exploit patented developments in SiC power semiconductor technology. Anvil says its approach to SiC switches should cost no more than their silicon counterparts. This involves growing a thin layer of cubic SiC (3C-SiC) on silicon substrates sufficient to fabricate active power devices. As well as crystal growth expertise, Anvil has IP relating to resolving the problem of the stress that inevitably arises when growing SiC on Si (which to date has prevented widespread adoption of the technology). The IP has been proven on 100mm silicon wafers and can be migrated to larger diameters without modification.

Fabricating gallium nitride (GaN)-based LEDs on large-diameter silicon wafers is recognized as a key path to reducing the cost of lighting systems and displays. But existing techniques for managing the large mismatches in lattice parameter and thermal coefficient of expansion between silicon and GaN are complex and costly and have struggled to deliver materials suitable for high-efficiency devices, says Anvil. However, with growth of GaN-based LED structures on SiC already well established, high-quality 3C-SiC on silicon produced using Anvil's stress relief technology could provide an alternative that can be readily migrated onto 150mm substrates and beyond, the firm reckons.

The grant will fund work to produce and characterize typical GaN-based epilayers on Anvil's 3C-SiC on silicon wafers. With Anvil's process able to produce high-quality 3C-SiC surfaces with orientation close to (100), the project will also explore the technology's potential for producing the elusive cubic and, importantly, non-polar form of GaN. This could pave the way for further device benefits including improved LED efficiencies and lower-power-consumption displays, it is foreseen.

"We're delighted to have been given this opportunity to explore the potential for Anvil's technology in another exciting market," says CEO Jill Shaw. "If we're successful, we will be looking for partners to help us take it forward."

www.anvil-semi.co.uk

Raytheon demonstrates GaN-on-diamond HEMT with 3x increase in power density over GaN-on-SiC

Data obtained on 10x125μm HEMT

Raytheon Company of Waltham, MA, USA says that it has achieved another milestone for next-generation gallium nitride (GaN) radio-frequency (RF) semiconductor technology. Through the US Defense Advanced Research Projects Agency (DARPA) Near Junction Thermal Transport (NJTT) effort under the Thermal Management Technologies program, Raytheon's team is replacing GaN's current substrate silicon carbide (SiC) with diamond, a material with 3–5x higher thermal conductivity, to create GaN-on-diamond devices.

Raytheon has demonstrated that GaN-on-diamond technology enables a 3x increase in transistor power density over GaN-on-SiC, overcoming a major barrier to unlocking the potential of GaN devices, it is reckoned. Data was obtained on a 10 x125μm GaN-on-diamond high-electron-mobility transistor (HEMT), a device representing a unit cell for constructing power amplifier monolithic microwave integrated circuits (MMICs), which are the foundation of solid-state RF transmitters and active electronically scanned arrays (AESAs). Raytheon says that this latest result builds on prior successes, including its industry-first demonstrations of GaN-on-diamond transistors in 2009 and of GaN-on-diamond MMICs in 2011.

We are now inserting GaN into DoD systems while remaining focused on continuing to increase performance of this revolutionary semiconductor to provide our warfighters with the most advanced sensing, communications and electronic warfare capabilities

"We are now inserting GaN into DoD systems while remaining focused on continuing to increase performance of this revolutionary semiconductor to provide our warfighters with the most advanced sensing, communications and electronic warfare capabilities in the world," says Joe Biondi, VP of Advanced Technology for Raytheon's Integrated Defense Systems (IDS) business in Tewksbury, MA.

GaN-on-diamond offers performance improvement by reducing thermal resistance within the device and enabling GaN to be used at higher power densities, which can dramatically reduce the cost, size, weight and power of defense systems, says Raytheon. GaN is a core competency within Raytheon and an integral technology behind some of the its major programs, including the US Navy's Air and Missile Defense Radar program (AMDR) and the Next Generation Jammer (NGJ) program. GaN's unique qualities allow radar, electronic warfare and communications systems to be smaller, more affordable and highly efficient, says Raytheon.

Raytheon also recently announced that, under the DARPA Microsystems Technology Office (MTO) Wide Bandgap Semiconductor (WBGS) program, it has systematically matured GaN from basic material to transistors, MMICs, transmit/receive (T/R) modules and finally transmit/receive integrated multi-channel modules (TRIMMs).

www.raytheon.com/capabilities/radar

GaN Systems' director of US business development elected to board of Power Electronics Industry

GaN Systems Inc of Ottawa, Ontario, Canada, a fabless developer of gallium nitride (GaN)-based power switching semiconductors for power conversion and control applications, says that Julian Styles, its director of business development USA, has been elected to the board of the Power Electronics Industry Collaborative (PEIC), the US industry-driven, membership-based consortium of suppliers, OEMs, research companies and other stakeholders working to accelerate the development and growth of power electronics in the USA. PEIC's aim is to increase investment in manufacturing capabilities and advance innovation in power electronics in the USA as energy efficiency becomes increasingly important globally.

GaN Systems has developed a range of gallium nitride power switching products based on its proprietary Island Technology. The firm says that its devices can overcome the limitations of traditional silicon semiconductors, offering far greater efficiency in power conversion applications such as solar, wind, smart-grid, electric and hybrid vehicles and power supply applications. GaN Systems recently said that its products will be widely commercially available this year.

"Innovative semiconductor companies like GaN Systems succeed best when they are part of a thriving power electronics ecosystem," believes Styles. "We are very impressed with PEIC's efforts to build and strengthen this ecosystem in the USA."

www.gansystems.com

DARPA's Mobile Hotspots phase 1 makes progress toward providing 1Gb/s backbone to remote troops

Gallium nitride E-band power amplifier providing 20%-PAE 20-watt output for UAV-borne millimeter-wave communications

The US Defense Advanced Research Projects Agency (DARPA) says that missions in remote, forward operating locations often suffer from a lack of connectivity to tactical operation centers and access to valuable intelligence, surveillance and reconnaissance (ISR) data. The assets needed for long-range, high-bandwidth communications capabilities are often unavailable to lower echelons due to theater-wide mission priorities.

DARPA's Mobile Hotspots program aims to help overcome this challenge by developing a reliable, on-demand capability for establishing long-range, high-capacity reachback that is organic to tactical units. The program is building and demonstrating a scalable, mobile millimeter-wave communications backhaul network mounted on small unmanned aerial vehicles (UAVs) and providing a 1Gb/s capacity. DARPA performers recently completed the first of three phases in which they developed and tested key technologies to be integrated into a complete system and flight tested in subsequent phases.

"We're pleased with the technical achievements we've seen so far in steerable millimeter-wave antennas and millimeter-wave amplifier technology," says program manager Dick Ridgway. "These successes — and the novel networking approaches needed to maintain these high-capacity links — are key to providing forward deployed units with the same high-capacity connectivity we all enjoy over our 4G cell-phone networks," he adds.

Phase 1 accomplishments include:

- **Smaller, steerable millimeter-wave antennas**

During field testing, the program demonstrated steerable, compact millimeter-wave antennas that rapidly acquire, track and establish a communications link between moving platforms. Steerable millimeter-wave antennas will enable the formation of a high-capacity backhaul network between aerial and ground platforms.

- **Low-noise amplifiers**

Performers also demonstrated an advanced low-noise amplifier (LNA) that boosts the desired communications signal while minimizing unwanted noise. The prototype achieved the world's lowest-noise millimeter-wave LNA, at about half the noise figure of a typical LNA.

- **More efficient and capable power amplifiers**

Efficient millimeter-wave amplification is required to achieve the long ranges (>50km) desired in the Mobile Hotspots program. During Phase 1, performers demonstrated output power exceeding 1 watt and 20% power-added efficiency (PAE) from a single gallium nitride (GaN) chip operating at E-band frequencies (71–86GHz). Output powers exceeding 20 watts and approaching 20% PAE were also achieved using power-combining techniques.

- **New approaches for robust airborne networking**

Mobile ad-hoc networking approaches were developed to maintain the high-capacity backhaul network among mobile air and ground platforms. Phase 1 performers developed unique solutions to overcome connectivity and network topology challenges associated with mobility and signal blockages due to terrain and platform shadowing.

- **Low-size, weight and power (SWAP) pod design to carry it all**

Performers created engineering designs for small, lightweight pods to be mounted on an RQ-7 Shadow UAV. The pods, with all of the Mobile Hotspots components inside, are designed to meet the challenging program goals of widths no more than 8 inches, weight less than 20 pounds, and power consumption less than 150 watts.

Phase 2 of the program began in March. Two performers — L-3 Communications and FIRST RF — were chosen to lead teams comprising several Phase 1 performers. Goals include integration of the selected Phase 1 technologies into Shadow-compatible aerial pods and ground vehicles. Phase 2 will conclude with a ground demonstration of at least four Shadow-compatible pods, two ground vehicles and a fixed ground node. A planned third phase will encompass field testing of the Mobile Hotspot systems on networks of multiple SRQ-7 Shadow UAVs and mobile ground vehicles.

www.darpa.mil/Our_Work/STO/Programs/Mobile_Hotspots.aspx

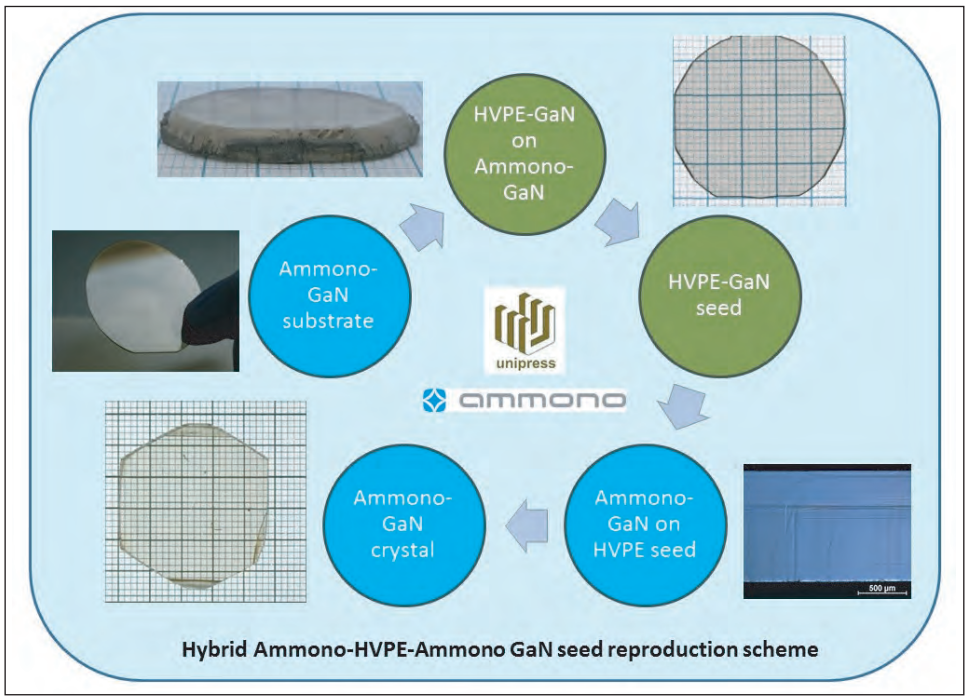
Ammono and Unipress devise fast, low-cost production of ammonothermal gallium nitride

Ammono S.A. in Warsaw, Poland, which produces bulk gallium nitride (GaN) using ammonothermal technology, and the Institute of High Pressure Physics of the Polish Academy of Sciences (Unipress) say they have conceived proprietary new technology that allows cheap and fast production of ammonothermal GaN on the basis of hybrid Ammono-HVPE GaN seeds.

Ammonothermal gallium nitride is seen as a perfect material for performance-driven electronic and optoelectronic applications, which require very good crystal quality, says Ammono. An example is the laser diode, where output power and lifetime depend strongly on GaN substrate quality. Other examples are power transistors and Schottky diodes, where reliability is related primarily to the device's crystalline structure and thus substrate quality. Last but not least, ultra-high-brightness LEDs benefit tremendously from the substrate's low dislocation density, which allows effective dissipation of the heat created during device operation.

Competing GaN production technologies such as hydride vapour phase epitaxy (HVPE) or liquid phase epitaxy (LPE) use foreign (non-GaN) seeds, and the quality of the GaN material obtained in this way results in the manufacture of devices that, on a long-term scale, do not achieve the quality targets set by device makers, claims Ammono. This lower quality is reflected in many parameters, most importantly the dislocation density, which in the case of ammonothermal GaN is of the order of $10^4 cm^{-2}$ whereas other technologies are at least two orders of magnitude worse, adds the firm.

Ammono and Unipress have shown that using hybrid HVPE-ammonothermal approaches allows the manufacture of GaN material fulfilling the strict requirements of high-end applications. In the framework of a grant received from the Polish National Center for Research and Development (PBS1/B5/7/2012) it was shown that, by using ammonothermally grown GaN (as a seed), one can obtain high-quality free-standing HVPE-GaN (for details, see Appl. Phys. Expri 6, 075504 (2013)).



Hybrid Ammono-HVPE-Ammono GaN seed reproduction scheme

Smooth GaN layers up to 2.5mm thick (crystallized with a stable growth rate of $240\mu m.hr^{-1}$) and of an excellent crystalline quality, without cracks, and with low threading dislocation density ($5x10^4$ cm^{-2}) have been grown and then sliced from the Ammono-GaN seed wafers (see Figure).

The structural properties of the free-standing HVPE-GaN do not differ from the structural properties of the Ammono-GaN seeds, notes the firm. Additionally, this is a high-purity material. According to the SIMS analysis the oxygen and carbon content is below $10^{16}cm^{-3}$. The only silicon impurity is of the order of $3x10^{16}cm^{-3}$.

Thus, from the point of view of physical properties, the HVPE-GaN is of a much higher quality than the that obtained using MOCVD-GaN/sapphire templates or GaAs crystals as seeds, it is claimed.

Subsequently, the new material was used again as a seed for the ammonothermal process. As a result, a new kind of GaN crystal was grown (Ammono-HVPE-Ammono). Their characteristics were presented for the first time during the Gallium Nitride Materials and Devices IX conference at SPIE's Photonics West 2014 event in San Francisco. A threading dislocation density of $2x10^5cm^{-2}$ and average full width at half maximum (FWHM) of 19 arcsec define the new ammonothermal material as top class compared with other GaN manufacturing approaches, claims Ammono.

The new proprietary and patent protected technology allows high-volume, high-quality GaN seed replication, which will accelerate the spread of ammonothermal GaN to mass-market applications, the firm reckons. It will also allow Ammono-GaN production costs to be driven down in an aggressive way due to much faster availability of a vast population of high-quality GaN seeds, it concludes.

www.ammono.com
www.unipress.waw.pl

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MACOM announces IP licensing program and supply deal with IQE for GaN-on-Si

IQE to produce 4", 6" & 8" epiwafers in high-volume for RF applications

M/A-COM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for analog, RF, microwave and millimeter-wave applications) has announced an IP licensing program that will make available its gallium nitride on silicon (GaN-on-Si) technology to select companies for use in RF applications. MACOM detailed recent progress in two areas critical to realizing its future vision of enabling the mainstream adoption of GaN as a large-scale RF semiconductor technology across the industry.

As a first step, MACOM has announced a license and supply agreement that will enable IQE plc to use its patent-protected technology to manufacture GaN-on-Si epitaxial wafers at 4-, 6- and 8-inch diameters in high-volume for RF applications. This move is expected to enable MACOM to deliver GaN RF products with breakthrough bandwidth and efficiency at mainstream 8-inch (200mm) silicon cost structures, and to enable IQE to accelerate GaN penetration into key target markets.

MACOM also says it is in active discussions to make GaN-on-silicon technology available to select companies for use in RF applications. The firm believes that establishing such large-diameter wafer manufacturing sources will be a key factor in driving mainstream, commercial adoption of GaN technology. Surety of supply is of critical importance in power-amplifier-dependent markets such as cellular base-stations, MACOM reckons. According to market research firm Strategy Analytics, power amplifier transistor revenue from base-stations will grow to more than $1bn in 2014.

"We are nearing a watershed moment for the RF & microwave industry, promising breakthrough performance for compound semiconductors and leveraging large-scale silicon production facilities that operate at orders-of-magnitude greater economies of scale," says MACOM's president & CEO John Croteau. "Our recent acquisition of Nitronex and its portfolio of fundamental IP rights related to GaN-on-silicon materials, process, and device technology for RF applications provides us with the foundation for a licensing program that will help bring our vision of GaN performance at mainstream 8-inch silicon cost structures a reality," he believes.

As the world's biggest supplier of compound semiconductor epitaxy (with the largest independent manufacturing capacity), IQE currently supplies over 50% of the world's RF epiwafers, and is already established as the leading provider of GaN high-electron-mobility transistor (HEMT) wafers for RF, broadband, and military power amplifiers. IQE can hence achieve enhanced economies of scale, says MACOM, helping to build the wafer capacity and cost structure needed to grow the GaN market.

Combining GaN HEMT performance with low-cost and large-diameter silicon substrates enables these wafers to be processed through existing high-volume silicon factories. We have already delivered MACOM 200mm-diameter GaN-on-Si wafers

Transistors for these applications have historically been fabricated using 3 inch and/or 4-inch (100mm) silicon carbide (SiC) substrates. To complement these products and increase market reach, IQE has developed and demonstrated growth of GaN HEMTs on industry-standard silicon substrates at wafer diameters of 100mm, 150mm and 200mm. IQE reckons that this technology, along with the comprehensive IP portfolio licensed from MACOM, will enable tremendous economies of scale, wafer capacity, and cost structure needed to advance the GaN market.

"We are beginning to see very significant traction for GaN occurring in the compound semiconductor industry, across a wide range of applications," comments IQE's president & CEO Drew Nelson. "Our agreement with MACOM allows us to further penetrate this new market by bringing decades of high-volume production experience to create the necessary supply chain needed to accelerate GaN adoption," he adds.

"Combining GaN HEMT performance with low-cost and large-diameter silicon substrates enables these wafers to be processed through existing high-volume silicon factories. Commercial availability of GaN HEMTs on 150mm and 200mm wafers represents a significant milestone toward the widespread adoption of this technology... We have already delivered MACOM 200mm-diameter GaN-on-Si wafers, and we look forward to a powerful ongoing relationship," Nelson says.

"This partnership achieves a critical milestone in the mainstream commercialization of GaN technology by establishing the manufacturing capability and capacity required to bring reliable, high-volume surety of supply to the industry," believes Croteau.

www.macom.com
www.iqep.com

IQE delivers 8" GaN-on-Si HEMT wafers to Singapore-MIT LEES next-generation CMOS program

Further collaboration to target other compound semiconductor on silicon technologies

Epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK has delivered the first 200mm (8") gallium nitride-on-silicon wafers (GaN-on-Si) into the Singapore–MIT Alliance for Research and Technology Center's Low Energy Electronic Systems (SMART-LEES) program.

Despite the ever decreasing transistor linewidths and highly complex architectures being deployed by leading semiconductor companies globally, conventional CMOS is now rapidly reaching fundamental limits of silicon performance, notes IQE. This has led to many foundries and integrated device manufacturers (IDMs) actively developing compound semiconductor on silicon (CSoS) technologies in order to exploit the advantageous electronic, optical and power handling properties of compound semiconductors, while continuing to use the scale and cost structure of existing silicon semiconductor fabs, adds the firm.

The SMART-LEES program in Singapore is developing (among other technologies) a comprehensive array of CSoS technologies to facilitate complete monolithic integration of CMOS and compound semiconductor circuits, in a way that allows the processing of wafers through conventional 200mm CMOS processing lines. In addition, design libraries will be developed to allow widespread adoption of these technologies across multiple end markets.

IQE has now delivered 200mm GaN-on-Si high-electron-mobility transistor (HEMT) wafers to this program, which should enable the realisation of a new generation of RF device architectures, integrated with highly efficient power control circuitry. It is expected that further collaboration will quickly lead to a wide variety of other compound semiconductor combinations to be realised as part of the full array of CSoS technologies.

"It has been clear for some time that conventional CMOS is no longer capable of continuing Moore's law," comments project leader Gene Fitzgerald, the Merton C Fleming Professor of Materials Science at MIT. "The ever increasing capital intensity of narrowing linewidths, coupled with the rapidly reducing performance benefit, means a new paradigm needs to be introduced. Compound semiconductors fully integrated on a silicon platform is a highly optimal solution, taking advantage of both the greatly superior performance of compound semiconductors in many applications, coupled with the cost benefits of the existing silicon fab infrastructure," he adds. "Our program fully integrates III-V devices into the silicon design platform, resulting in the ability to develop fundamentally new circuit designs for a wide-range of applications," Fitzgerald continues.

The technologies will drive a new phase of growth in the semiconductor industry, believes IQE's president & CEO Dr Drew Nelson. "Compound semiconductors have always been the next obvious choice to carry forward the silicon industry, and we are very excited about being a major part of the next revolution in fully integrated CMOS technology, bringing the next leap in performance across a great range of technologies."

www.iqep.com

http://smart.mit.edu/research/lees/lees.html

IN BRIEF

IQE's Infrared Division wins its first $1m order for InSb substrates

Epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK has received its first $1m purchase order agreement for indium antimonide (InSb) substrates, which are used in mid-wavelength infrared (MWIR) imaging technology.

IQE Infrared's US substrate division Galaxy Compound Semiconductor Inc of Spokane, WA, USA has been contracted to deliver volume quantities of InSb substrates to an industry leader and long-term customer of the group. This represents the largest order to date for this new range of infrared substrates.

InSb is the material of choice for MWIR imaging technology, and cameras fabricated from InSb are used in a wide variety of imaging applications (defence, security, medical and industrial). IQE Infrared says it is uniquely positioned in this market and is the exclusive supplier of all InSb to industry, with IQE's US (Galaxy) and UK (Wafer Technology) operations collectively meeting the requirements of customers to provide a secure, dual-source supply of InSb substrates.

"The scale of this commitment reflects our success in being able to offer a volume manufacturing capability for InSb materials," says IQE's CEO Dr Drew Nelson. "The investments that we have made to enhance our crystal growth, wafering and substrate polishing capabilities at both Galaxy and Wafer Technology will enable us to fully meet the InSb product demands of our customers, both in terms of volume and quality, across a full 2-6" product range," he adds.

www.iqep.com

IQE's revenue and profits rise strongly, driven by robust wireless business and diversification

Business integration yielding £7m in annualized cost savings

For full-year 2013, epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK has reported record revenue of £126.8m, up 44% on 2012's £88m (despite an adverse second-half currency impact as sterling appreciated 3% against the US dollar). However, this includes £30.9m from Kopin Wireless (the MOCVD-based HBT epiwafer manufacturing business of Kopin Corp of Taunton, MA, USA, acquired in January 2013).

For second-half 2013 (compared with first-half 2013, on a constant currency basis), wireless sales were up 3% and photonic sales up 12%.

"IQE's core wireless division has again delivered a robust performance, with continued growth despite a significant downstream inventory correction in the major chip companies due to softness in the high-end smartphone market," says CEO Dr Drew Nelson. "As a direct result of our customer risk mitigation strategy, which we have executed over the last 18 months and completed with the acquisition of Kopin Wireless, we are much less sensitive to market share shifts between the major chip supply companies."

For full-year 2013 compared with full-year 2012, adjusted profit before tax (PBT) was up 51% from £8.6m to £13m (reported PBT was £5.2m). Adjusted fully diluted earnings per share (EPS) was up 43% from 1.4p to 2p (reported fully diluted EPS was 0.89p).

Cash inflow from operations (before exceptional items) was up 346% from £4.7m to £16.2m (reported cash inflow from operations was £12.8m). Cash conversion (before exceptional items) has more than doubled, from 51% to 111%. During second-half 2013, net debt rose from £15.5m to £34.4m, but this was due primarily to £25m of debt to part fund the Kopin acquisition.

IQE says that the integration of Kopin Wireless has been reflected in strong operational performance and major customer service awards. In particular, operational efficiency has improved through the benefit of synergies including sharing best practice and economies of scale. The firm is on track to eliminate duplicate overheads through the consolidation of operations without any loss of capacity or technology, saving more than £7m on an annualised basis.

"Concerns in the UK over the last year that silicon CMOS would significantly damage the compound semiconductor industry have proved unfounded and are not reflected in our financial performance nor in our customers' expectation of future long-term demand drivers," says Nelson.

"Wireless remains an attractive market for us over the coming years, with demand continuing to be driven by the proliferation of wireless applications and the need for sophisticated GaAs chips to deal with the explosive growth in data traffic," continues Nelson. "Beyond this, the next waves of innovation which will drive handset-replacement cycles are likely to include lasers and sensors using compound semiconductor technology, for gaming, 3D image capture, gesture recognition, and sensing for a variety of applications including healthcare monitoring devices," he adds.

The integration of Kopin Wireless has been reflected in strong operational performance and major customer service awards

"Our business diversification strategy also gained strong traction, and we achieved a number of significant technical and commercial milestones during 2013 which reflect the strong progress made in our other key markets including photonic sensors and lasers, advanced solar (CPV), power semiconductors, infrared, LED and advanced electronics," says Nelson.

IQE notes that its concentrated photovoltaics (CPV) commercialization strategy has been strengthened by the acquisition this month of its stake in CPV cell maker Solar Junction Corp (SJC) of San Jose, CA, USA by a strategic investor. In particular, a robust supply chain is being established and qualification is progressing well, says IQE.

IQE says it is making progress on its diversification strategy through new product development and qualifications, including:

- a major three-year supply contract with Philips for vertical-cavity surface-emitting laser (VCSEL) applications (announced in October);
- a new 150mm VCSEL product for high-volume applications (launched in mid-March);
- the achievement of record VCSEL energy-efficiency and speed performance (announced in February and March, respectively);
- the development of silicon photonics technology (reported in late January); and
- the world's first 150mm indium antimonide (InSb) substrates for infrared applications (launched at Photonics West 2014 in February);

IQE states that the reorganization of its business into market streams reflects confidence of strong growth in emerging markets and revenue diversification. "IQE is at the forefront of the enabling technologies that are at the very heart of many of the 21st-century trends and products," says Nelson. "We are confident that the group is well positioned for continued growth in earnings and cash flow in 2014 and beyond."

www.iqep.com

5N Plus acquires remaining stake in Sylarus

Specialty metal and chemical products firm 5N Plus Inc of Montreal, Québec, Canada has acquired the remaining 33.33% ownership stake in Sylarus Technologies LLC of St. George, UT, USA and has changed the subsidiary's name to 5N Plus Semiconductors LLC.

5N Plus provides purified metals such as bismuth, gallium, germanium, indium, antimony, cadmium, selenium and tellurium, and also produces related II-VI semiconducting compounds like cadmium telluride (CdTe), cadmium sulphide (CdS) and indium antimonide (InSb) as precursors for the growth of crystals for solar, LED and eco-friendly materials applications.

5N Plus Semiconductors is the sole US domestic space-qualified germanium substrate supplier to National Security Space (NSS) customers, and is one of only two National Defense Stockpile (NDS)-qualified germanium substrate suppliers worldwide. Since its inception, 5N Plus Semiconductors has been awarded over US$10m in contracts from the US Government, including a US$1.32m contract by the Defense Logistics Agency (DLA) to upgrade a portion of the NDS high-purity germanium metal inventory to unfinished germanium substrates for multifunction photovoltaic solar cells employed in NSS applications.

The DLA award was strategic in nature as 5N Plus Semiconductors is now part of the US NDS for strategic materials, with the potential for follow-on business both as a strategic metal supplier and NDS inventory manager.

"Through this platform that we have renamed 5N Plus Semiconductors, we intend to grow our semiconductor substrate business," says president & CEO Jacques L'Écuyer.

http://sylarus.com

5N appoints COO

5N Plus has appointed Bertrand Lessard as chief operating officer.

Lessard has nearly 30 years of experience in technical, operational and leadership positions. Prior to joining 5N, he was general manager of SEC Bloom Lake Iron Mine of Cliffs Natural Resources. Lessard has worked for over 25 years at Xstrata (formerly Noranda and Falconbridge now Glencore Xstrata). His career began in 1985 at the Canadian Copper Refinery in Montreal where he held several technical and management positions, eventually taking the lead of Operations in 1998. He also served as director (Recycling), headquartered in Toronto, Ontario, and in 2008 as director (Copper) of the Kidd Creek metallurgical site in Timmins, Ontario, until 2010 when he joined Cliffs Natural Resources.

"His prior experience in the minor metals field and in senior management positions of sizeable metallurgical facilities promise to be great assets to leverage our worldwide network of operations, execute on our growth plan and become a more efficient organization," comments president & CEO Jacques L'Écuyer.

www.5nplus.com

AXT reports higher-than-expected GaAs and InP revenue in Q1

Cost savings yield cut in losses

For first-quarter 2014, AXT Inc of Fremont, CA, USA has reported revenue of $19.3m, up 3.8% on $18.6m last quarter although still down 13.8% on $22.4m a year ago.

By product sector, gallium arsenide (GaAs) substrate revenue was $8.5m, down 27% on $11.7m a year ago but only 4.5% on $8.9m last quarter. Indium phosphide (InP) substrate revenue was $2.2m, up 22% on $1.8m last quarter and a year ago. Germanium (Ge) substrate revenue was $3.2m, down 11% on $3.6m last quarter but up 23% on $2.6m a year ago. Raw materials sales were $5.4m, up 26% on $4.3m last quarter (although still down 14% on $6.3m a year ago).

"Despite normal seasonality, our results exceeded our expectations in the first quarter, led by higher-than-anticipated revenues in semiconducting gallium arsenide and indium phosphide substrates, as well as strength in raw material sales," says CEO Morris Young.

After rebounding to 15.1% last quarter, gross margin fell back slightly to 14.1% (compared with 15.6% a year ago). Operating expenses were $5.1m, up from $4.7m a year ago and $4.4m last quarter. However, excluding a one-time restructuring charge of $0.9m related to cost-reduction initiatives, underlying operating expenses have been cut to $4.2m (with selling, general & administrative expenses falling from $3.9m a year ago to $3.4m, and R&D expenses down slightly from $0.82m to $0.78m).

After being halved to $1.2m last quarter, net loss has risen slightly to $2m, although this is still less than the $2.4m a year ago. Correspondingly, during Q4/2013, cash and cash equivalents fell further, from $25m to $22.8m.

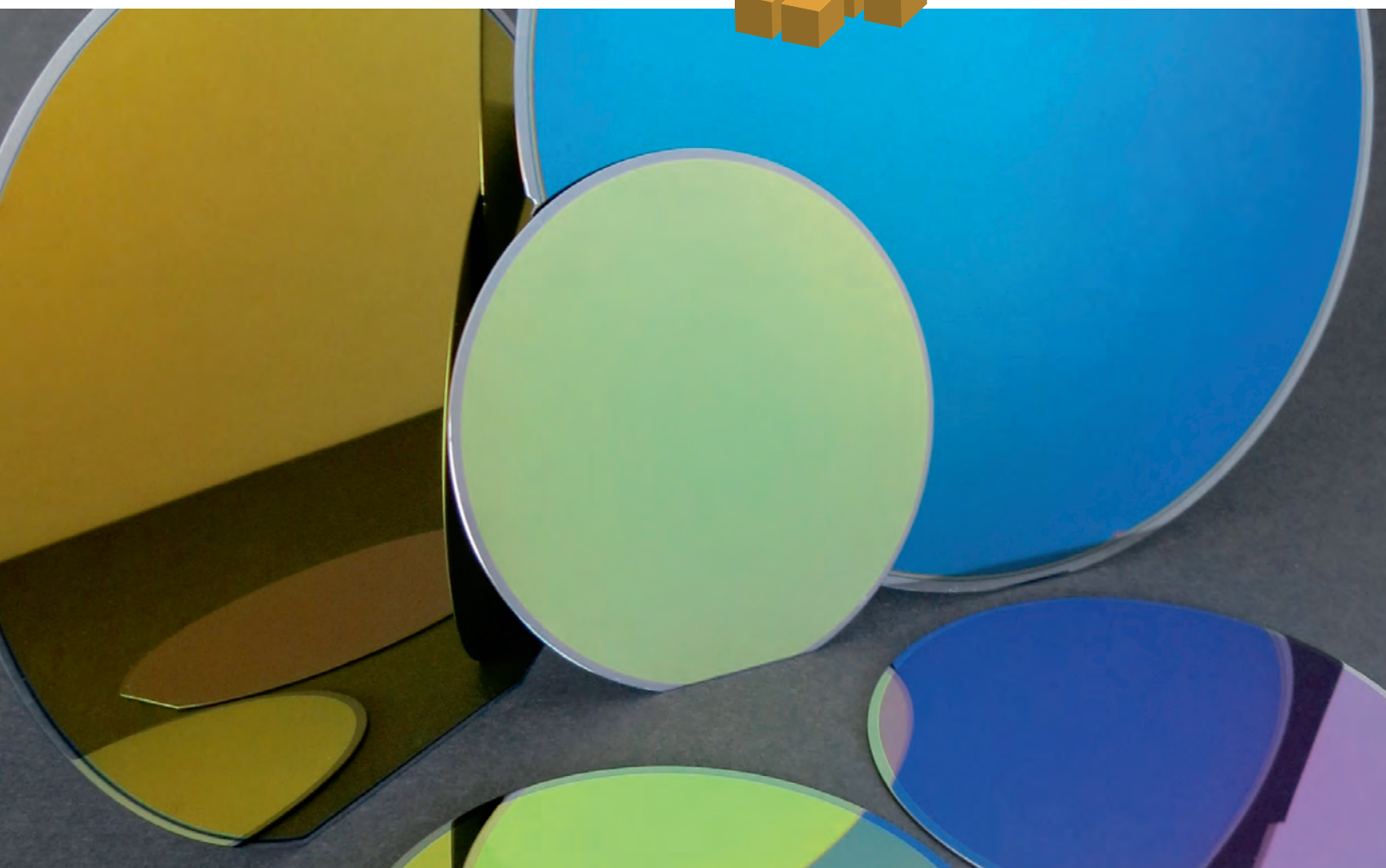
"In addition to revenue growth, we began to see the benefit of cost-saving measures implemented during the quarter, which contributed to improvement in our earnings per share [compared with a year ago]," says Young. "Our goal is to improve in both our gross margins and our operating margins in the coming quarters as the full benefit of these measures take effect," he adds. "We are highly committed to returning the company to profitability."

www.axt.com

THE FUTURE OF SEMICONDUCTORS HAS ARRIVED...

Translucent

www.translucentinc.com



III-N MOCVD HEMT
Rare Earth Oxide (REO)
Silicon

GaN-on-Si Epiwafers

Translucent's revolutionary GaN-on-Si technology employs a patented Rare Earth Oxide (REO) layer that electrically isolates the device layers from the substrate and also provides a physical barrier to stop silicon diffusion.

- Insulating REO buffer isolates GaN from silicon
- REO enables superior high voltage device performance at a competitive price

Germanium
Silicon

Ge-on-Si Epiwafers

Translucent's germanium-on-silicon technology forms the foundation for our photonics materials and multi-junction solar cells for Concentrated Photovoltaic (CPV) applications.

- Germanium directly on silicon
- Tailored bandgap via Group IV alloys

Silex a subsidiary of Silex Systems Limited (ASX: SLX)

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Palo Alto, CA94022, USA

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Riber makes profit in 2013 despite revenue falling 14%

Growth in core R&D business offsets lack of production system sales

After reporting revenue for full-year 2013 in late January, Riber S.A. of Bezons, France, which manufactures molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells, has now reported its full earnings figures.

Revenue was €23.5m for 2013, down 14% on 2012's €27.4m.

MBE system revenue of €16.9m was down 13% on 2012's €19.4m. No production machines were sold in 2013 (compared with 2 in 2012). However, this was partly offset by sales of systems to research customers rising from 15 in 2012 to 17. Riber says that, during the past year, it has further strengthened its positions in research markets in order to limit the significant downturn affecting industrial markets due to their current excess capacity.

Revenues from services and accessories (€5.3m, down 13% from €6m) and cells and sources (€1.3m, down 35% on €2m) are down 18% overall, due primarily to the weak level of demand in 2013 from industrial customers. Sales of cells for new markets — organic light-emitting diodes (OLEDs) and thin-film solar — have remained sluggish, pending the next wave of capacity investments in South Korea. However, this decrease has been limited by the development of sales of MBE effusion sources to R&D customers.

Gross profit was €7.5m in 2013 (down 17% from €9.1m), representing gross margin of 32.2% of revenue (down only slightly from 33.2%). More specifically, the 1-point drop in margin reflects the provisioning for inventories, with a net charge of €0.2m for 2013, compared with a €0.6m reversal in 2012.

Also, operating expenses are down year-on-year, notably benefiting from the policy rolled out by Riber at the beginning of 2013 to reduce its fixed costs. Hence, Riber still made a net income of €0.2m (1% of revenue), albeit down from €1.9m (7% of revenue) in 2012.

During 2013, cash reserves fell from €3.6m to €1.7m, factoring in the high level of billing at the very end of the year and the ramping up of innovation efforts during the year. Despite a lower level of business, the firm generated +€1.2m in cash flow from operations in 2013.

In view of the results for 2013 and the requirements for financing innovation, Riber's management board will not be submitting a proposal for a dividend at the general meeting on 3 June.

At the end of February, order backlog was €7.4m (up from €7m at the end of 2013), with six research systems to be delivered from second-quarter 2014 and significant levels of orders for services and accessories. The firm says that it is currently seeing an increase in deals for the R&D MBE market.

Riber says that in 2014 it is focusing its efforts on:

- promoting its new Compact 21 DZ R&D MBE system;
- extending its range of MBE effusion sources, and continuing to make gains in market share;
- developing thin-layer complex material deposition equipment, particularly for the buoyant OLED flat-screen sector;
- over the longer term, incorporating MBE into the silicon manufacturing chain (for III-V on silicon materials, etc).

Riber's technological expertise, its presence in South Korea, and the quality of its research partnerships represent strong assets to support these developments.

www.riber.com

SemiTEq launches new generation of PVD and PECVD systems for R&D and small-scale production applications

SemiTEq of Saint-Petersburg, Russia, which designs and manufactures high-vacuum and ultra-high-vacuum (UHV) equipment including molecular beam epitaxy (MBE) deposition systems, has launched a new generation of physical vapor deposition (PVD) and plasma-enhanced chemical vapor deposition (PECVD) systems intended for intensive R&D as well as small-scale production for wafers up to 8" in diameter.

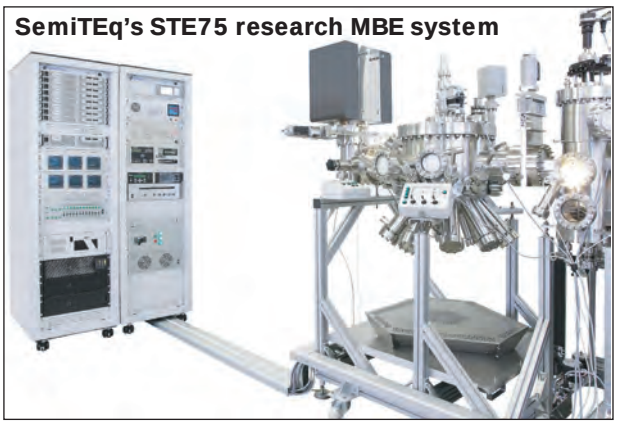
The systems are based on the versatile STE ICP platform for inductively coupled plasma etching (STE ICP200E) and PECVD (STE ICP200D). The platform has an aluminium process chamber and a new design of load-lock chamber, specially configured for installation through the cleanroom wall. Also, the work table design provides efficient helium cooling for long etching processes as well as precision heating with thermal stabilization for PECVD. Software allows flexible programming of the etching or deposition process.

SemiTEq's STE ICP platform

http://semiteq.org

University of Toronto's Center for Nanotechnology orders second SemiTEq R&D MBE system

SemiTEq of Saint Petersburg, Russia, which designs and manufactures high-vacuum and ultra-high-vacuum (UHV) equipment including molecular beam epitaxy (MBE) deposition systems, has sold an STE75 research MBE system to the Centre for Advanced Nanotechnology at the University of Toronto, Canada.



SemiTEq's STE75 research MBE system

SemiTEq says that it is actively expanding into foreign markets. In particular, this is the second MBE system order from the University of Toronto's Center for Nanotechnology.

The new STE75 is intended as a compact and versatile tool for a wide range of R&D applications for semiconductors based on III-V, II-VI and III-nitride materials. The MBE system is claimed to be one of the most compact in the R&D class. The basic configuration has a compact footprint, flexible design and all the necessary tools for in-situ monitoring of growth process data, making the STE75 the optimal choice for research centers and universities, it is claimed.

http://semiteq.org

IN BRIEF

MBE systems for Asian lab's arsenide and antimonide R&D

Riber says that it has secured an order for two MBE 412 R&D systems, for installation during 2014 in a leading laboratory in Asia.

Connected via an ultra-high-vacuum (UHV) fully automated central robot, both systems will be used for III-V material research, in particular for developing arsenide and antimonide structures.

Riber claims that the MBE 412 is the world's best-selling research system for 100mm wafers, offering flexibility that enables it to meet the most demanding expectations for fundamental high-level research into new concepts in the major fields of semiconductors.

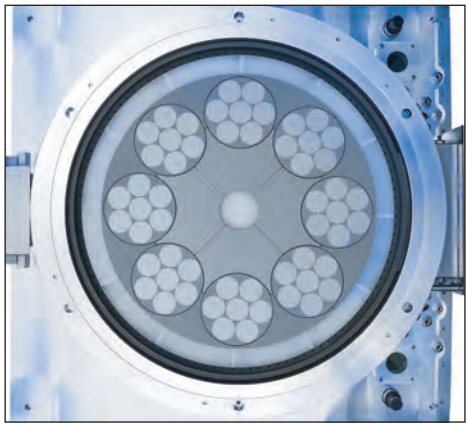
www.riber.com

Trifortune orders Aixtron MOCVD system for GaN LEDs on alternative substrates

Jiangsu Trifortune Electronic Technology Co Ltd of Jintan City, China has ordered an AIX G5 HT metal-organic chemical vapor deposition (MOCVD) system from deposition equipment maker Aixtron SE of Aachen, Germany in order to develop gallium nitride (GaN)-based high-brightness light-emitting diodes (HB-LEDs).

Trifortune was founded in May 2013. In phase one of its strategic business plan the firm made an initial investment into a pre-production demonstration line located at Shahe, Beijing.

The new system will be equipped to handle 56x2-inch wafers per run and will be installed at Trifortune's R&D center. The developed process will be transferred to mass production in the Jiangsu area upon completion of the research.



Aixtron's AIX G5 HT MOCVD reactor chamber.

We are developing GaN processes to grow LEDs on substrates that offer some advantages compared to the well-established sapphire substrates

"We are developing GaN processes to grow LEDs on substrates that offer some advantages compared to the well-established sapphire substrates," says technical head Dr Hu. "To compete in the HB-LED market, there is a real need to achieve the maximum yield in our manufacturing process, so that products with better performance in lumen per dollar can be established. The AIX G5 HT system is widely acknowledged as having the top yields in LED mass production, along with excellently repeatable performance at high growth rates," he comments.

"We are very pleased to contribute to Trifortune's success and to share our comprehensive expertise in optimization of epitaxy yields with them," says Aixtron's chief technology officer Andreas Toennis.

www.aixtron.com

Picodeon appoints Applied Materials veteran as CEO

Finland-based nanotech firm Picodeon Ltd Oy, which specializes in thin-film coatings and surface treatments, says that Fergus Clarke has joined it as CEO.

As well as having a B.Sc, and M.Sc. in Mechanical Engineering and an MBA, Clarke brings over 25 years of global high-tech management experience. Clarke was at Applied Materials for 18 years, in leadership positions in Operations, Business Development and General Management, working in Germany, Ireland, and the USA (contributing to revenue growth from $1bn to $10bn). Subsequently, he led start-ups in healthcare and nutraceuticals, and most recently was vice president at global supply chain company UTi.

"Fergus' depth of leadership experience at Applied Materials and smaller high-growth companies will be important as Picodeon grows its business to meet the demand from our customer base," says Picodeon's chairman Nikolay Danilov.

Picodeon's new CEO Fergus Clarke.

Clarke's appointment comes at a point where Picodeon says it is experiencing strong interest from OEMs in battery, LED, optical, and life science applications. Picodeon has developed the ColdAb Series 4 thin-film deposition system (unveiled last October), which is claimed to be the world's first production equipment for the use of pulsed laser deposition (PLD) in volume manufacturing, via the patented Coldab ultra-short pulsed laser deposition (USPLD) process. The system provides multi-layer deposition capability for materials including oxides, metals and several composites. Picodeon will use the system to commercialize new applications based on a wide range of coating materials. Precious metals such as gold (Au) and oxides for the semiconductor and sensor industries are in the development roadmap.

"Picodeon's innovative technology, highly skilled team, and focussed investors have positioned them uniquely to bring new solutions to emerging application spaces," comments Clarke. "I look forward to scaling the company so that all our customers can benefit from Picodeon's capabilities," he adds.

"I would like to thank Jari Liimatainen for leading the team in the dual role of CEO/CTO until my appointment," Clarke continues. "I look forward to working closely with Jari as he now focusses on our Technology Roadmap, and developing solutions for our customers."

www.picodeon.com

Valence Process Equipment's MOCVD systems to be distributed by SAMCO

Valence Process Equipment Inc (VPE) of Branchburg NJ, USA has signed an agreement for SAMCO International of Kyoto, Japan to distribute its metal-organic chemical vapor deposition (MOCVD) equipment. The agreement gives SAMCO exclusive distribution rights in Japan as well as non-exclusive rights to sell the products in other areas including China, South Korea and Europe.

VPE has developed a novel MOCVD reactor for gallium nitride-based devices including high-brightness LEDs for solid-state lighting. The system's unique, patented design reduces consumption of expensive gases and metal-organic precursors by up to 40% in comparison with competing products, the firm claims. VPE's initial product was the GaN-500 reactor, announced in 2011, with a current capacity of 59x2" or 18x4" wafers. The firm recently released the GaN-550 MOCVD reactor, with a capacity of 72x2" or 20x4" wafers.

SAMCO is an established provider of dry etch, plasma CVD and surface treatment systems for compound semiconductor applications, including wide-bandgap materials (e.g. for RF devices, LEDs and laser diodes). While gaining market share in Japan, it is expanding its sales in Europe and North America.

Recently, SAMCO placed a focus on selling next-generation production equipment for GaN power devices. The addition of MOCVD strengthens SAMCO's product line-up, as MOCVD, plasma CVD, dry etching and surface treatment systems can be bundled to provide a 'one-stop solution' for users involved in GaN semiconductor applications.

As part of the agreement, SAMCO will purchase and install a GaN-550 MOCVD system in its facility in Kyoto for customer demonstrations. Installation is planned for July and the system will be used to develop novel power device epitaxial structures on large-diameter wafers in collaboration with a key customer.

"Our MOCVD system complements SAMCO's existing product range and creates a unique suite of products for the GaN semiconductor community," VPE's CEO & founder Frank Campanale.

www.samcointl.com
www.valenceprocess.com

SPTS named Company of the Year

Plasma etch, deposition and thermal wafer processing equipment maker SPTS Technologies Ltd of Newport, UK was named both Exporter and Company of the Year at the annual ESTnet Awards. The event honors prominent businesses and individuals in the Welsh electronics and high-technology industry.

ESTnet is a network representing electronic and software technologies enterprises in Wales, created to form strong business relationships, exchange knowledge and share ideas. Edwina Hart, Minister for Economy, Science and Transport, was at the gala dinner in Cardiff.

Also, test engineer Matt Hill, who started with SPTS as an apprentice, reached the final three in the category 'young engineer of the year'.

"There is a real wealth of talent in the industry in Wales and the ESTnet Awards program further raised the profile of the sector and celebrated its key achievements," says ESTnet's managing director Avril Lewis. SPTS "has the drive, passion and the vision to make their business a success," she comments.

"We have worked hard to maintain our market-leading position through constant technological innovation, while earning extraordinary customer loyalty," says SPTS' president & chief operating officer Kevin Crofton.

www.estnet.uk.net

University of Washington selects Altatech's CVD system

Altatech Semiconductor S.A. of Montbonnot, near Grenoble, France (a subsidiary of Soitec since January 2012) has received an order from the University of Washington in Seattle for an AltaCVD chemical vapor deposition (CVD) system, whose unique combination of capabilities allows users to develop new process materials, says the firm.

The CVD system will be installed at the university's Washington Nanofabrication Facility (WNF), a full-service user facility that is a part of the National Nanotechnology Infrastructure Network (NNIN). It will be used by both internal and external researchers to fabricate devices including CMOS transistors, micro-electro-mechanical systems (MEMS), ICs built with the latest in through-silicon-via (TSV) technology, advanced LEDs, and solar cells.

Altatech's pulsed CVD systems are used in R&D and pilot-production facilities throughout Europe. However, the new order represents the first system to be delivered to a North American university R&D and pilot-production facility. The AltaCVD system, along with the university's recent installations of an advanced deep reactive-ion etcher (DRIE) and a plasma-enhanced CVD (PECVD) tool, enables the assembly of an electroplated TSV fill process.

"The AltaCVD system provides a unique capability that enables researchers to deposit conformal metal films for TSV applications as well as metal oxides and nitrides for high-k dielectrics and piezoelectric materials," comments Dr Michael Khbeis, acting director of the WNF. "The higher deposition rate enabled by pulsed CVD makes ALD (atomic layer deposition) films a tractable solution for scale-up paths toward high-volume manufacturing for our researchers and industrial clients. This ensures a viable pathway from academia to real economic impact in our region," he adds.

"Extending the use of our CVD systems into this acclaimed user facility in North America continues to demonstrate the widely recognized advantages of our pulsed deposition technology," claims Altatech's general manager Jean-Luc Delcarri.

Altatech will support its AltaCVD installation at the University of Washington from its US-based business & service operation center.

The AltaCVD system uses pulsed deposition technology to offer what is claimed to be a unique combination of capabilities for developing new materials. It can perform ALD for 3D coverage at deposition rates matching those of more conventional CVD techniques, allowing superior stoichiometry control while creating highly conformal thin and thick films, which cannot be achieved using many existing technologies, it is claimed.

www.altatech-sc.com

https://www.wnf.washington.edu

SEMI-GAS expands GigaGuard GSM controller with PLC control for 6-, 7- and 8-stick gas distribution systems

SEMI-GAS Systems, a division of Applied Energy Systems Inc of Malvern, PA, USA and a manufacturer of high-purity gas source and distribution systems, has expanded the capabilities of its GigaGuard GSM controller to include programmable logic control (PLC) operation of 6-, 7- and 8-stick gas distribution systems, providing fully automatic purging capability and gas management from a single source to multiple points of use, as needed in semiconductor and LED manufacturing.

Used in conjunction with the SEMI-GAS Nanoturion valve manifold box, the GigaGuard GSM controller is designed for the safe and continuous distribution of hazardous process gases. It supersedes the previous model with modern PLC technology and enhances the GigaGuard GSM line of semi-automatic and fully automatic distribution controllers.

The adaptable new controller offers adjustable alarm set points and user-configurable inputs and outputs to maximize customization for each application. It also features a 4.3" color touch-screen with software prompts and alarms, helping to reduce operator error and increase safety, the company adds.

The GigaGuard independently operates ESO valves, monitors analog and digital process sensors, displays delivery pressures, maintains alarm logs, and continuously monitors system operations for hazardous conditions. For added safety, both local and remote system shutdown capabilities are incorporated in the event of an alarm trip.

All GigaGuard controllers meet SEMI S2, SEMI S8 and uniform fire code requirements, as required for the safe handling of hazardous process gases. The controller enclosure is constructed of 16-gauge steel and includes a SEMI-approved EMO (emergency off) button and multi-color LED panel status lights. A flip-down door provides access to controller components, including the Siemens S7-1200 series PLC.

"The new GigaGuard controller offers a dramatic upgrade in performance, versatility and value compared to the previous version," says SEMI-GAS Systems' division manager Jim Murphy.

www.semi-gas.com

IN BRIEF

Altatech's Orion LedMax wafer inspection/metrology tool for Osram

Altatech of Montbonnot, near Grenoble, France (a subsidiary of Soitec since January 2012) has received an order for its Orion LedMax wafer inspection and metrology system from Osram Opto Semiconductors GmbH of Regensburg, Germany.

Osram will use the tool to improve the performance, cost efficiency and yield of its LED processing operations. Suitable for both volume manufacturing and R&D applications, the inspection system will perform production control and new product qualification of Osram's epiwafers used in fabricating LEDs.

Capable of inspecting wafers from 4" to 8" in diameter, the Orion system combines the diverse capabilities of 2D inspection, defect height measurement and dark-field inspection in one platform, producing what are claimed to be the industry's most thorough wafer-metrology results. The tool generates more information than just diffracted light signature, identifying potentially critical defects amid noisy backgrounds, providing superior matching performance and reducing maintenance costs, it is claimed.

Orion offers the full range of inspection and metrology capabilities for front-end manufacturing process flows including incoming wafer qualification, process development and line monitoring. Proprietary Orion modules are designed to conduct front-side and back side surface inspection, edge inspection, bump and TSV (through-silicon via) metrology by detecting, counting and classifying defects on patterned and unpatterned wafers.

www.altatech-sc.com

Obducat launches 2nd-generation mass-production nanoimprint lithography system

Obducat's SINDRE 400 G2 system.

Obducat AB of Lund, Sweden, a developer and supplier of technologies, products and processes based on proprietary nanoimprint litho-graphy (NIL), has launched the second-generation SINDRE system which, due to improved performance, will be the most cost-effective NIL production solution on the market, it is claimed. The system is based on Obducat's patented SoftPress, Intermediate Polymer Stamp (IPS) and Simultaneous Thermal and UV (STU) technologies.

The fully automated SINDRE system, which enables throughputs of up to 60 wafers per hour, provides what is claimed to be state-of-the-art performance combined with industry-leading cost of ownership (CoO). The new SINDRE integrates the latest advances in manufacturing technology, enabling high throughput and high repeatability at a defectivity level that surpass industry requirements. The first system has already been delivered and passed customer final approval in January. The next system will be delivered in third-quarter 2014.

The new SINDRE platform is a fully integrated NIL system that includes integrated fabrication of the intermediate polymer stamp. Obducat says that this is a proven and reliable process that was also integrated in the previous generation of SINDRE systems delivered over the last five years. The patented IPS technology covers the use of a transparent flexible stamp in any kind of imprint process. IPS ensures a long life-time of the stampers, minimizing stamp-related costs per imprint. The unique SoftPress technology ensures the necessary level of conformity between the stamp and substrate vital for establishing high imprint uniformity, says the firm. This enables a large process window for downstream processes, leading to high yield and low CoO. All this has been integrated into a compact system with a small footprint.

The new system also offers wide flexibility, including the possibility of using different resists and IPS materials to support customization of the imprint process. Additionally, it can run both UV- as well as thermal-based NIL processes, giving the capability to imprint structure sizes from 20nm upwards, on substrate sizes up to 200mm in diameter. "The versatility and superior performance of our patented key technologies has been extended further," says chief technology officer Babak Heidari.

Example of components that can be produced using the system are optical, photonic, LED, fluidic and other biomedical components. "With more than 130 NIL systems delivered during the last decade and several of these being used for manufacturing purposes in LEDs, photonics and biomedical applications, we are breaking new barriers in terms of performance and cost efficiency" reckons CEO Patrik Lundström.

www.obducat.com

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Luminus appoints former Bridgelux chief sales & marketing officer as its executive VP of sales & marketing

Luminus Devices Inc of Billerica, MA, USA, which makes PhlatLight (photonic lattice) LEDs for solid-state lighting (SSL) applications, has appointed Jim Miller as executive VP of sales & marketing.

Prior to joining Luminus, Miller was chief sales & marketing officer at Bridgelux, which experienced strong revenue and market expansion under his leadership. He was also president & CEO of TerraLUX Inc, and was an integral part of establishing the firm and securing early-stage venture capital financing to fuel its growth. Previously, Miller was VP of global geographic sales at Philips Lumileds, responsible for worldwide sales of all SSL illumination products.

"Luminus is a company that is poised for tremendous growth," says Miller. "The new illumination COB [chip-on-board] products represent best-in-class performance and greatly increase the portfolio of the company," he adds.

Miller attended the Light + Building 2014 tradefair in Frankfurt, Germany (30 March—4 April), where Luminus exhibited its latest new products.

www.luminus.com

Luminus launches XNOVA mid-power LED product line for replacement lamps and luminaires

At the Light + Building 2014 tradefair in Frankfurt, Germany (30 March–4 April), Luminus Devices Inc of Billerica, MA, USA, which makes PhlatLight (photonic lattice) LEDs for solid-state lighting (SSL) applications, announced the release to mass production of its new XNOVA line of mid-power LEDs developed for the general lighting market.

XNOVA mid-power LEDs are targeted at high-growth lighting applications ranging from linear T8 lamps to diffused panel lighting and replacement lamps and luminaires. The new product line consists of the 2016, 3014, 3020 and 3030 platforms, with nominal input powers ranging from 0.18W to 0.93W and corresponding flux output from 22 lumens to 107 lumens.

XNOVA mid-power LEDs achieve luminous efficacy of 130+ lumens per watt (LPW) at nominal test conditions, and 170+ LPW at lower input power. The products span the ANSI color gamut from 2700–6500K, with standard minimum color rendering index (CRI) of 70 and 80. In addition, Luminus is offering each mid-power platform in a high-CRI configuration of 90+ for applications that require the highest color quality for demanding illumination applications.

"Mid-power LEDs are becoming broadly accepted in general lighting and Luminus is taking a leadership position with this launch to address the most demanding applications," says Dr Decai Sun, chairman & CEO of Luminus Devices. "Luminus continues to invest in market-leading light-source solutions for the highest-growth illumination market segments," he adds. Luminus previously launched XNOVA white chip-on-board (COB) LEDs in late February.

www.luminus.com/products

Luminus XNOVA COB LEDs achieve 145lm/W at 5000K

Luminus Devices Inc of Billerica, MA, USA, which makes PhlatLight (photonic lattice) LEDs for solid-state lighting (SSL) applications, says that its flagship XNOVA white chip-on-board (COB) products reached full mass production while setting another benchmark with industry-leading efficacy for both cool and warm white. Typical performance was measured at up to 145lm/W at 5000K, and 132lm/W for 3000K at room temperature. Hot lumens per Watt at 85C, a more representative view of what customers can expect in real-life conditions, attained a remarkable 134lm /W at 5000K and 122lm/W at 3000K.

The XNOVA COB LED portfolio offers a wide range of devices with Light Emitting Surface (LES) from 6mm to 27mm. Products are currently available with 80, 90 or 95 minimum CRI and color temperatures of 2700K, 3000K, 3500K,4000K, 5000K, with 6500K launching next month. In addition, devices with AccuWhite technology combine a high color rendering with high efficacy and are ideal for directional lighting applications in commercial, retail and hospitality markets.

"Our LED portfolio has a solution for virtually every directional application from 300 lm MR-16s to over 10,000lm commercial lighting fixtures," says Stephane Bellosguardo, VP of global marketing. "COBs are one of the fastest-growing technologies in global lighting markets. Each XNOVA COB product achieves top metrics for its target applications enabling lighting equipment designers to create cost-effective yet innovative products whether targeting commercial or residential markets," Bellosguardo adds.

www.luminus.com

Epistar extends LED collaborative development program and IP licensing agreement with Intermolecular

LED chipmaker Epistar Corp of Hsinchu, Taiwan and Intermolecular Inc of San Jose, CA, USA have signed a multi-year extension of their existing collaborative development program (CDP) and royalty-bearing IP licensing agreement of April 2013 to increase the efficiency and reduce the cost of Epistar's LEDs.

Under the terms of the agreement, the firms' engineers will continue to work together to leverage Intermolecular's proprietary high-productivity combinatorial (HPC) technology platform to accelerate development and manufacturing qualification of novel materials and processes for advanced LED products.

Founded in 2004, Intermolecular says it has pioneered a proprietary approach to accelerate research and development, innovation, and time-to-market for the semiconductor and clean energy industries. The approach consists of its HPC platform, application-specific workflows and its multi-disciplinary team. Through paid collaborative development programs with customers, Intermolecular develops proprietary technology and intellectual property for its customers focused on advanced materials, processes, integration and device architectures. Intermolecular's aim is to improve R&D efficiency in the semiconductor and clean energy industries through collaborations that use its HPC platform, which allows R&D experimentation to be performed at speeds up to 100 times faster than traditional methods.

"Epistar is leveraging Intermolecular's HPC methodology and technology in order to accelerate R&D experimentation as we bring more advanced, higher-performing LED devices to market," says Carson Hsieh, Epistar's vice president of R&D. "Our CDP with Intermolecular helped to significantly increase the performance of one of our LED products during development, and we are now in the process of implementing that technology in production. In the coming years we expect our continuing relationship with Intermolecular to support further advancements in our technology roadmap," he adds.

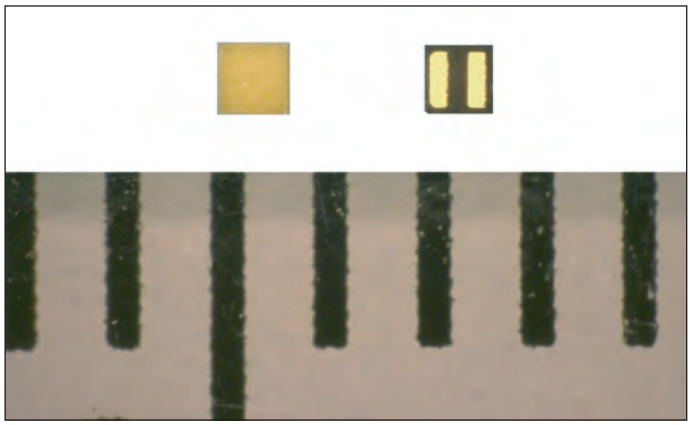
"Increasing LED efficiency is the key to reducing LED system cost and enabling widespread adoption of more innovative lighting products," says Sandeep Nijhawan, senior VP & general manager, Clean Energy Group at Intermolecular. The multi-year agreement extension will support Epistar's product innovation strategy through accelerated materials development and LED device integration, he adds.

www.epistar.com.tw
www.intermolecular.com

Toshiba launches chip-scale package white LEDs for lighting applications, cutting mounting area by 90%

Tokyo-based semiconductor manufacturer Toshiba Corp has launched ultra-small chip-scale-package (CSP) white LEDs for lighting applications that can reduce the mounting area by 90% compared to conventional 3.0mm x 1.4mm packaged products, the firm reckons.

The new products use gallium nitride-on-silicon (GaN-on-Si) and a new process technology that fabricates the elements of a packaged LED on an 8-inch silicon wafer. With a package size of just 0.65mm x 0.65mm, the LEDs are reckoned to be the industry's smallest in the sub-watt class (¼W–½W) of white LEDs. However, they achieve luminous efficacy of 130lm/W (during 60mA operation) and what is claimed to be superior heat dissipation. Maximum forward current is 180mA. The color temperature is 5000K and the color rendering index (Ra) is 80 (minimum). Other planned color variants include 4000K, 3000K and 2700K.



Toshiba's chip-scale-package white LEDs.

Using the new white LEDs makes it possible to achieve a narrow beam in small-size lighting equipment, says Toshiba. Applications of the TL1WK series LEDs are light sources for general lighting, including straight tube lights, light bulbs and ceiling lights.

The TL1WK series LEDs are being showcased at the Light+Building 2014 trade fair in Frankfurt, Germany (30 March to 4 April). Sample shipments began in April.

www.semicon.toshiba.co.jp/eng

Lextar debuts packaging-free White Chip LED

At the Light + Building 2014 tradefair in Frankfurt, Germany (30 March–4 April), Lextar Electronics Corp of Hsinchu Science Park, Taiwan — founded in 2008 as a subsidiary of display panel maker AU Optronics (AUO) — has debuted its packaging-free White Chip LED, exhibited in various LED lighting applications including a 50-Watt halogen-equivalent GU10 LED spot lamp, a point-light candle lamp, and an omni-directional LED tube with ultra-high efficiency (demonstrating the synergy of the firm's vertical integration of LED epiwafer, chip and package operations, as well as lighting products.).

Lextar's new White Chip technology involves a substrate-free flip-chip and phosphor molding process, and can be fabricated using existing surface-mount technology (SMT) equipment (features that can significantly simplify the manufacturing process, says the firm). White Chip is a chip-scale die without a packaging process, featuring high lumen densities, high lumen output, wide beam angle. Also, it can be packaged closer, simplifying optical lens design, claims Lextar. White Chip can be applied to lighting products, especially small sized lamps such as spot or candle lamps. It can also be applied to backlighting, helping to reduce the thickness of direct-lit backlight modules.

Since LED companies have been eager in the last few years to develop simplified manufacturing process with reduced costs, flip-chip and several packaging-free LED products are becoming more popular

Lextar says that, when used in GU10 spot lamps, the White Chip can achieve high lumen output and high lumen intensity, reaching up to 2500cd at 25° with a high color rendering index (CRI) of 90, making it a suitable replacement for a 50-watt halogen lamp.

The White Chip also gives the firm's point-light candle lamp identically glowing effects to starlight, claims Lextar. Moreover, the firm's light tube — equipped with the White Chip and chip-on-glass (COG) technology — enables 360° illumination, reaching luminous efficiency of 200 lumens per watt.

Since LED companies have been eager in the last few years to develop simplified manufacturing process with reduced costs, flip-chip and several packaging-free LED products are becoming more popular, says Dr Reg Tsai, director of Lextar's Technology R&D Division. The firm says that, due to its vertical integration, Lextar can provide products and services through various stages from upstream chips to finished lighting products. The firm expects to transition its new White Chip technology into the market in second-quarter 2014.

www.lextar.com

www.light-building.messefrankfurt.com

Bridgelux unveils exterior and industrial LED sub-system as high-pressure sodium lamp replacement

Bridgelux Inc of Livermore, CA, USA, a vertically integrated manufacturer of solid-state light sources for lighting applications, has unveiled the Outdoor Lighting Module (OLM); a new line of LED sub-systems that integrates optics, environmental protection and the LED source for roadways, parking garages and other outdoor and industrial applications. The OLM aims to allow manufacturers to rapidly expand their product lines while lowering costs.

Outdoor applications, including roadways, parking lots and flood lighting, are some of the fastest-growing segments in the industry. According to McKinsey & Company, LED-based outdoor lighting solutions are expected to grow from 6% of the market ($10bn) to 74% by 2020.

Bridgelux says that the new OLM Series incorporates technology advances and features that will help luminaire manufacturers develop a broad range of differentiated outdoor lighting products with lower total costs, faster time to market, and energy efficacy.

The OLM Series is a platform that integrates fundamental components for building solid-state luminaires into a single sub-system. Bridgelux reckons that it reduces product development time by 3–6 months, eliminating up to $100,000 in R&D expenses. Building solid-state fixtures with OLM can reduce manufacturing time by 5–7 days, it adds.

Bridgelux's new Outdoor Lighting Module

Compared to conventional high-pressure sodium systems, OLM can reduce the manufacturing cost of outdoor solid-state lighting fixtures by 10–20%, and reduce maintenance costs while lowering power consumption by up to 65%, claims the firm. Also, OLM has been specifically designed to enable lighting manufacturers to reduce the overall bill of material (BoM) cost of their luminaires.

The OLM's slim profile, impact-resistant optics, and broad area lighting capabilities make it a suitable platform for outdoor wall pack and flood light applications. Designed to be compliant with key light pattern standards (IESNA, EN13-201, NEMA), the sub-system also has an Ingress Protection (IP) rating of 66; making it suitable for harsh outdoor environments.

Bridgelux says that its proprietary integrated symmetric and asymmetric optics enable lighting manufacturers to design luminaires for targeted applications that spread light in more effective and efficient ways. OLM-based fixtures can also be designed into applications with specific lighting pattern requirements such as glare reduction and dark sky, it adds.

The firm is initially launching six OLM subsystems ranging in power from 18 to 40 watts and estimated product lifetimes of 50,000–100,000 hours. They will be commercially available in June, with pre-orders being accepted now.

Bridgelux demonstrated the OLM at the Light + Building 2014 tradeshow in Frankfurt, Germany (30 March–4 April).

www.bridgelux.com/products/olm-series

Bridgelux announces world's first 10-year warranty for chip-on-board LED light sources

Bridgelux says that its new Vero Series LED array light source will be backed with what it claims is the world's first 10-year warranty for chip-on-board (COB) products, reflecting the lifespan of LED lighting.

In 2010, Bridgelux was the first company to introduce a 5-year warranty for COB products. The new 10-year warranty applies to Vero Series LED arrays shipped on or after 16 April 2014.

The announcement was made at the Light + Building 2014 tradefair in Frankfurt, Germany (30 March–4 April), where Bridgelux has introduced the OLM Series integrated subsystem for outdoor applications as well as several new CCT and CRI combinations available for its Vero Series LED product line. The firm says that its Vero Series LED array portfolio gives manufacturers the flexibility to develop and manufacture light solutions tailored for specific applications, delivering the light output and color temperatures required for retail, hospitality, commercial, industrial, residential and outdoor lighting applications.

For example, Vero Series LED arrays can be used to create fixtures that deliver ultra-white light for surgical theaters and healthcare facilities, or cool-white ultra-high-CRI light combinations for television studios. Vero Series products can also be used to tune color temperatures for bakery, grocery, deli or textile displays.

Also at Light + Building 2014, Bridgelux showcased new Zhaga options for the Vero Series LED arrays, further enhancing its compatibility and flexibility with Zhaga-based luminaries worldwide.

SemiLEDs' quarterly revenue rebounds by 22%

Margins to improve as acquired LED packaging line boosts higher-ASP component revenue

For its fiscal second-quarter 2014 (to end-February), LED chip and component maker SemiLEDs Corp of Hsinchu, Taiwan has reported revenue of $4.2m, down 12.5% on $4.8m a year ago but rebounding by 22% from $3.4m last quarter.

Revenue from LED chips rose by 117% sequentially (jumping from 29% of total revenue last quarter to 51%). Revenue from LED components rose by 6% (falling from 34% to 30% of total revenue). Revenue from lighting products fell by 43% (dropping from 36% to 17% of total revenue).

"We are pleased with the sequential revenue growth we achieved in the quarter, however we continue to take actions to reduce our cost and lower our negative cash flow while reorienting the business toward more profitable and specialty segments of the industry, such as UV, entertainment and architecture," says chairman, president & CEO Trung Doan.

Gross margin was –75%, worsening from – 68% last quarter, due mainly to inventory write-downs as a result of increasing pressure on average selling prices (ASPs) for the firm's LED chips plus excess capacity charges. Despite this, operating margin has improved slightly, from –179% last quarter to –159%. While R&D expenses remained steady at $1.1–1.2m, selling, general & administrative (SG&A) expenses have been cut further, from $2.6m last quarter to $2.3m, due mainly to reduced professional service expenses. Total operating expenses have hence fallen further, from $3.8m last quarter to $3.5m.

On a non-GAAP basis, net loss was $5.9m, up slightly from $5.8m last quarter (compared with the slight drop that was expected).

Cash used in operating activities has been cut from $5.4m last quarter to $4.2m. Despite capital expenditure almost doubling from $0.48m to $0.93m, total free cash outflow has been cut from $5.9m to $5.1m. During the quarter, cash and cash equivalents fell from $28.1m to $21.5m, following final payment of $443,000 in December on the purchase in fiscal Q4/2013 of an LED component production line and related products and technology (for which a partial payment of $1.6m had already been made last quarter).

For fiscal third-quarter 2014, SemiLEDs expects revenue of $4.3–4.8m. Gross margin should remain negative, as production capacity will again not be fully utilized. Net loss is expected to rise again.

"With the recent acquisition of an LED packaging production line and associated new LED component products and technology now behind us, we expect to see greater contribution from component revenue in the quarters ahead," says Doan.

"Our packaged products carry higher ASPs and generally higher margins than our chip products which, as product mix changes over time, should drive higher overall corporate margins," he notes.

In addition, in mid-March SemiLEDs launched its new EV-W series of white LED chips, which incorporate the firm's proprietary ReadyWhite phosphor technology. "ReadyWhite technology delivers a highly uniform phosphor coating across the chip emitter surface, greatly increasing color precision and uniformity while eliminating the phosphor application from the packaging process," says Doan. "As a result, the availability of high-output, high-consistency unpackaged white chips offers LED packaging and luminaire manufacturers a wide variety of new chip on board (COB) and package options," he adds.

"As we continue to develop new innovative products and design wins in specialty markets such as UV applications, entertainment and architecture, we expect to grow our volumes, and improve our margins," says Doan. "Taken in combination, we believe the new component product offerings, advances in phosphor technology through our ReadyWhite technology and our focus on specialty markets will improve our financial results."

www.semileds.com

Soraa's full-visible-spectrum MR16 lamps gain ENERGY STAR label

Soraa Inc of Fremont, CA, USA, which develops solid-state lighting technology built on 'GaN on GaN' (gallium nitride on gallium nitride) substrates, says that eight of its MR16 products have been recognized with the ENERGY STAR qualification from the Environmental Protection Agency (EPA), the first full-visible-spectrum LEDs to attain this qualification. The ENERGY STAR label certifies that Soraa's MR16 products have met the stringent energy-efficiency standards and performance criteria established by the EPA.

Soraa's MR16 lamp

Soraa products already qualify for a wide range of rebate programs based on their color rendering and energy efficiency. With the ENERGY STAR label, the LED lamps now qualify for additional utility rebate programs nationwide.

Soraa will roll out its full portfolio of full-visible-spectrum products through the rest of 2014.

www.soraa.com

Lumileds unveils chip-on-board LED arrays for PAR38-equivalent lamps and spotlights

Philips Lumileds of San Jose, CA, USA has unveiled chip-on-board (CoB) arrays for PAR38-equivalent lamps that reach 10% or greater efficacy than competing solutions, it claims. Also suitable for spotlights, the LUXEON CoB 1202 has efficacy of 115lm/W typically, varying from 95–130lm/W depending on the array's correlated color temperature (CCT) and color rendering index (CRI).

"The high efficacy, combined with our lineup of compatible reflectors and drivers, enables the most affordable PAR38 and spotlight designs to date," reckons product line director Eric Senders.

The LUXEON CoB 1202 completes Lumileds' portfolio for PAR lamps.

LUXEON COB 1202 LED array

Together with the LUXEON CoB 1203, the 9mm Light-Emitting Surface (LES) versions are optimal best in price/performance for directional retrofit lamps, the firm claims. Due to the CoB 1202's mechanical and optical compatibility with the 1203, the same ecosystem can be used to create a highly efficient and cost-effective solution, Lumileds adds.

The performance range of the CoB 1202 arrays is 95-130lm/W over a range of CCTs of 2700-5700K at a CRI of 70, 80 or >90. Typical output for warm white (3000K, 80 CRI) is 800lm when driven at a current of 200mA. The warm-white arrays can be driven at up to 400mA to achieve a flux of 1500 lumens. The high-CRI (>90) versions deliver an R9 of >80 for demanding applications such as retail downlights and spotlights.

www.philipslumileds.com/LUXEONCoB

Flux and efficacy of LUXEON 3535 2D mid-power LED boosted 10%

As part of its 'Mid-Power March' series of product announcements, Lumileds said that its LUXEON 3535 2D mid-power LED (launched in May 2013) has had its typical flux output boosted by 10%, delivering optimized performance in combination with the quality of light needed for distributed light source applications.

For LUXEON 3535 2D parts with a correlated color temperature (CCT) of 2700K and color rendering index (CRI) of 90, typical flux levels have increased from 55lm to 61lm. Also, typical voltage has been lowered, boosting luminous efficacy more than 10%. Lumileds reckons that this performance increase will drive adoption of LED lighting for consumer bulbs, by providing the color quality to which consumers are accustomed with their lamps.

This is in line with Lumileds' targeted improvements in flux and efficacy for 90-CRI warm-white LEDs. Developed to address the rapidly growing market for high-color-rendering light sources, this boost in performance of 90-CRI warm-white emitters mimics the color quality of traditional incandescent bulbs. Increasingly, customers seeking retrofit lamp solutions are specifying a minimum of 90 CRI, says Lumileds. For example, the California Energy Commission (CEC) is requiring minimum CRI of 90 and R9 of 50 for light fixtures installed in California.

www.philipslumileds.com/LUXEON35352D

Lumileds boosts LUXEON Z ES LED flux by 18%

Lumileds says that, with newly improved efficacy and precise optical control, its LUXEON Z ES LED (first introduced in March 2013) is now a better choice for applications requiring tight beam angles such as spotlights, downlights, retrofit lamps and outdoor streetlights.

Measuring only 1.6mm x 2.0mm in size and hence 75% smaller than a standard 3535 package, the LUXEON Z ES features an undomed design that enables close packing density in space-constrained applications. "The small size of the LED allows 25% smaller optics, thereby reducing the overall cost of the application without sacrificing performance," says product marketing manager Jennifer Holland, LEED AP. "We simultaneously achieve greater luminance and punch from our high-density high-power emitter."

In addition to upgraded performance across the existing portfolio, Lumileds has introduced new emitters with correlated color temperatures (CCTs) of 4000K and 5700K and color rendering index (CRI) in the 90 range to address needs in stadium and museum lighting.

Color consistency of the Z ES is ensured by the emitters' 5-, 3- and first-ever 1-step MacAdam Ellipse binning options. "Designers can select color consistency based on the demands of their specific application," adds Holland.

The LUXEON Z ES emitters are now available across a broad range of CCTs at 70, 80 and 90 CRI

www.philipslumileds.com/LUXEONZES

Cree's quarterly revenue grows 16% year-on-year to $405m, driven by 35% growth in lighting products

CapEx target raised again to support new-product capacity

For fiscal third-quarter 2014 (to end-March), LED chip, lamp and lighting maker Cree Inc of Durham, NC, USA has reported revenue of $405.3m, down 2.4% on $415.1m last quarter but up 16% on $348.9m a year ago.

Specifically, by product sector:

- Power & RF product revenue was $27.4m, up 4% on $26.4m last quarter and 21% on $22.7m a year ago (remaining about 7% of total revenue). After rising to 58% last quarter, Power & RF product gross margin has fallen to 57.1%, although this is still up on 53% a year ago due to higher sales, cost reductions and higher factory utilization.
- LED product revenue (LED components, LED chips and SiC materials) was $201m, down 6.5% on $215m last quarter but up 3% on $195.6m a year ago (though still falling from 56% of total revenue to 49%). LED product gross margin has risen further, from 43.8% a year ago and 45.4% last quarter to 45.6%, due to a combination of higher sales, lower-cost new products, cost reductions and higher factory utilization.
- Lighting product revenue was $176.7m, up 1.7% on $173.7m last quarter and 35% on $130.7m a year ago (rising from 37% of total revenue to 44%), driven by double-digit growth in lighting fixtures. After rising to 27.9% last quarter, Lighting product gross margin has fallen to 27.4% (down on 30.6% a year ago), slightly below target as LED bulb price reductions offset a more favorable product mix. LED bulb cost reductions that support the lower price points have already being implemented and are targeted to benefit fiscal Q4.

Overall gross margin (on a non-GAAP basis) has fallen further, from 38.8% a year ago and 38.2% last quarter to 37.8% (rather than the expected rise to 38.5%). Operating expenses were about $100m.

Net income was $47.7m, down from $56.8m last quarter but up from $40.8m a year ago.

Cash from operations was $60.2m, down from $98.8m last quarter but up on $45.8m a year ago. However, after rising to $49.8m last quarter, capital expenditures (for property, plant and equipment) have fallen back to $36.2m (again, excluding about $5m related to patents). Hence, free cash flow rose fell back from $43.7m to $19.3m (though still up on $15m a year ago).

During the quarter, cash and investments rose by $39m to $1.2bn, which "puts us in a great position to increase the level of capacity investments over the next year," says chairman & CEO Chuck Swoboda. For fiscal 2014, Cree has raised its property, plant & equipment (PPE) expenditure target again, from $145m to $175m (after raising the target from $120m just last quarter), in order to support new-product priorities and to provide incremental capacity, as needed, primarily to make capacity investments to support forecasted growth over the next year and infrastructure investments to support longer-term forecasted growth," Swoboda adds.

"Fiscal Q3 was a solid quarter as revenue and operating income were in line with our target range and the business is well positioned to grow in fiscal Q4," says Swoboda. "These results once again demonstrate our ability to deliver strong operating results while continuing to make longer-term investments in new technology."

"Factory utilization remains high; we're expanding capacity in the short term and making investments for the mid to longer term," says Swoboda. "Execution is a critical factor to supporting growth in all three product lines, which continue to operate with short lead times," he adds. "We're raising our inventory days on hand target from 80 to 90 days to reflect the increased lighting mix as we plan greater flexibility to support our quick-ship program and better service our sales channels."

For fiscal fourth-quarter 2014 (ending 29 June), Cree targets revenue growth to $430–460m, with growth in all three product segments, led by double-digit growth in lighting in both LED fixtures and LED bulbs, single-digit growth in LED products, and slightly higher Power & RF sales. Gross margin is expected to fall slightly to 37.5%. Operating expenses should rise by $7m, due mainly to the higher sales cost associated with higher targeted revenue, the marketing cost to support two major lighting trade shows within the quarter, increased patent-related legal cost, and a slight increase to Cree brand spending. Even with the increased investment, Cree targets operating profit to grow sequentially faster than sales. Net income should be $46.5–54.6m.

"We continue to take advantage of the global shift to LED lighting and our strategy to use new product innovation to drive our growth by taking share from traditional technologies," says Swoboda.

"We are also in the process of working at potential strategic opportunities to expand the Cree product portfolio and gain access to new customers," says Swoboda. "Some opportunities may emerge over the next 24 months to leverage the Cree brand as the shift to new technology accelerates and industry begins to go through a consolidation phase," he adds. "The strength of our operating model gives us the flexibility to make these investments and continue to maintain a strong balance sheet to support the future growth as we remain focused on our long-term customer goal of a 100% upgrade to LED lighting.

www.cree.com

Cree launches first 8000lm LED module, enabling replacement of 150W CMH lamps

LED chip, lamp and lighting maker Cree Inc of Durham, NC, USA has launched what it claims is the first 8000 lumen LED module.

The 8000 lumen LMH2 LED module is designed to replace 150-watt ceramic metal halide (CMH) lamps in high-ceiling applications while using only 63% the power and lasting three times as long. Cree claims that its LMH2 LED module family now offers the industry's greatest range of lumen output from a single form factor, making it possible to obsolete CMH technology.

"The new Cree 8000 lumen LMH2 module allows us to effectively address high-ceiling, high- lumen applications without having to sacrifice color quality or reliability," comments Wesley Johnson, product manager of lighting firm Hi-Lite Manufacturing Company of Chino, CA, USA. "We can now easily offer our customers better lighting solutions to replace 150-watt ceramic metal halide lamps in spaces such as convention centers, airports, auditoriums and shopping malls," he adds.

The LMH2 LED Module family provides an extensive range of light output (850–8000lm) from a single light source, enabling lighting manufacturers to quickly develop an entire product portfolio with just one set of tooling and optical design, says Cree. Lighting designers can now use one light source and technology to illuminate an entire space, and avoid problems such as color inconsistency and re-lamping, it adds.

"Having an 8000 lumen option in the LMH2 LED module family gives us the flexibility to create an entire product family from a single form factor," comments Chris Roemlein, president of Spectrum Lighting Inc of Fall River, MA, USA. "Cree's ability to increase the performance of the LMH2 module allows us to address a wide range of ceiling heights with minimal design investment."

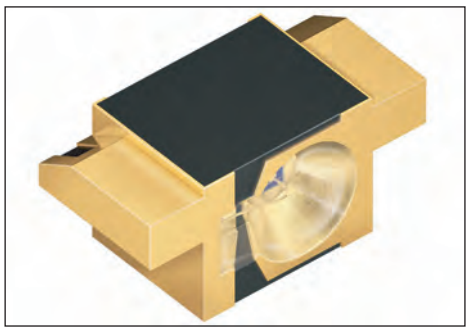
Cree exhibited the LMH2 LED module family at the Light+Building 2014 trade fair in Frankfurt, Germany (30 March – 4 April). Samples and production quantities are available with standard lead times from distributors.

www.cree.com/lmh2

Osram unveils first flush-mountable infrared LED, giving smartphones and tablets remote control functionality

Osram Opto Semiconductors GmbH of Regensburg, Germany has unveiled what it claims is the first flush-mountable infrared LED, enabling remote control functionality to be incorporated in a lower profile than ever before. The compact (3.1mm x 1.5mm x 1.5mm) side-looking T-shaped SFH 4140 Midled offers high radiant intensity and protrudes only fractions of a millimeter from a 0.3mm-thick board. An IR transmitter can therefore now be integrated in extra-thin smartphones or tablet computers.

Osram has succeeded in sinking a surface-mountable infrared LED in a printed-circuit board for the first time. "We want to enable our customers to install a powerful infrared transmitter even if there is very little height in the device to work with," says Bianka Schnabel, who is responsible for the product at Osram Opto. "We have therefore developed a transmitter that disappears almost entirely into the board. Only 0.6mm extends above and below the board. That saves plenty of height."



Osram's T-shaped Midled SFH 4140.

High output from extremely small space

The T-shaped transmitter takes up only 4.6mm^2 of board space and emits a powerful focused beam to the side. The beam angle of ±25° is created by an integrated reflector – an advantage in terms of space requirements. The SFH 4140 produces 50 milliwatts per steradiant (mW/sr) as its typical radiant intensity from a drive current of 100mA, so it achieves the ranges needed for remote control functions. The wavelength of 940nm is also suitable for meeting the requirements of this application.

Smartphones and tablet computers as remote controls

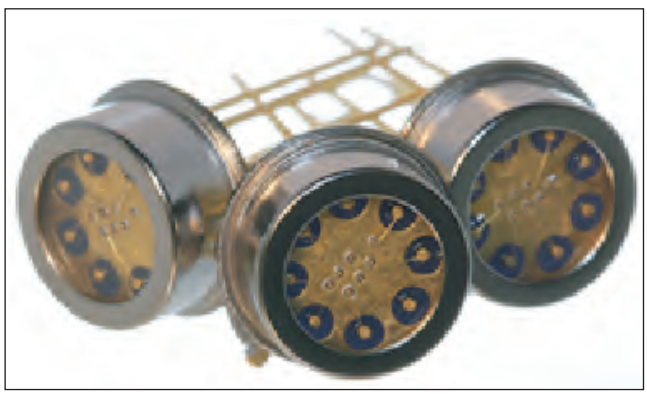
Osram Opto says that the new LED is its contribution to the trend of turning smartphones and tablet computers into universal remote controls, particularly for home entertainment electronics. If the device is equipped with the appropriate IR transmitter diode, then the diode can be controlled with a suitable app. Whereas classic remote controls traditionally use radial infrared LEDs, this option is not attractive for slim smartphones and tablets. These need a low-profile SMT solution that can nevertheless operate over the required distance. Up to now, manufacturers have been using transmitters such as Midled, Mini Midled and Chipled. The T-Midled SFH 4140 is Osram Opto's latest addition to its portfolio of remote control transmitters, providing a no-compromise low-profile solution for which there will almost always be sufficient space, the firm reckons.

www.osram-os.com

Marktech launches multichip emitters and LEDs for illumination purposes, emission and detection

Marktech Optoelectronics of Latham, NY, USA, whose capabilities span wafer growth through finished packaging and custom solutions, has introduced its new line of multichip LEDs.

As electronic products continue to evolve technologically and the push for miniaturization continues, space constraints for electronics continue to be a concern for design engineers. Marktech has long specialized in chip-on-board (COB) solutions, where multiple LED die can be placed into a small space, offering advantages compared with standard packaging. In addition to using COB technology for illumination purposes, emission and detection functions of a sensor application can also be greatly enhanced. With the ability to pack more light emission or light detection chips into an area, performance of the circuit can greatly increase, says Marktech.



Marktech's multichip emitters and LEDs.

The multichip devices are supplied in a variety of packages, including TO-18, PLCC, TO-5 and surface mount. The devices hold anywhere from 2 to 7 die and are available in selected standard die (ultraviolet UV through SWIR short-wave infrared) or can be modified to a customer's specification (including power and wavelength sorting).

The standard multichip LED product is available through Digi-key.

www.marktechopto.com

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The Optoelectronics Company launches direct-emission 520nm green laser diode modules

Optoelectronic component manufacturer and distributor The Optoelectronics Company Ltd of Henham, UK has launched a range of direct-emission 520nm green laser diode modules that are said to offer OEMs and system integrators a realistic, cost- and energy-efficient alternative to low-tech DPSS (diode-pumped solid-state) green laser modules.

Green DPSS laser modules are generally large, expensive and noisy, with low thermal stability. Green light is produced by the cumbersome method of doubling the frequency of an infrared laser.

In contrast, direct-emission green laser diode modules are small, robust and offer power stability over a wide operating temperature up to 50°C. Their high beam quality and low power consumption open up new possibilities as light sources, says the firm.

"By using a low-power, direct-emission green laser, it is possible to achieve the same or better visibility as a high-power red laser diode," says managing director Tony Pope. "This is because the human eye is most sensitive to green light, which appears brighter to the eye than red light of the same output power. This is obviously beneficial when laser safety classifications must be taken into consideration," he adds.

Because green light is more visible than red laser light of the same power output and laser safety class, the green lasers are particularly suitable for outdoor applications. Rangefinders and distance meters, such as those used by builders and surveyors, can be used over longer distances without losing beam quality and coherence.

With what is claimed to be excellent beam quality, the new range of green laser modules is also suitable for optical imaging, and their small package size is advantageous for very compact designs. The new technology makes high colour rendering and contrast very achievable and enables fine details to be displayed, even over large distances, which is of interest to manufacturers of show lasers, says the firm. Other applications include machine vision, biotechnology and spectroscopy.

The green laser diode modules produce a high-quality elliptical beam at 520nm and offer high output stability, with optical output powers of up to 35mW.

With an operating voltage of 9V DC and a broad ambient operating temperature range from –10°C to +50°C, the new laser modules are energy-efficient, requiring an operating current of typically 140mA at 35mW and offering a long lifetime at continuous operation.

Robust and reliable with externally adjustable optics and self-contained drive electronics, the modules are static, surge and reverse-polarity protected and RoHS compliant. Mechanical dimensions are 53mm in length and 12mm in diameter. The housing is anodized aluminium. Electrical connections are made via 300mm external flying leads.

www.oe-company.com

QD Laser launches picosecond pulsed driver board integrated with 1μm-wavelength-range DFB laser modules

At Photonix 2014 in Tokyo, Japan (16–18 April), QD Laser Inc of Kanagawa, Japan has launched a picosecond pulsed driver board integrated with its QLD1x6x series 1μm-wavelength-range (1020–1180nm) 14-pin butterfly distributed feedback (DFB) laser modules. The new QC2D1x6x series driver board is designed to generate 50ps optical pulses with a stable single longitudinal mode.

Recently, many fiber lasers for micro-machining have adopted MOPA (master oscillator power amplifier) systems using directly modulated semiconductor seed lasers with pulses that are highly controllable in shape, width and repetition rate, says QD Laser. In particular, high-quality glazing and marking etc requires picosecond pulses to reduce heat effects on processed materials. The firm says that its QLD1x6x series DFB laser modules, which have a very short optical pulse of 50ps and stable single-mode oscillation, have gained widespread attention, but in addition pulsed driver boards are required to achieve stable, flexible and easy operation of the laser diodes.

Featuring stable 50ps optical pulse generation, a tunable pulse width up to 9ns and continuous-wave (CW) operation, the new QC2D1x6x series can aid the design and development of picosecond fiber lasers, and is suitable for micro-machining, sensing and time-resolved measurement, says the firm. The main features of the new product are as follows:

- peak optical output of 100mW (typical) under 50ps operation;
- a tunable repetition rate of single shot to 250MHz;
- fine wavelength tuning through temperature control of the laser diode chips;
- flexible parameter control via a USB interface; and
- a single +5V power supply.

After providing engineering samples since second-half 2013, QD Laser plans to start mass production of the QC2D1x6x series in first-half 2014.

www.qdlaser.com

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POET adds VP of product development and files strategic patent applications for quantum computing

POET Technologies Inc of Toronto, Canada — which, through 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 announced an addition to its key staff and a rapid expansion of intellectual property (IP) assets. The firm has filed new IP portfolio protection documents with the US Patent and Trademark office (USPTO) and in other key jurisdictions to support strategic applications in POET-based quantum computing.

Daniel DeSimone is joining POET's laboratories as VP, product development. He was most recently senior manager, Test and Wafer Sort Engineering, at Fairchild Semiconductor, where his team achieved significant increases in quality and yield during wafer production in several 0.5μm and 0.35μm CMOS/BiCMOS/bipolar technologies. In addition to manufacturing experience, DeSimone has experience in two distinct areas:

- strategic product roadmap definition, addressing server and storage vertical markets; and
- broad integrated circuit development, encompassing analog mixed-signal through large digital application-specific integrated circuits.

"Over the last few months, the company has moved dramatically from proof-of-principle through lab device demonstration, full third-party validation with a commercial foundry, and working with select potential partners on technical design kits," says executive chairman & interim CEO Peter Copetti. "We are entering a new parallel stage - increasing quality and design robustness for manufacturability as part of commercialization of our game-changing IP - and Mr DeSimone's combined experience is exactly what we need to assist the team in moving to the next level," he adds.

The firm is also announcing a key expansion of its IP asset base. It already has a large inventory of key and ancillary patents protecting its unique platform for monolithic fabrication of integrated circuit devices containing both electronic and optical elements on a single semiconductor wafer (details of the existing portfolio are available through USPTO).

In addition, the firm recently filed for protection a number of new IP classes with USPTO, as well as in Canada, Japan, Korea, and other key jurisdictions.

"The commercialization process of the company's POET platform has historically yielded intellectual assets with future commercial development potential meriting IP protection," says Copetti. "While the company has focused assets and effort on near-term commercialization goals, our labs are generating future IP as well."

The new portfolio includes:

- Closed Loop Rectangular Resonators in POET & Thyristor Memory (OPE-069; 14/238,649; PCT/US12/51265; EPO 12824167.6);
- Fiber Optic Coupling Array (OPE-070; 14/104,230; PCT/US13/74658);
- Quantum Dot Lasers in POET for 1310-1550nm Operation (OPE-072; 13/921,311);
- Universal Memory Cell in POET for DRAM, SRAM and NVRAM Applications (OPE-073; 13/951,578);
- IR Imaging Structures in POET based on Quantum Dot Epitaxy (OPE-074; 14/023,525); and
- Whispering Gallery Mode Resonators in the Planar OptoElectronic Technology; and Implementation of 1550nm Optoelectronics in the Planar OptoElectronic Technology (OPE-075; PROV 61/962,303; 14/222,841).

"In this latest round of patent applications, the company has filed patent protection for IP that, in the medium-to-long-term, supports theoretical quantum computing applications, such as the fabrication of quantum-dot-based spin qubits and the devices needed to read and write them on the same die," says Copetti. "With POET integrated optoelectronics, we are already ahead of the curve," he reckons.

A qubit (quantum bit, the unit of information in quantum computing) is the quantum analog of a bit in a classical computing system, which would have to be in one of two states. Quantum mechanics allows a qubit to be in a superposition of both states at the same time (a property that is fundamental to quantum computing).

The new patent applications are for medium-to-long-term strategic positioning, and are complementary to the core POET intellectual assets.

www.poet-technologies.com

MACOM demos optical solutions at Fiber Optics Expo

At the 2014 Fiber Optics Expo in Tokyo (16–18 April), M/A-COM Technology Solutions Inc of Lowell, MA, USA demonstrated the following optical networking solutions, suitable for data-center, client access, metro and long-haul applications.

- 10G-PON solutions for next-generation FTTx access networks;
- 10G SFP+ solutions for wireless backhaul networks; and
- 4x28G chipset solutions for 100G client-side networks.

www.foe.jp/en

www.macom.com

Michigan-based Thorlabs Ultrafast Optoelectronics business unit formed to enter high-speed opto

Focus on bandwidths up to 100GHz outside traditional telecoms

In late March, vertically integrated photonics product maker Thorlabs Inc of Newton, NJ, USA announced a greenfield initiative to start the new business unit Thorlabs Ultrafast Optoelectronics (Thorlabs-UFO).

The team will focus on addressing the need for high-speed optoelectronic products with bandwidths as high as 100GHz for deployment in applications outside the traditional telecoms market. The new products will range from basic components to instrumentation consistent with Thorlabs' expanding catalog of photonic tools. Dedicated to establishing R&D facilities distributed geographically, the firm made the decision to locate the new venture in the heart of Michigan's photonics community in Ann Arbor.

Thorlabs-UFO aims to design, develop and manufacture photonics and optoelectronics products and systems, guided by key insights from customers in the marketplace. The team will be able to leverage the technical expertise that already exists within the organization's optomechanical, semiconductor, ultrafast laser and imaging system product development areas. The firm reckons that, together, this combined knowledge and feedback loop will contribute to a high-speed product line aimed at meeting the specific needs of the market, expanding Thorlabs' catalog offering and supporting R&D initiatives within other Thorlabs' business units.

"Our initial efforts will be in the area of ultrafast optoelectronic components such as lasers, modulators, and subsystems," says Janis Valdmanis, general manager of the Michigan operation. "Ultimately, our research and development efforts here at Thorlabs Ultrafast Optoelectronics will also serve to complement and advance Thorlabs' other initiatives in ultrafast and high-power lasers, optical & fiber optic instrumentation, and life science products," he adds.

"There is a long tradition of successful photonics-related research activity going on right here at the University of Michigan and other Michigan-based industrial and educational institutions," notes Valdmanis. "We hope to promote a strong interaction with that research community and attract strong talent from those channels in the coming years, contributing to Michigan's overall job growth."

Michigan is also home to the state-sponsored photonics cluster Mi-Light (launched in April 2013), consisting of 30 companies and educational institutions. This cohesive effort to enhance the photonics industry in Michigan in conjunction with national photonics initiatives provides a backdrop for Thorlabs' new venture.

www.thorlabs.com
www.mi-light.org

Skorpios joins 100G CLR4 Alliance

Fabless integrated silicon photonics system-on-a-chip firm Skorpios Technologies Inc of Albuquerque, NM, USA has joined an alliance of companies supporting the 100G CLR4 CWDM (coarse wavelength-division multiplexing) specifications for data-center applications.

Announced at the Interop Las Vegas event on 1 April by Intel Corp and Arista Networks, the 100G CLR4 Alliance was organized by a group of industry leaders, major data center providers, networking companies and optical vendors who are in support of a transceiver based on 100G CWDM LR4 (long-reach four-wavelength) in the 1310nm window and 20nm spacing. Alliance partners believe that this approach will enable the rapid development and adoption of this market segment. Conversely, the lack of low-cost, 100G transceivers may become an impediment to the adoption of advanced CPUs (central processing units), FLASH, SSDs (solid-state drives) and switching silicon to build the next-generation systems for cloud, HPC (high-performance computing) and enterprise data centers. The alliance may evolve into an MSA (multi-source agreement) over time, says Skorpios.

At the Optical Fiber Communications conference (OFC 2014) in San Francisco (9–13 March), Skorpios launched and demonstrated products based on proprietary Skorpios Template Assisted Bonding (STAB) process. In particular, it showcased its 100G 10km, CLR4 transceiver in a QSFP 28 package, together with its silicon photonics-based micro-ITLA (integrable tunable laser assembly). Skorpios claims that, with these products, it is delivering on the promise of silicon photonics with the highest-density form factor, lowest-power dissipation and lowest-cost products available on the market.

"Joining this alliance of industry leaders enables quicker adoption of Skorpios' leading 100G QSFP28 product line," says Alfredo Viglienzoni, senior VP of sales, marketing & business development. "Our novel technology platform allows us to deliver a single product that covers applications from a few hundreds of meters to 10 kilometers," he adds. "At this point, the technology innovation, which has been the foundation of this company, evolves into product innovation as Skorpios ramps-up production."

www.skorpiosinc.com

NeoPhotonics cuts loss as it confirms Q3's record revenue

Demand for 100G ramping after slower-than-expected growth in China

NeoPhotonics Corp of San Jose, CA, a vertically integrated designer and manufacturer of both indium phosphide (InP) and silica-on-silicon photonic integrated circuit (PIC)-based modules and subsystems for high-speed communication networks, has filed with the US Securities and Exchange Commission amended Form 10-Q reports with restated financial results for first and second quarters 2013, respectively, together with its Form 10-Q report for Q3/2013 (for which it reported revenue alone last November).

Losses cut in Q3/2013

For Q3/2013, revenue was $76.8m, up 2.4%, on Q2/2013's $75m and up 16.1% on Q3/2012's $66.2m. In addition, the firm now reports that, on a non-GAAP basis, gross margin was 27.5%, down from 32.9% in Q3/2012 but up from 25.1% in Q2/2013. Net loss was $3.2m ($0.10 per diluted share), cut from $3.8m ($0.12 per diluted share) in Q2/2013 but compared with income of $2.7m ($0.08 per diluted share) in Q3/2012. Adjusted EBITDA was $1.9m, up from $1.4m in Q2/2013 but still down on $6.4m in Q3/2012. During Q3/2013, combined cash, cash equivalents and short-term investments fell from $74.4m to $70.6m. Combined notes payable and debt fell from $45.9m to $44.9m.

"After several quarters of slower-than-expected growth in China, we are pleased to see the ramp in demand for 100G solutions now beginning to materialize," says chairman, president & CEO Tim Jenks. "Further, we are excited to see the shift to 100G in the metro and data center gaining momentum and believe these could be sizeable market opportunities for the industry as well as NeoPhotonics in the years ahead," concludes Jenks.

Q1–Q2/2013 restatements

As disclosed in the Form 8-K filed with the SEC on 14 November 2013, NeoPhotonics determined that its unaudited financial statements for the three months to end-March 2013 and the three and six months to end-June 2013 contained an error related to its accounting for a real-estate registration tax that was incorrectly reflected as a component of the property, plant and equipment acquired as part of the purchase of NeoPhotonics Semiconductor (formerly the Optical Component Unit of LAPIS Semiconductor). In addition, the firm has made other corrections related to the acquisition, primarily additional real-estate registration tax and fixed-asset valuation modifications, reclassified certain amounts and made other adjustments, all of which were discovered during the close of its Q3/2013 accounting records. Full details will be contained within the amended quarterly reports on Form 10/Q-A, when filed. Although there are no changes in revenue, the restatements and revisions involve:

- for Q1/2013, a rise in diluted net loss per share by $0.06 to $0.40;
- for Q2/2013, a drop in diluted net loss per share by $0.04 to $0.27;
- for the six months to end-June 2013, an increase in diluted net loss per share by $0.02 to $0.67.

Revision of end-December 2012 balance sheet

As disclosed previously, NeoPhotonics may need to pay a $5m penalty if it does not achieve certain performance obligations agreed to in connection with the sale of its common stock in a private placement transaction on 27 April 2012. The penalty payment was originally classified outside of equity as redeemable common stock at end-December 2012. The firm has since determined that the $5m penalty payment is an embedded derivative instrument and has thus classified $4.9m of the $5m to additional paid-in capital and the remaining $0.1m (representing the estimated fair value of the derivative) to other non-current liabilities at end-December 2012. This revision is reflected in the balance sheet as of end-December 2012.

Outlook for Q4/2013 & Q1/2014

NeoPhotonics has updated its expectations for Q4/2013 as follows:

- revenue of $74–75m (versus November's $70–76m estimate);
- gross margin of 25–28% (versus November's 24–28% estimate);
- net loss per diluted share of $0.05–0.10.

For Q1/2014, NeoPhotonics expects revenue to fall to $67-69m (though up about 21% from Q1/2013's $56.1m).

Update on NYSE listing

On 3 April, NeoPhotonics received a letter from NYSE Regulation Inc indicating that, due to failing to file its annual report on Form 10-K for 2013, it is not in compliance with the New York Stock Exchange's continued listing requirements.

As disclosed in its Notification of Late Filing on Form 12b-25 dated 18 March, the firm delayed filing its annual report on Form 10-K because it required extra time to complete the adjustments to its financial statements for Q1–Q2/2013 and its quarterly report on Form 10-Q for Q3. With the adjustments now completed, the firm now needs to complete its financial statements and disclosures as of end-2013, finalize preparation of Form 10-K, conclude testing of internal controls and complete the audit process with its independent public accounting firm.

Under NYSE rules, NeoPhotonics will have six months from the filing due date (i.e. until 1 October) to file its Form 10-K. It can regain compliance prior to that date once it files the Form 10-K with the SEC, along with Form 10-Q for Q3/2013. Otherwise, the NYSE may grant a further extension of up to six months. However, the NYSE may commence delisting proceedings at any time if the circumstances warrant.

In the meantime, NeoPhotonics' common stock will remain listed on the NYSE under the symbol NPTN, but with an 'LF' indicator to signify the late filing status.

www.neophotonics.com

Avago's latest 100G MicroPOD and MiniPOD optical modules extend beyond 500m

Avago Technologies Ltd (a designer and supplier of III-V-based analog components for communications, industrial and consumer applications) says that its latest series of MicroPOD and MiniPOD optical modules support 100 Gigabit Ethernet (100GbE) data transmission over a 550m link distance.

Avago and Corning Inc have collaborated to provide long-reach, high-density embedded optical connectivity solutions targeting 100G interconnects for data-center and enterprise network applications. The joint solutions enable data centers and enterprise networks to transition from 10G to 100G Ethernet while supporting a 400m link distance per IEEE 10G Ethernet standards and a 550m link distance using Corning's PretiumEDGE Cables with Corning ClearCurve OM4 bend-insensitive multimode optical fiber.

"As the data network infrastructure transitions to 100G data speeds to meet high-bandwidth demands, the need for long-reach high-density 100G embedded optical connectivity is imperative for modern data centers and enterprise networks," says Philip Gadd, VP & general manager of Avago's Fiber Optics Product Division. "Together with Corning, we are now able to support a high-density 100G embedded optical link beyond 500m," he adds.

"Corning has a long history of developing innovative fiber-optic technology, resulting in superior bandwidth performance for data centers," says Stuart Hoiness, senior VP, Enterprise Networks, Corning Optical Communications. "We look forward to future collaboration with Avago and other industry leaders as we create the next generation of optical technologies that will transform data centers."

QSFP+ MMF optical transceiver shipments pass 500,000 modules

Avago has now shipped more than 500,000 units of QSFP+ multimode fiber (MMF) optical transceiver modules for enterprise networking, computing and storage applications.

The shipment of QSFP+ MMF optical transceiver modules has increased significantly due to growing demands of 10G/40G Ethernet links supporting modern data-center expansion and 16G Fibre Channel (FC) links supporting increased server storage capacity, says the firm.

Avago's QSFP+ solutions comprise the following:

- AFBR-79ExPZ — claimed to be the industry's longest-reach 40G QSFP+ optical transceiver supporting extended link distances for data-center interconnects; and
- AFBR-79FIPZ — claimed to be the industry's first QSFP+ optical transceiver supporting 4x16G FC and 4x10G Ethernet for converged network systems.

"As the QSFP+ continues to be a dominant form factor for data-center interconnects, we will continue to innovate and introduce new breakthrough products based on this form factor supporting next-generation data speeds," says Philip Gadd, VP & general manager of Avago's Fiber Optics product division.

"In just a few short years, the compact QSFP+ form factor transformed, focused and accelerated the adoption of 40Gbps links in data center," notes Dale Murray, principal analyst with LightCounting Market Research. "Avago Technologies has been a major contributor to this success story."

Mellanox does not infringe Avago's laser driver patent

Mellanox Technologies Ltd of Sunnyvale, CA, USA and Yokneam, Israel, a supplier of end-to-end InfiniBand and Ethernet interconnect solutions for data-center services and storage systems, says that, on 17 April, the US International Trade Commission (ITC) issued its Final Determination ruling that its active optical cable (AOC) products and vertical-cavity surface-emitting laser (VCSEL) drivers do not infringe Avago Technologies' US patent number 5,596,456, directed to a laser driver, which was asserted against Mellanox by Avago in an ITC complaint (Inv. No. 337-TA-860) filed in September 2012.

"Mellanox and IPtronics do not infringe the key patent at issue in the case," says Mellanox's president & CEO Eyal Waldman.

However, the ITC affirmed the administrative law judge (ALJ) ruling that certain Mellanox cable products containing a particular type of VCSEL do infringe another of Avago's patents (US patent no. 5,596,595) directed to a VCSEL, and issued a limited exclusion order and cease and desist orders with respect to those products. The VCSELs in the products at issue are supplied to Mellanox by third parties.

Nevertheless, Mellanox says that these orders will not interrupt its ability to supply cables or otherwise impact its current or planned product offerings. Those orders are also not expected to have a material adverse effect on the firm's business, financial position, results of operations or cash flow, it adds.

www.avagotech.com
www.mellanox.com

Soitec's modules selected in 13 new French solar projects

Soitec of Bernin, France says that its concentrator photovoltaic (CPV) modules are included in 80% of the projects selected as a result of the second call for tenders from the French Energy Regulatory Commission (CRE, Commission de Régulation de l'Energie) for the creation and operation of solar power plants with installed capacity of over 250kWc.

Published in March 2013, the CRE's second call for tenders calls for the allocation of 20MWc for ground plants to be based exclusively on CPV technology, plus 80MWc of ground plants to be at least 50% CPV based, with a minimum total of 60MWc allocated to CPV.

The 16 projects finally selected after this second call for tenders represent a total volume of 102.94MWc: 13 of them (more than 80%) plan to use CPV modules manufactured by Soitec.

"It represents a volume of more than 50MWc for Soitec," says José Bériot, VP of solar projects development with Soitec's Solar Energy division. "This success is proof that our customers recognize the performance and reliability of our modules, and our ability to achieve profitability for future power plants."

Construction of the projects that have just been selected should be completed by spring 2016, and the winning developers are now selecting the engineering, procurement & construction (EPC) contractors with whom they will partner on the construction sites.

Soitec's CPV technology uses triple-junction cells mounted on glass support plates. Fresnel lenses (manufactured using silicone on glass) concentrate sunlight 500 times before it reaches the cells. A metal frame holds two glass plates to form what are described as highly robust, durable and resilient modules. By combining several modules on biaxial trackers (which use a proprietary algorithm to automatically optimize their position based on the path of the sun), Soitec's technology maximizes energy generation throughout the day. The modules achieve a yield of 31.8%, the firm concludes.

www.soitec.com

CPV project completed at Moapa Travel Plaza on tribal land

The Moapa Band of Paiutes Tribe and the US Department of Agriculture (USDA) Rural Utilities Service (RUS) administrator John Padalino have celebrated the completion by contractor Stronghold Engineering of a $2.38m solar power array at the newly remodeled Moapa Travel Plaza (the Tribe's largest employer, including a shop offering Native American art, a café, recreational supplies, fireworks and fuel) located off Exit 75 of Nevada's I-15 North interstate highway.

The project included installation of LED lights around the travel plaza plus development of an off-grid, self-contained concentrated photovoltaic (CPV) hybrid system. Manufactured in Rancho Bernardo, CA, the CPV hybrid system includes nine towers with dual-axis CPV trackers made by Soitec of Bernin, France (each producing 28kW, making a total of 252kW), plus a battery backup system, two 250kVA generators and a 375kVA diesel generator to maintain energy flow at night and to keep a reserve for fuel pump operations.

The micro-grid project was funded via USDA's High Energy Cost Grant program, which provides funding for energy efficiency improvements in areas with energy costs at least 275% of the national average. "USDA funding of this innovative 252kW solar facility is fundamental to economic opportunities of the Moapa Tribe and aligns with their commitment to environmental protection," says Padalino.

The tribe expects the solar power array to reduce reliance on diesel-powered generators at the off-grid site and will result in a 34% power offset, saving over $700,000 annually in fuel costs. In the past, diesel power and generator rental cost exceeded $650,000 annually.

Stronghold Engineering, which designed, engineered and constructed the CPV hybrid system, estimates that the new system will use 162,480 fewer gallons of diesel fuel annually. Each gallon burned releases about 22.38 pounds of carbon emissions into the environment, so emissions will be reduced by an estimated 3.6 million pounds annually.

The Moapa Band of Paiutes is also hosting the nearby 250MW Moapa Southern Paiute Solar Project, which is under development by cadmium telluride (CdTe) thin-film photovoltaic module maker First Solar Inc of Tempe, AZ, USA.

www.rurdev.usda.gov

Tenaska decides against using Soitec modules for CSOLAR IV West

CSOLAR IV West LLC has notified San Diego Gas & Electric (SDG&E) of its decision not to use the CPV module technology of Soitec Solar for its power purchase agreement (PPA) to produce 150MW of energy at its CSOLAR IV West solar plant. CSOLAR, a subsidiary of Tenaska Solar Ventures LLC, will instead use traditional PV technology.

Soitec Solar says that the decision neither materially jeopardizes prospects for its North American manufacturing facility in California (from which it supplies demand for its CPV technology worldwide) nor impacts Soitec's PPAs with SDG&E that were previously approved by the CPUC and are currently under development.

www.tenaska.com

Soitec and Exosun combine expertise to launch new CPV tracker system

Paris-based Exosun, which designs and supplies solar trackers for ground-mounted utility-scale solar power plants, and concentrating photovoltaic (CPV) solar module maker Soitec of Bernin, France have joined forces to offer a new CPV system. Comprising an Exosun tracker holding 18–24 Soitec CPV modules, the CX S540 model delivers output per unit of up to 61.2kW. Already being sold by both firms, it will be used in the majority of CPV projects that the French Ministry of Energy selected at the end of the second call to tender for large-scale PV installations issued in March 2013 by the French Energy Regulatory Commission (CRE, Commission de Régulation de l'Energie).

Exosun and Soitec have combined their expertise over the last two years to develop the product. Exosun designed and developed dual-axis solar trackers using a patented control system to give tracking precision of 0.1°. The resultant Exotrack CPV combines technical and economic performance to exploit the full potential of Soitec's CPV modules. The drive mechanism, parts tolerance and assembly procedures have been designed to be practical, flexible and modular under any large-scale installation. The trackers are said to be simple, fast and easy to install and maintain.

Meanwhile, Soitec developed modules achieving up to 31.8% efficiency. Using Fresnel lenses (made using silicone on glass), light is concentrated 500 times before it reaches the triple-junction cells. The use of highly resistant materials such as glass and metal ensures robustness and durability of the modules, it is said.

Combining the performance of the Exosun trackers and Soitec modules, CX S540 systems maximize power generation while optimizing the footprint and keeping height down to 4.5m (under 15 feet).

Comprising an Exosun tracker holding 18–24 Soitec CPV modules, the CX S540 model delivers output per unit of up to 61.2kW

"The call to tender relating to ground-mounted photovoltaic installations of more than 250kWp issued by the French energy regulator was implemented by the French Government in order to build a solar industry in France, in particular by encouraging innovative technologies like CPV with a total volume of at least 60MW," comments Jean-Noël de Charentenay, Exosun's VP of business development. "This partnership with Soitec illustrates the way in which two French industry leaders contribute to forming a strong French photovoltaic sector," de Charentenay adds.

"The projects that will be built in France are part of the country's energy transition and will serve as a benchmark for this industry of the future, enabling it to win market share internationally," believes Jose Beriot, VP of solar projects development with Soitec's Solar Energy division.

www.exosun.net/solar-trackers/solar-tracker-cpv
www.soitec.com

Calyxo gains financing from IBG

CdTe PV technology to be developed further and new EPC project markets to be opened up

Calyxo GmbH of Bitterfeld/Wolfen-Thalheim, Germany, the largest manufacturer of cadmium telluride (CdTe) thin-film solar panels in Europe, has concluded an agreement for further financing from venture capital investor IBG Beteiligungsgesellschaft Saxony-Anhalt mbH of Magdeburg, Germany.

IBG is involved in technology-oriented, innovative companies and projects, and is investing in Calyxo due to its integrated value chain, from the production of CdTe thin-film PV modules to the implementation of engineering, procurement & construction (EPC) projects.

Calyxo say it is confident that it can produce modules in the short term at a cost of €0.25/Wp using its low-cost atmospheric deposition process. The core semiconductor deposition equipment was designed and developed by Calyxo's own team of engineers. Major system components are constructed by Calyxo and have been transferred to patent applications.

Calyxo reckons that IBG's participation secures business opportunities through their financial commitment and know-how. In particular, the technology will be further developed and new markets for EPC projects opened up, the firm adds.

IBG has consistently promoted Calyxo's development as well as the efficiency of the photovoltaic unique technology, achieving the existing CdTe PV efficiency record of 20.4%, which should be transferred to mass production soon.

Calyxo says that IBG's participation is welcomed by its main shareholder Solar Fields LLC of Toledo, OH, USA, which assumed ownership of Calyxo in February 2011 from former partner Q-Cells SE (which founded Calyxo in 2005), as it extends the long-term relationship with Saxony-Anhalt state.

www.calyxo.com
www.ibg-vc.de

Solar Frontier sets thin-film PV cell record of 20.9%

In joint research with Japan's New Energy and Industrial Technology Development Organization (NEDO), Tokyo-based Solar Frontier — the largest manufacturer of CIS (copper indium selenium) thin-film photovoltaic (PV) solar modules — has achieved record energy conversion efficiency of 20.9% for cadmium-free, thin-film solar cells measuring 0.5cm2 (independently verified by Germany's Fraunhofer Institute). This is a record for thin-film PV technologies, beating Solar Frontier's previous record of 19.7% for CIS thin-film cells, as well as the previous 20.8% record for all thin-film PV technologies.

"Solar Frontier's new 20.9% efficiency record resulted from a CIS cell cut from a 30cm by 30cm substrate produced using a sputtering-selenization formation method — the same method we use in our factories," says chief technology officer Satoru Kuriyagawa. "The significance is twofold: it ensures we can transfer our latest achievement into mass production faster, and it proves the long-term conversion efficiency potential of Solar Frontier's proprietary CIS technology," Kuriyagawa adds. "Solar Frontier has entered into the next phase in the development of CIS technology, and we look forward to building on this achievement and driving our efficiency even higher."

Although conversion efficiency is used to compare the performance of solar modules, actual performance after installation depends on how differing PV technologies react to their surrounding environment and climate. Solar Frontier claims that its CIS modules are proven to generate more electricity (kWh/kWp) in real operating conditions than crystalline silicon modules. Together with high automation and precision manufacturing in Japan, CIS modules provide long-term competitive and reliable returns on investments, the firm adds.

Solar Frontier's latest efficiency record was achieved at the Atsugi Research Center (ARC) in Kanagawa, Japan, which has been setting world records since it was established in 2009. As part of the ARC's customer-centric approach, it focuses on boosting the efficiency of its CIS modules, developing its proprietary mass-production machinery, and reducing overall system costs for end users.

www.solar-frontier.com

Solar Frontier & Chopro to build and operate Nagasaki's largest plant

Solar Frontier and Chopro Co Ltd have signed a letter of agreement with the Nagasaki Prefectural Government and the Land Development Public Corporation of Nagasaki Prefecture regarding the construction and operation of a 29.1MW solar power plant on 35.1ha of leased land adjoining Nagasaki Airport, Japan. The project will be the largest in Nagasaki Prefecture and one of the largest in Japan.

"We now look forward to working on one of the world's largest installations at an airport – at home in Nagasaki," says Kenji Araki, representative director at Chopro. Chopro is a liquefied petroleum gas (LPG) distributor and more recently a solar power producer headquartered in Nagasaki Prefecture.

"Our Nagasaki project integrates the economical advantages of Solar Frontier's CIS solar energy system solutions, from supplying high-performance CIS modules through to operation & maintenance, with Chopro's expertise as an energy supplier local to Nagasaki," says Hiroto Tamai, Solar Frontier's president & representative director. "Together with leading regional companies like Chopro, we will continue to meet the high demand for solar projects that offer competitive and reliable returns on investment," he adds.

Graphic rendering of Nagasaki Airport solar project.

After the Kansai International Airport Megasolar Power Plant (completed in late January), this will be the second large-scale installation at an airport that leverages Solar Frontier's CIS thin-film technology. The firm claims that, compared with crystalline silicon modules, its CIS modules have a higher electricity yield (kWh/kWp) in real operating conditions. Also, their anti-glare properties ensure that they do not affect aircraft operations.

The Nagasaki Prefectural Government announced its partner selection on 27 December 2013, as part of its 'Nagasaki Green New Deal' solar and renewable energy initiative. In addition to working with local companies, a pre-determined percentage of proceeds from this project will go to Nagasaki Prefecture to support its economic growth.

Sierra Nevada awards Emcore solar panel contract for NASA's CYGNSS Mission

Emcore Corp of Albuquerque, NM, USA, which makes compound semiconductor-based components and subsystems for the fiber-optic and solar power markets, has been awarded a contract by Sierra Nevada Corp (SNC) of Sparks, NV, USA to design and manufacture solar panels to be used on the Cyclone Global Navigation Satellite System (CYGNSS) of the US National Aeronautics and Space Administration (NASA). The CYGNSS mission will be managed by Southwest Research Institute (SwRI) and is planned for launch in October 2016.

Emcore will populate solar panels with its ZTJ triple-junction solar cells. SNC will then deliver the finished panels to SwRI for integration into the eight low-earth orbiting (LEO) satellites that will be carried on a single launch vehicle.

The goal of NASA's mission is a fundamental improvement in hurricane forecasting. CYGNSS will make frequent and accurate measurements of ocean surface winds throughout the life-cycle of tropical storms and hurricanes. The data generated will enable scientists to probe key air-sea interaction processes that take place near the core of storms, which play a critical role in the genesis and intensification of hurricanes.

"Emcore is a valued and strategic partner supporting a critical element of SNC's growing, complete and integrated satellite electrical power system (EPS) offering," comments Matt Johnson, director of programs for SNC's Space Systems. "We continue to expand the EPS market with higher-value, lower-cost and turn-key system solutions," he adds.

Emcore previously delivered solar panels to SNC for the ORBCOMM Generation 2 (OG2) satellites in 2010. "We are appreciative of SNC's continued confidence in our ability to deliver the highest reliability solar panels for their missions," says Dr Brad Clevenger, executive VP & general manager of Emcore's Photovoltaics Division.

Since 2001 Emcore solar cells or panels have supplied primary power to more than 130 space missions with zero on-orbit failures.

With a beginning-of-life (BOL) conversion efficiency nearing 30% and the option for a patented, onboard monolithic bypass diode, Emcore's multi-junction solar cells provide amongst the highest available power to interplanetary spacecraft and earth-orbiting satellites, claims the firm.

www.emcore.com

Solar Frontier explores building R&D and manufacturing plant outside Japan with CNSE

Tokyo-based Showa Shell Sekiyu subsidiary Solar Frontier – the largest manufacturer of CIS (copper indium selenium) thin-film photovoltaic (PV) solar modules – and the State University of New York (SUNY) College of Nanoscale Science and Engineering (CNSE) in Albany, NY, USA have entered into an agreement to explore development and implementation of a joint research, development and manufacturing initiative in New York State, with the creation of more than 1000 jobs and nearly $700m in investments projected.

Due to increased worldwide demand and forecasts for continued strength in solar panel sales, Solar Frontier has started developing blueprints and making preparations for future manufacturing facilities overseas, including potential sites throughout New York. The collaboration with CNSE represents an key step in Solar Frontier's plans to establish production bases for its proprietary technology outside Japan, the firm's home market that currently accounts for 100% of its production.

"Collaboration would provide Solar Frontier the opportunity for significant growth, by establishing overseas production bases," says Hiroto Tamai, president & representative director of Solar Frontier. "Under the leadership of Governor Andrew Cuomo, New York is a leading candidate for an international manufacturing facility," he adds.

"This announcement is a direct result of Governor Andrew M. Cuomo's s NY-Sun and Energy Highway initiatives to make New York an international leader in green energy innovation and manufacturing," comments CNSE's CEO Dr Alain Kaloyeros. "Solar Frontier recognizes New York is uniquely capable of supporting the level of research, development and manufacturing it requires," he adds.

CNSE and Solar Frontier have signed an agreement to explore building a key Solar Frontier solar module manufacturing plant outside Japan in western New York and establishing Solar Frontier's North American headquarters at CNSE in Albany. Development and implementation of the initiative is projected to generate over $678m in investments over 7 years. Solar Frontier anticipates the creation of 250 direct research, development and manufacturing jobs, and 700-1000 indirect jobs from contractors and suppliers expected to locate in and around its New York facilities.

www.solar-frontier.com

Exploring optoelectronics potential of monolayer tungsten diselenide

Three groups have recently reported on preliminary experiments with photovoltaic and light-emission effects from pn junctions created using split-gate electrostatic doping. Mike Cooke reports.

Researchers are beginning to explore the semiconductor potential of monolayer materials beyond graphene with hopes of developing robust devices that are flexible and transparent for deployment in wearable formats, interactive displays, and efficient solar cells.

An interesting class of materials that has recently come to the fore is that of few-layer group-VIB transition-metal dichalcogenides (TMDs) such as molybdenum disulfide (MoS_2), molybdenum diselenide ($MoSe_2$), tungsten disulfide (WS_2), and tungsten diselenide (WSe_2).

The crystal structure consists of the metal atoms encapsulated between two layers of sulfur/selenium chalcogenide atoms. The bonding within a monolayer is strong while the bonding between monolayers is weak. Like with graphene/graphite, the monolayers of TMD can be exfoliated.

Electronically, TMDs in bulk form tend to have an indirect-bandgap semiconductor behavior, meaning that photon emission is very difficult. However, monolayers of TMD have a wider direct bandgap that opens up opportunities for creating optoelectronic devices such as solar cells and light-emitting diodes (LEDs). Monolayers have about 95% transparency, suggesting uses as transparent conductive electrodes. The transparency also points to stacking of devices for solar energy harvesting. Other possibilities include optical interconnect, logic and sensor applications.

Monolayer WSe_2 has a photoluminescence direct bandgap of 1.64eV with a full-width at half maximum (FWHM) of 56meV. The quantum yield from multi-layer WSe_2 reduces with thickness, signaling the transition to an indirect bandgap.

Another feature of monolayer TMDs is that electron–hole interactions are much stronger than in conventional semiconductors due to a large carrier effective mass and reduced screening in two dimensions. This leads to large binding energies for both charged and neutral excitons which, as a result, are spectrally sharp, robust and amenable to electrical manipulation.

Three separate research groups have reported promising preliminary results for WSe_2 devices that can both convert light into current and current into light. The creation of n- and p-type conductivity in these devices was achieved electrostatically with a split gate beneath the WSe_2 monolayer.

Vienna University of Technology [Andreas Pospischil et al, Nature Nanotechnology, vol 9 (2014), p257] began its fabrication by forming a split gate of titanium/gold with a 460nm gap on a silicon/silicon dioxide wafer (Figure 1). Gate bonding pads were also formed with titanium/gold. The split gate was covered with silicon nitride, except for the bonding pads.

WSe_2 flakes were exfoliated from bulk material supplied by Nanosurf onto a stack of polymer layers on a sacrificial silicon substrate. Suitable flakes were identified under an optical microscope. The bottom polymer layers were dissolved in water and the top layer was used to transfer the flake to overlap both sides of the gate electrode by about 900nm. The polymer was then dissolved and anode and cathode electrodes formed.

Palladium was used for the anode hole injector since the metal's high-workfunction Fermi level is aligned to the valence band edge of the WSe_2 monolayer. The cathode was titanium with a low workfunction. Nickel might be a suitable alternative that would be less prone to oxidation.

The device was finally vacuum-annealed for several hours at 380K to remove doping adsorbates and water. Although the device was functional in air, the measurements were carried out under high vacuum to ensure better long-term stability.

Experiments with the split gates shorted together gave a device with an on–off current ratio in the range 100–500. The device exhibits ambipolar characteristics with both electron and hole injection, depending on gate potential. The poor performance as a transistor is attributed to the inefficient gate structure.

A pn junction is created by putting a positive potential on one gate and a negative potential on the other. Under these conditions, the device "clearly shows rectifying behavior".

The n-type resistance of the monolayer under positive gate potential was found to be an order of magnitude

smaller than the p-type resistance under negative gate potential.

Under illumination, the device created a photocurrent when the gates were biased in a pn configuration but not in the resistive p- or n-type modes. The researchers comment: "This is a clear indication that the photoresponse does not arise from one of the Schottky contacts, as it relies on the existence of a p–n junction. Moreover, the photocurrent changes sign when the gate polarities are flipped, which cannot be explained by the built-in potential due to asymmetric contact metallization."

With 1400W/m^2 illumination, the solar cell maximum output power was 9pW at a voltage of 0.64V and current of 14pA. The fill factor compared with the product of the short-circuit current and open-circuit voltage was 0.5. The conversion efficiency was estimated to be 0.5%, similar to values obtained for devices based on bulk WSe_2. "To our knowledge, this constitutes the first demonstration of efficient photovoltaic energy conversion in a 2D atomic crystal," the researchers write.

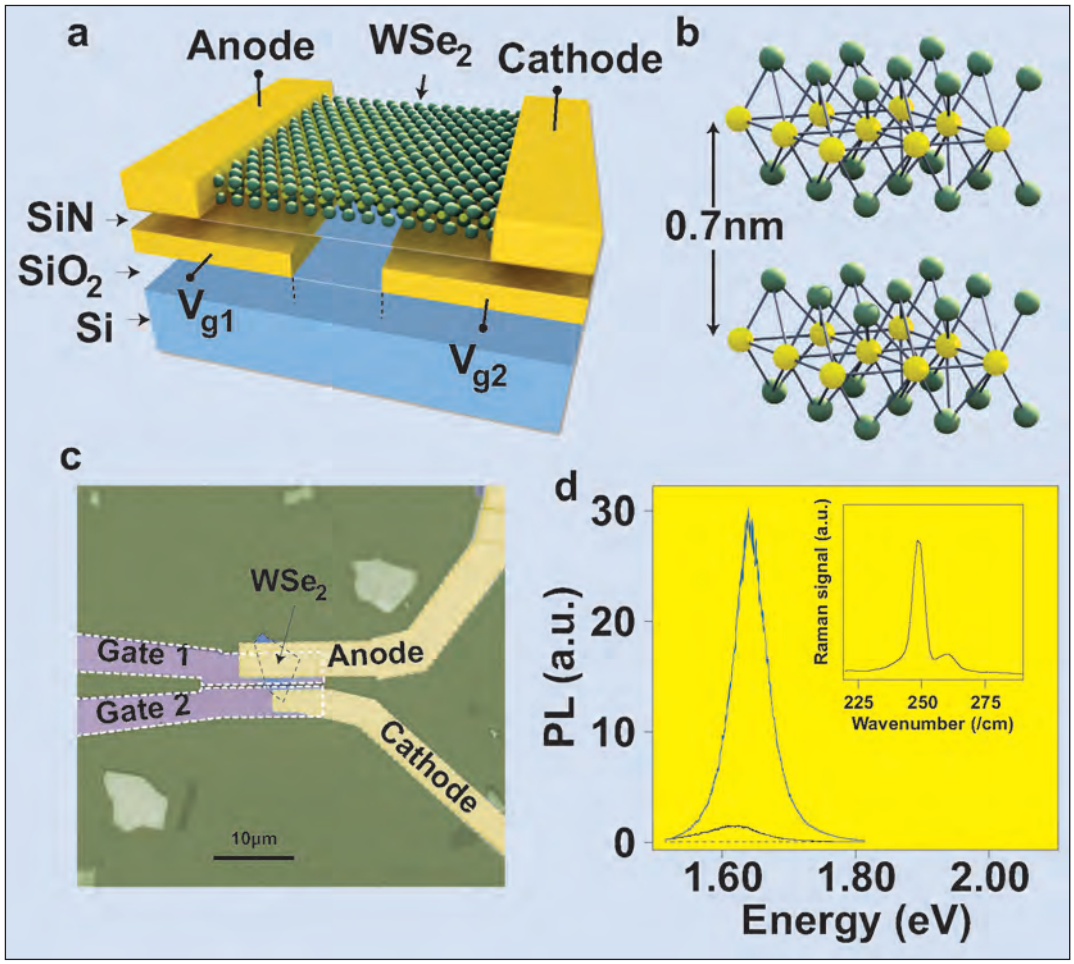

Figure 1. WSe_2 monolayer device with split gate electrodes. a, Schematic of device structure. b, Three-dimensional schematic representation of WSe_2. W, yellow spheres; Se, green spheres. c, Colored microscope image of device. d, PL from monolayer (solid blue line), bilayer (solid black line) and multilayer (dashed black line) WSe_2 flakes. Inset: Raman spectrum of monolayer.

The solar cell performance suggests there is shunt resistance associated with recombination losses, indicating room for improvements from material quality enhancement. Reverse biasing the pn junction at –1V gives a photodiode responsivity of 16mA/W.

The pn junction also emitted light with estimated electroluminescence efficiency (η_{EL}) of 0.1% (Figure 2). The researchers comment: "Currently, η_{EL} is limited by resistive losses in R_S and by non-radiative recombination in the WSe_2. It can therefore be increased by reducing the contact resistance or by using a crystalline substrate to reduce the density of disorder-induced recombination centers."

This light emission compares with electroluminescence efficiency of 0.01% in a similar setup with monolayer molybdenum diselenide ($MoSe_2$). In the case of $MoSe_2$, the light is generated by excitons (electron–hole bound states) resulting from impact excitation. "In contrast, our device is operated as a true light-emitting diode with ambipolar carrier injection," the researchers write.

The monolayer WSe_2 LED had an EL emission peak at 1.547eV, 93meV below that of photoluminescence measurements on monolayer WSe_2. The researchers "assign the shift to different dielectric environments in both experiments, which influence the exciton binding energy due to Coulomb screening."

The researchers comment on potential applications: "For the future, we envision low-cost, flexible and semi-transparent solar cells that could be deployed on glass facades or other surfaces for energy harvesting. Two-dimensional light-emitting diodes could lead to new generations of large-area lighting units and transparent, flexible displays. We also expect applications in the emerging field of valleytronics."

Valleytronics refers to proposals of controlling valleys of the band structure to achieve new ways to manipulate nature for useful ends.

Massachusetts Institute of Technology [Britton W. H. Baugher et al, Nature Nanotechnology, vol 9 (2014), p262] constructed their split gates (20nm gold) with 100nm separation. The high-k gate dielectric consisted of 20nm hafnium dioxide. The structure was

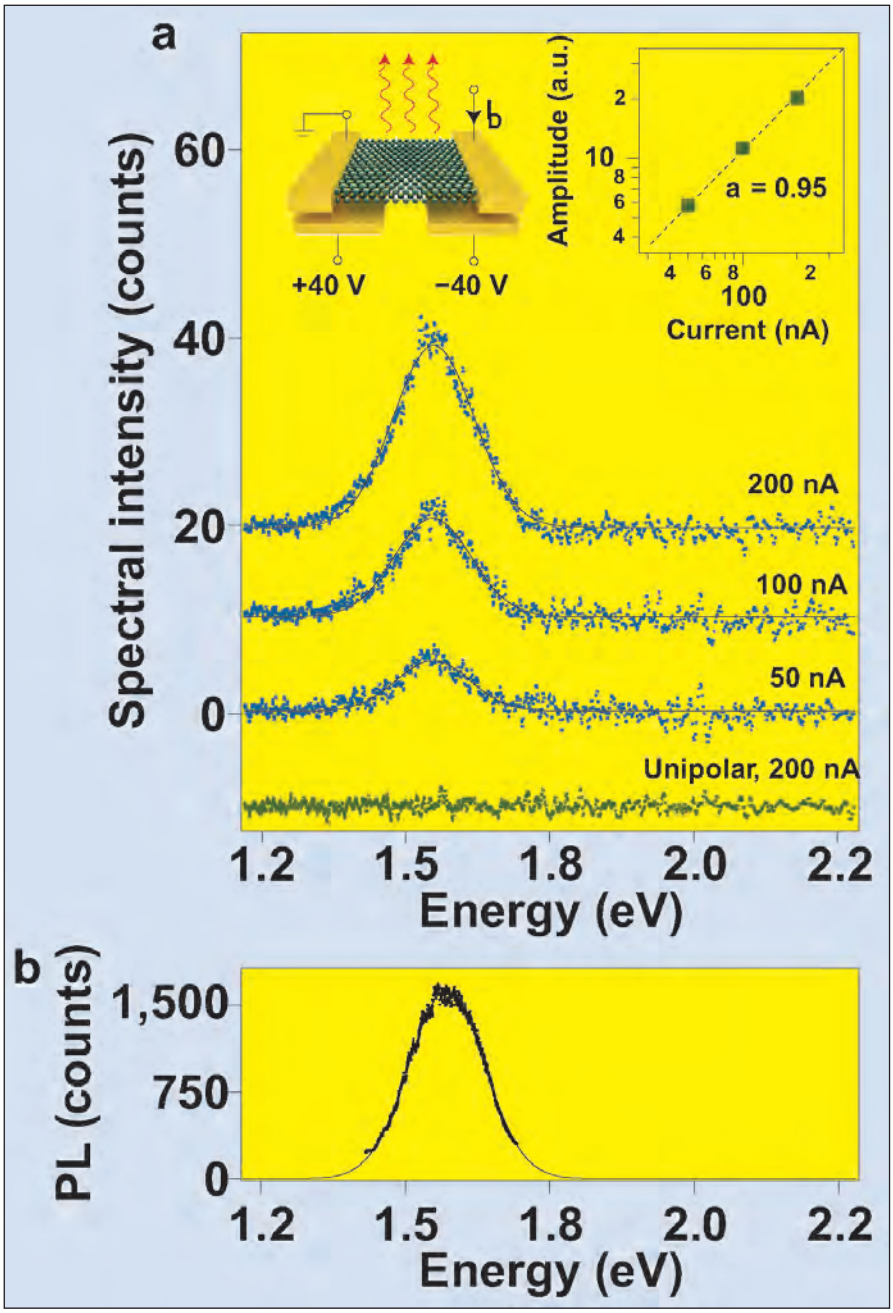

Figure 2. Device operation as LED. a, Electroluminescence emission spectra recorded for gate voltages as shown in left inset and constant currents of 50nA, 100nA and 200nA, respectively (blue symbols, measurements; black lines, Gaussian fits). Curves are offset for clarity. Right inset: emission amplitude versus current on a double-logarithmic scale. Symbols, measurements; dashed line, data fit by a power-law I^{α}, with α close to one (α ~0.95). b, Photoluminescence recorded from WSe_2 flake on device. Symbols, measurements; lines, Gaussian fit.

constructed on highly doped silicon with a 285nm thermal oxide layer. The WSe_2 was transferred to the gate on a stack consisting of glass, polydimethylsiloxane (PDMS) polymer and methyl methacrylate (MMA) resist.

Measurements were made in vacuum at room temperature. The researchers believe that encapsulation methods could be developed to avoid problems with device degradation from the adsorbates that are present in air.

The MIT researchers also found that the n-type conductivity was higher than the p-type, which they attribute to the lower contact resistance between gold and n-type WSe_2. The n- and p-type conduction was achieved, respectively, with +10V and –10V gate potentials.

With oppositely biased gates, pn junctions were formed. The current–voltage behavior suggests that recombination dominates over diffusion. "Investigating this recombination, including contributions from Shockley–Read–Hall or Auger processes, will be a focus of future work," the researchers say.

The shunt resistance (leakage) is high at 0.5TΩ: "This large shunt resistance indicates a high-quality p–n interface and is an expected advantage of a lateral device geometry." The reverse-bias current was less than 1pA up to 1V. The researchers see this as promising for low-power electronics.

The photoresponse of the device to 532nm wavelengths (green) was as high as 210mA/W, comparable to commercial silicon photodetectors. Spectral measurements from visible to near-infrared wavelengths suggest peaks from the lowest three excitonic levels.

A photovoltaic external quantum efficiency (EQE) peak of 0.2% occurred at 522nm wavelength (Figure 3). The researchers comment: "This value does not take into account the low absorption of monolayer WSe_2 or the narrow cross-section of the p–n junction relative to the size of the laser spot, which together suggest an internal quantum efficiency at least an order of magnitude larger than the EQE reported here."

The researchers attempted to improve the performance for electroluminescence by constructing a device with a palladium p-contact. The light emission peaked at 752nm wavelength (red) with a 2V bias and 100nA injection current. The peak is attributed to a direct-gap exciton transition. The researchers report: "Using a blackbody source for calibration, we estimate the electroluminescence efficiency, defined as optical output power divided by electrical input power, to be ~1%."

The researchers anticipate a "prominent role" for devices based on monolayer dichalcogenide p–n junctions. "Taking into account the three-atom thickness and low optical absorption of monolayer WSe_2, the responsivity and EQE reported here are quite substantial," the

researchers comment.

They add: "We expect that vertical junctions based on transfer-aligned exfoliated flakes or large-area dichalcogenides grown by chemical vapor deposition could increase responsivity and EQE by more than an order of magnitude. Additionally, improved contact resistance, particularly for holes, should dramatically improve device performance."

A collaboration of researchers from USA, Germany, Japan and China used a ~10nm sheet of smooth, disorder-free hexagonal boron nitride as gate dielectric with 7nm palladium split-gate electrodes. [Jason S. Ross et al, Nature Nanotechnology, vol9, p268, 2014]. The use of boron nitride was designed to "minimize non-radiative energy relaxation pathways".

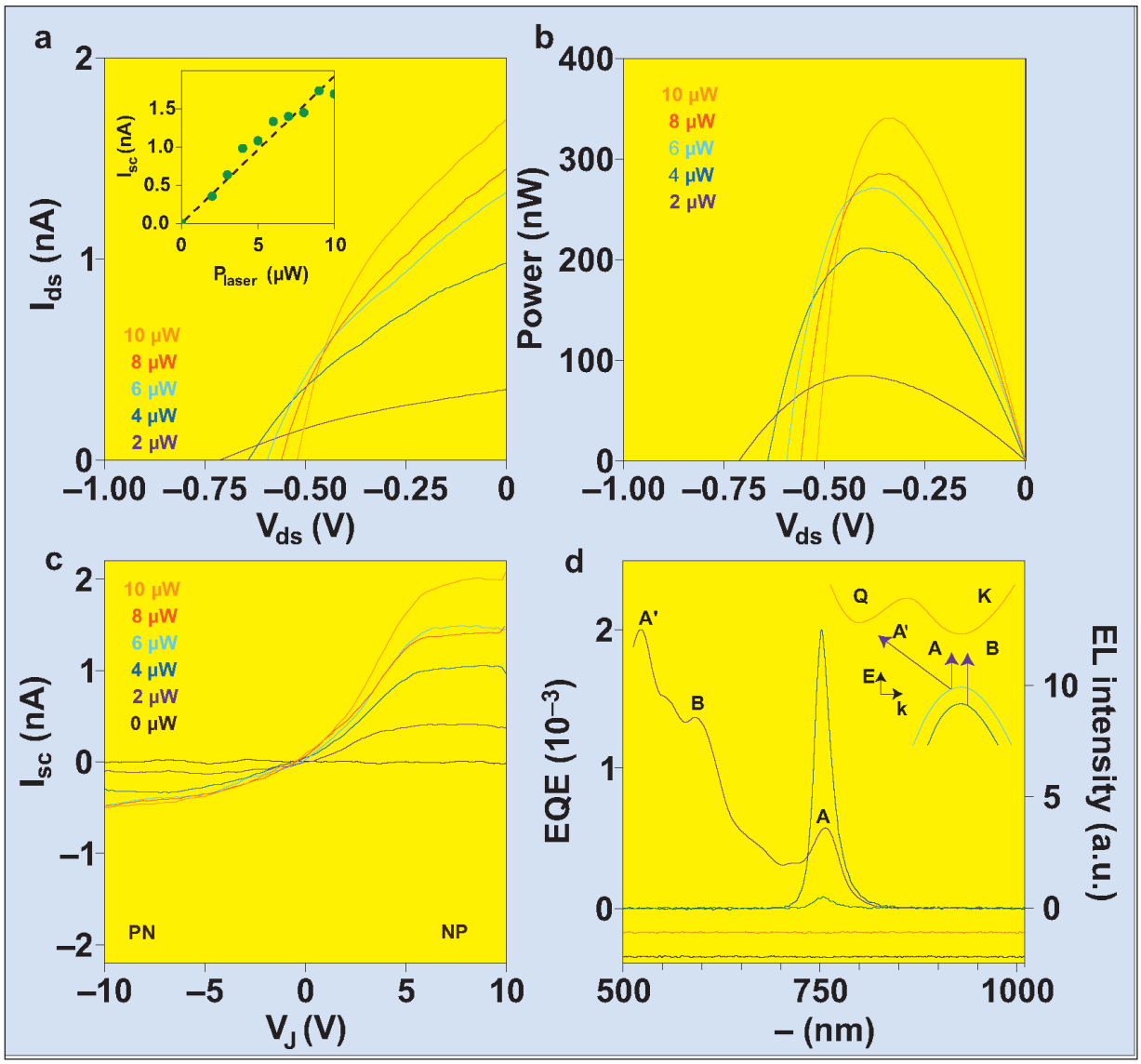

Figure 3. Photovoltaic response and light emission. a, I_{ds} as function of V_{ds} in NP configuration for laser powers 2–10mW (wavelength 700nm). Positive I_{ds} and negative V_{ds} in this regime reflects PV power generation. Inset: short-circuit current I_{sc} (green dots) versus laser power with a linear fit (black dashed line). b, Power P = $I_{ds}V_{ds}$ produced by device as function of V_{ds} for different incident laser powers, calculated from data in a. c, I_{sc} as a function of asymmetric gate voltage, V_J, for different laser powers. d, Left axis: EQE as a function of wavelength at constant laser power of 2mW in NP configuration (purple line). Peaks in EQE correspond to exciton transitions A, B and A', as labelled. Right axis: EL intensity from second monolayer WSe_2 device with one gold and one palladium contact. V_{ds} = 2V in PN (blue trace), NN (yellow trace) and PP (black trace) configurations, and V_{ds} = –2V in NP (green trace) configuration. NN and PP traces are offset vertically for clarity. Inset: Band structure around K and Q points; arrows indicating lowest-energy exciton transitions for monolayer WSe_2.

The structure was supported by a silicon dioxide on silicon substrate. The separation between the gates was 300nm. Gold/vanadium was used for the source/drain contacts, which overlapped the gate regions to reduce the Schottky barrier and provide more ohmic-like carrier injection. The silicon substrate was grounded during measurements.

This research involved University of Washington, USA; Justus Liebig University in Germany, University of Tennessee, USA; Oak Ridge National Laboratory, USA; National Institute for Materials Science, Japan; and the University of Hong Kong, China.

Again, pn junction behavior was achieved. The maximum photocurrent from a 660nm laser scanned over the sample was 5nA with the gates biased at +8V and –8V. The maximum internal quantum efficiency was estimated at 5%. Photoluminescence studies suggested the presence of neutral excitons (electron–hole bound pairs) and charged trions (bound eeh/ehh), depending on the scan position of the exciting laser spot.

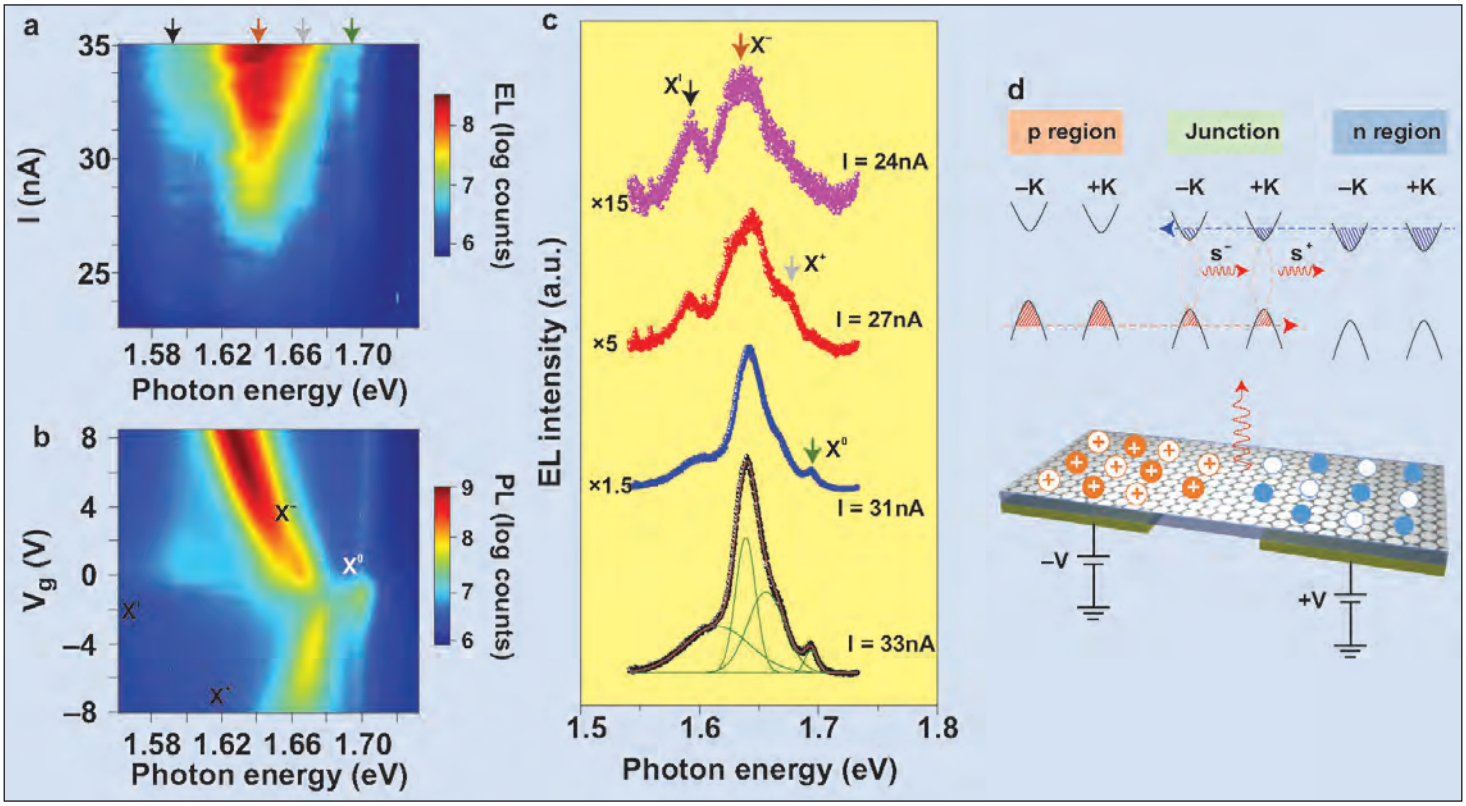

Figure 4. Tuning valley-exciton EL at 60K. a, EL intensity plot as function of bias current and photon energy. Left to right, arrows show impurity-bound exciton (X^I), charged excitons (X^- then X^+) and neutral exciton (X^0). b, PL intensity as function of photon energy and gate voltage $V_g = V_{g1} = V_{g2}$. c, Selected EL spectra at various bias currents. Bottom spectrum is fit by four Gaussian lineshapes, one for each exciton species. d, Band diagram and device schematic showing EL generation from valley excitons. Wavy red arrows indicate EL. Dashed red (blue) arrow indicates direction of hole (electron) flow. Filled and empty circles show carriers in +K and –K valleys. Both valleys are shown to be populated, leading to EL with both right (σ^+) and left (σ^-) circular polarization.

Room-temperature (300K) electroluminescence was observed with currents as low as 200pA. The spectral peak is associated with emission from excitons, "a natural consequence of the large exciton binding energy due to the strong Coulomb interaction in monolayer TMDs," according to the research team.

A more complex spectral structure was seen in electroluminescence at low temperatures of 60K with contributions from free and bound excitons (X^0, X^I), and trions (X^-, X^+), with the balance depending on gate voltage and injection current (Figure 4). The trion states were sensitive to changes in the perpendicular electric field across the junction.

The X^0 peak centered on 1.69eV was narrow. The X^- states emitted over a broad range from 1.633–1.625eV, giving the strongest contribution to the spectra. Light from the X^+ trions gave a shoulder to the spectrum around 1.670eV. The bound exciton (X^I) emissions were around 1.59eV. The X^0 linewidth was ~5meV, an order of magnitude smaller than for MoS_2.

The total photon emission rate at 35nA was 16million/second. The researchers comment: "This is 10 times larger, for 1000 times smaller current, than reported for MoS_2 devices. It corresponds to one photon per 10^4 injected electron–hole pairs."

It is hoped that better performance could be achieved by reducing the contact resistance, enhancing the WSe_2 crystal quality, and improving the membrane transfer technique. The researchers also believe that ferromagnetic contacts could create spin-polarized injection that would allow the creation of spin- and valley-LEDs with the emission of controllably polarized photons.

The team concludes: "This system has the required ingredients for new types of optoelectronic device, such as spin- and valley-polarized light-emitting diodes, on-chip lasers and two-dimensional electro-optic modulators."

Finally, researchers in USA and Japan have been seeking better contacts for TMDs by creating nanowires or nanoribbons of the material with a guided electron beam [Junhao Lin et al, Nature Nanotechnology, published online 28 April 2014]. It was found that such nanowires/ribbons become more metallic/ohmic for narrow geometries. The collaboration involved Vanderbilt University (USA), Oak Ridge National Laboratory (USA), National Institute of Advanced Industrial Science and Technology (AIST, Japan), University of Tsukuba (Japan), Fisk University (USA) and University of Tennessee (USA). ■

http://dx.doi.org/10.1038/nnano.2014.14
http://dx.doi.org/10.1038/nnano.2014.26
http://dx.doi.org/10.1038/nnano.2014.25

EU project DEEPEN to develop atom-to-device simulation environment for photonic and electronic nanostructures

Tyndall National Institute in Cork, Ireland is leading a European research project to develop a test environment to help create the electronic and photonic devices of the future.

Led by professor Eoin P. O'Reilly, head of the Theory, Modelling and Design Centre at Tyndall, the project DEEPEN (from atom-to-Device Explicit simulation Environment for Photonic and Electronic Nanostructures) will involve Tyndall-based researchers working in close partnership with research teams from across Europe, including ETH Zurich (Switzerland), Osram Opto Semiconductors GmbH (Regensburg, Germany), Paul-Drude-Institut für Festkörperelektronik (PDI, Berlin, Germany), technology computer-aided design (TCAD) software provider Synopsys (Zurich, Switzerland) and University of Rome 'Tor Vergata' spin-off Tiberlab S.r.l. (Rome, Italy). The project will use its members' combined expertise in device design and nanomaterials to help revolutionize the design and implementation of future electronic and photonic devices.

Specifically, DEEPEN will develop an integrated open-source multi-scale simulation environment, targeted at problems common to future nanoscale electronic and photonic devices. New device simulators require an atomic-scale description of selected critical regions of a transistor or LED to capture details that are otherwise inaccessible. They must also resolve the considerable uncertainty in many critical parameters required for device optimization. DEEPEN is addressing both these issues, coherently combining state-of-the-art existing methods and developing new methodologies, integrated within a multiscale framework spanning from first-principles to macroscopic models.

DEEPEN brings together groups with expertise not just in simulation,

DEEPEN project team (left to right): professor Mathieu Luisier (ETH Zurich), Dr Lutz Geelhaar (Paul Drude Institute Berlin), professor Eoin O'Reilly (Tyndall), Dr Alvaro Gomez-Iglesias (Osram Opto Semiconductors), Dr Fabio Sacconi (TiberLab) and Dr Axel Erlebach (Synopsys).

but also in its application to device design and optimization. It builds on Tyndall and ETH Zurich's expertise in material and device properties, with experimental input from PDI also critical for validation of the multiscale models to be developed. Of the industry partners, Tiberlab will implement the multiscale software framework, Synopsys will provide technology computer-aided design (TCAD) simulation software, and industrial end-user Osram Opto Semiconductors will provide experimental validation and test the simulation environment for device design and investigation. Future code distribution will be supported through TiberLAB's existing support environment at www.tibercad.org.

The nanoscale models to be developed will address the challenging problem not just of predicting quantitatively the electronic bands and quantum phenomena at the nanoscale but also of linking these critical properties to overall device behaviour. The project emphasizes aggressive dissemination of results to maximize impact, including the organization of Training Schools and an International Workshop, as well as the release and support of demonstration software and the open-source interfaces. Overall, the project aims to strengthen European competitiveness, with clear routes to exploitation of the technology.

Funded by a €2.69m contribution under the European Union's Seventh Framework Program (EU FP7, subprogram NMP.2013.1.4-1), the three-year €3.82m project (from January 2014 to end-2016) was formally launched in Athens, Greece at the Industrial Technologies 2014 conference (9–11 April), which integrates nanotechnology, biotechnology, advanced materials and new production technologies, and offers opportunities for developing research and industry collaborations by showcasing research, innovations and rising companies from around Europe.

DEEPEN is a direct response to industry's need to track and analyse performance at the atomic scale of a design process. To address this issue, researchers aim to develop an efficient and robust framework that allows different computer codes to be merged. Using this open-source framework, the integrated simulation tools will enable developers to track a device's overall performance changes at a particularly detailed and precise level during testing.

"The DEEPEN project gives us an opportunity to work with leading academic and industry partners in this challenging but highly rewarding area," said O'Reilly at the conference. "Our work will have a direct impact on future device design and optimization. In addition, our development of open-source codes will help to open up this field to the wider research community".

DEEPEN is part of a cluster of five projects funded under FP7 that are being launched at the Multiscale Modelling workshop in Athens. The cluster is intended to enable knowledge exchange, in order to foster adoption of novel approaches for multi-scale modelling.

http://cordis.europa.eu/projects/rcn/110555_en.html
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A decade of solid-state lighting R&D highlights at ISCAS

Here we present a summary of the progress made in solid-state lighting by the Institute of Semiconductors, Chinese Academy of Sciences over the last 10 years.

Over the last decade, China has made great progress in solid-state lighting (SSL). R&D has undoubtedly played a key role in supporting China's SSL industry, with more than 50 institutes and universities involved in SSL R&D. In particular, there is one institute that should not be overlooked when discussing China's SSL R&D: the Institute of Semiconductors, Chinese Academy of Sciences (ISCAS). ISCAS proposed that the Chinese government support SSL R&D as early as 2003. It is now China's biggest institute in SSL R&D, with numerous achievements. Here we present its most important SSL R&D highlights.

VLED with low operating voltage and thermal resistance

Constrained by poor thermal and electrical conductivity of the widely used sapphire substrate, vertical-injection gallium nitride (GaN)-based light-emitting diodes (VLEDs) have recently been investigated extensively. Fabricated by removal of the insulating sapphire substrate and transferred to a new thermal and electrical conductive substrate, VLEDs have a lower operating voltage, lower thermal resistance and higher saturation currents, so they have been considered as the candidate for future high-power and high-efficiency LED devices.

Considering thermal dissipation, a method for manufacturing GaN-based LEDs with a back-side via hole structure has been adopted. By introducing the back-side via hole technique of silicon-based microelectronics processing into this method, the silicon oxide insulation layer in the

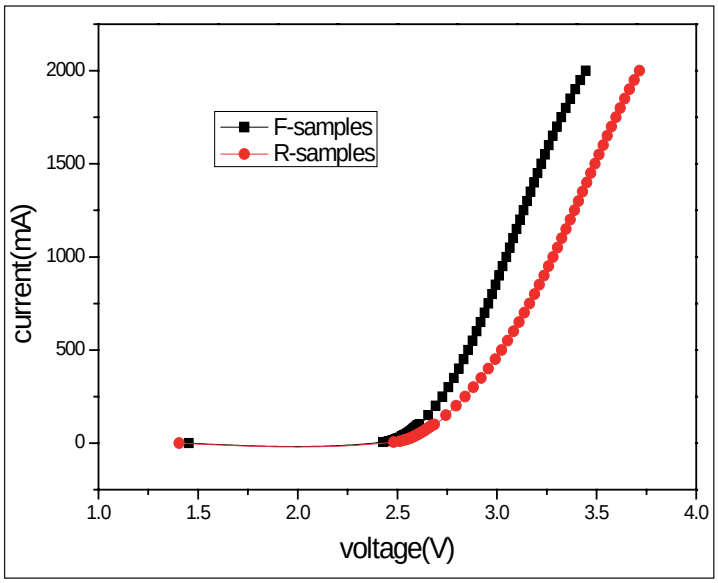


Figure 1. I–V curves of VLEDs with flat (F-samples) and roughed N contacts.

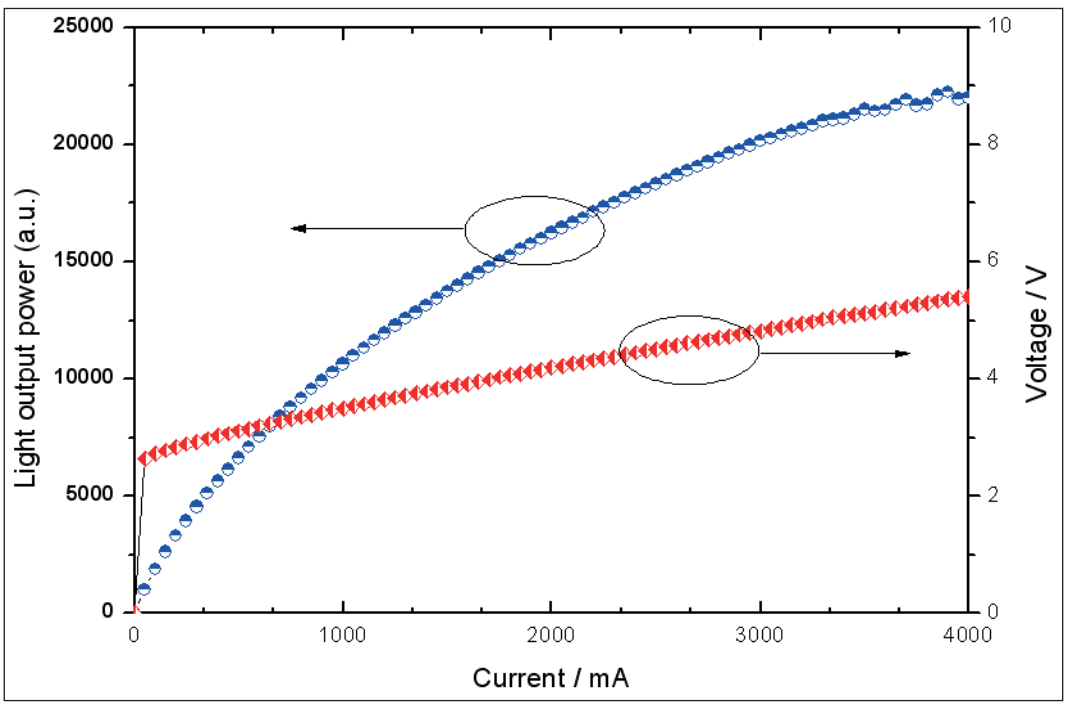


Figure 2. Transient saturation measurement of VLEDs.

heat-conducting path can be removed, and the silicon can be replaced by copper (whose heat conductivity is almost three times that of silicon). This enables the heat produced in the active region of the LED die to be conducted directly to the heat-sink through the metal, which is an excellent heat conductor, and the whole heat dissipation path includes no poor heat conductor, reducing thermal resistance as much as possible and realizing heat dissipation with 'sub-zero' thermal resistance. This method not only enables the LEDs to work at a larger operating current, but also improves the ability to work continuously for a long duration and enhances performance and reliability, facilitating the realization of power LEDs for illumination.

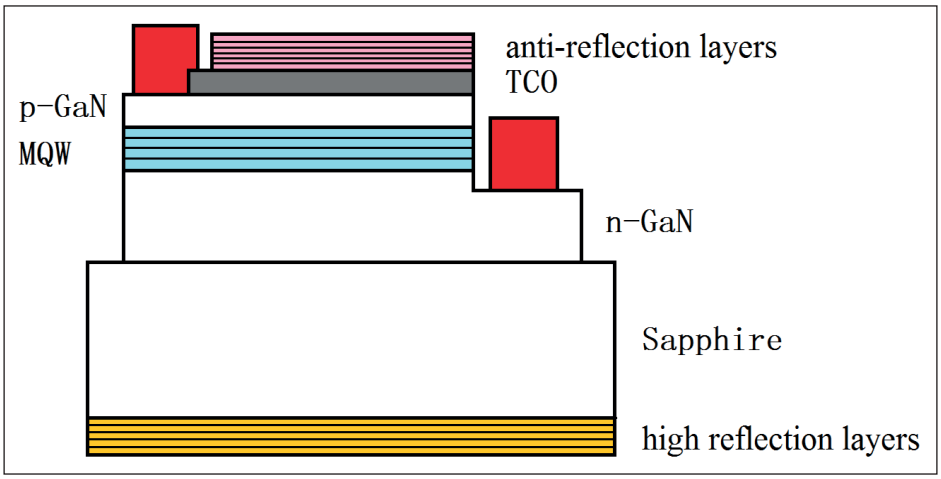


Fig. 3. Composite optical coatings used in LEDs.

As a p-type contact, nickel-silver (NiAg)-based metal layers were used, since they have high reflectivity in the visible light region. The p-type ohmic contact resistance was reduced through optimized p-GaN growth conditions and p-metal annealing. To reduce the n-type ohmic contact resistances, a new scheme for depositing metallization contacts was developed. This includes chemical cleaning, selectively wet etched surface roughing, and multiple Al-based metal layers were deposited on the n-type GaN. Chemical cleaning is effective in reducing the contact resistance.

These methods were used to fabricated VLEDs that showed extremely low operating voltage (2.75V@350mA), low reverse leakage current (0.015μA@-5V), low thermal resistance (2.5 K/W) and high saturation current.

(Related publications: Liancheng Wang, et al. 'Interface and Transport Properties of Metallization Contacts to Flat and Wet-Etching Roughed N-Polar n-Type GaN', ACS Applied Materials & Interfaces Vol. 5, Issue 12, pp5797 (2013).)

Composite optical coatings used in LEDs

The light extraction efficiency of GaN-based LEDs is quite low due to total internal reflection, Fresnel reflection, and absorption by GaN and electrodes. In lateral structure LEDs, the p-electrode is made of composite optical coatings with high transparency and high electrical conductivity. Another composite optical coating with high reflectivity is formed on the bottom surface of the sapphire substrate. When the light emitted from the active region transmits into the sapphire substrate, it is mostly be reflected back into the GaN epilayers and then mostly escapes from the top composite optical coatings into the free space, since the top composite optical coatings are anti-reflection layers.

To increase the extraction efficiency of the light emitted from a power GaN LED, a fabrication method has been developed for GaN flip-chip LEDs with both p-type and n-type electrodes formed by composite optical coatings. Since the contact electrodes for both p-GaN and n-GaN are formed from a composite optical coating comprising a transparent and electrically conductive film and an optical anti-reflection film, the light loss between the GaN medium and the transmission medium (e.g. air) can be reduced. Consequently, luminous efficiency is greatly improved.

As for a vertically structured chip, an optical composite electrode with high transparency on the top surface of the GaN LED epilayers is formed, and an optical composite electrode with high reflectivity is buried under the bottom surface of the GaN LED epilayers. In this LED structure, the light emitted from the active region mostly escapes from the top transparent electrode into space, and so light loss is reduced.

(Related publications: Xiaoyan Yi, et al. 'Research and Fabrication of High Power LEDs with Transparent Electrodes', Proc. of SPIE Vol. 6841, 68410B, (2007); Liancheng Wang, et al. "Combined transparent electrodes for high power GaN-based LEDs with long life time", 9th International Conference on Solid-State and Integrated-Circuit Technology, Vol. 1-4, p1051 (2008).)

Polarization-induced 3D hole gas

P-type conductivity has always been a technical difficulty for wide-bandgap III-nitride semiconductor materials. In 2010, a p-type doping method called polarization-doping was proposed by Simon in an N-face graded AlGaN layer (Science 327, p60, 2010). However, N-face GaN-based structures tend to have poor surface morphology and high impurity concentration, whether grown by metal-organic chemical vapor deposition (MOCVD) or molecular beam epitaxy (MBE). By using polarization-doping, researchers at ISCAS have achieved a three-dimensional hole gas (3DHG) in (0001)-oriented graded AlGaN. The hole concentration in the graded AlGaN layer is as high as ~10^{18}/cm^3 at room temperature (RT) and shows a weak tempera-

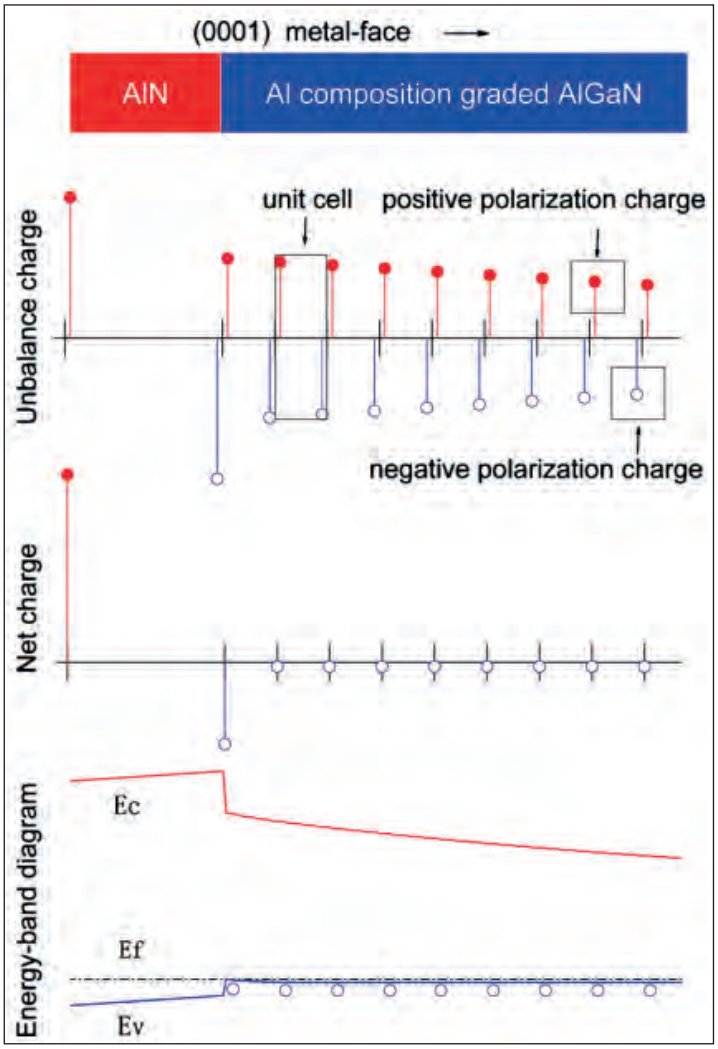


Figure 4. Schematic illustration of polarization-induced 3DHG in (0001)-oriented metal-face III-nitride structure.

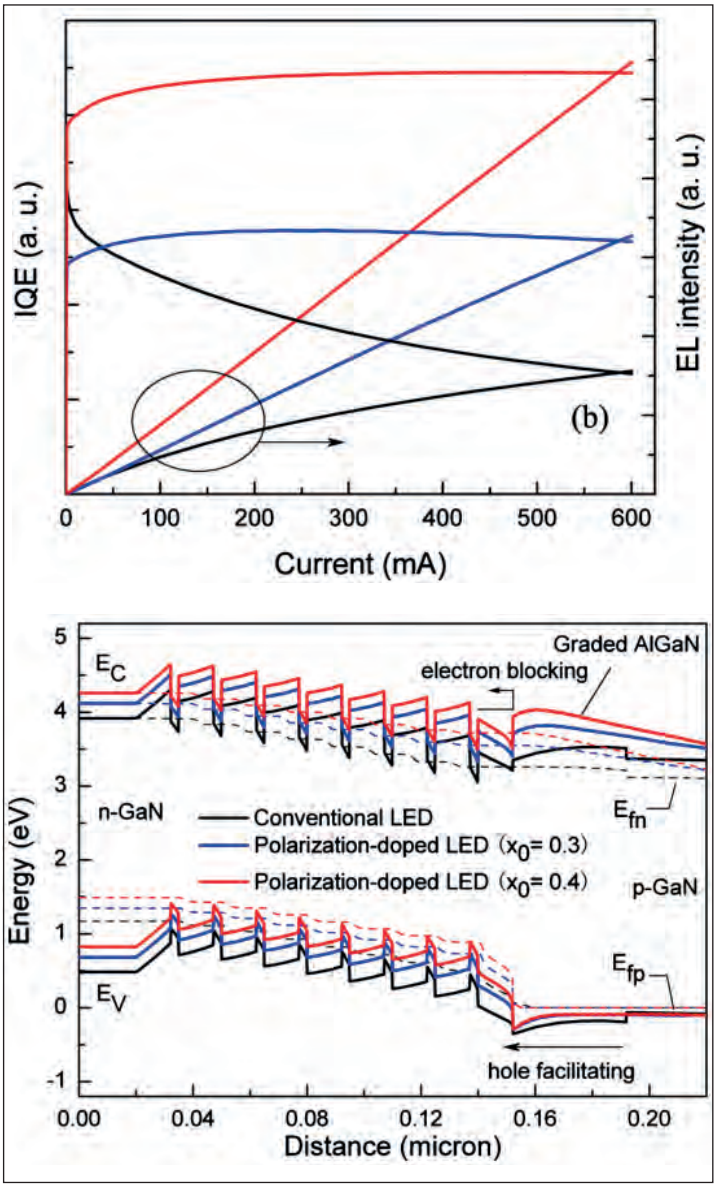


Figure 5. Optical performance and band diagrams of the polarization-doped LED and the conventional LED.

ture dependence.

The metal-face graded AlGaN is grown using a single-wafer home-made MOCVD reactor. Before growing the graded AlGaN layer, a 1μm-thick undoped AlN layer is deposited on the c-plane sapphire at 1200°C. Then a 100nm-thick Mg-doped graded $Al_xGa_{1-x}N$ layer (with Al composition ranging from x = 0.3 to 0) is grown on the AlN layer.

For the metal-face graded AlGaN layer grown on the AlN layer, it can be deemed as an N unit cells with an Al composition decreasing linearly from $x = x_0$ to 0. The unbalance bound sheet charge density is dependent on Al composition, which decreases as the Al composition decreases. The net bound sheet charge density at the interface of the ith and (i+1)th unit cell is then summed as $[(P_i^{sp}+P_i^{pe}) - (P_{i+1}^{sp}+P_{i+1}^{pe})]/q$. $P_i^{sp}-P_{i+1}^{sp} < 0$ and $P_i^{pe}-P_{i+1}^{pe} < 0$, so the net bound sheet charges are negative at the interface of each unit cell. Consequently, equivalent holes at the interface of each unit cell are induced from the acceptors (Mg) by the polarization field to neutralize the negative bound sheet charges. These holes spread over the graded AlGaN layer continuously, forming a mobile 3DHG.

The RT hole concentration of the graded AlGaN layer is $2.6\times10^{18}cm^3$, which is one order of magnitude higher than that of the GaN layer ($2.5\times10^{17}cm^3$). As the temperature decreases, the hole concentration of the GaN layer drops exponentially, caused by carrier freeze-out due to the high activation energy of Mg in GaN. While for the graded AlGaN layer the hole concentration shows weak temperature dependence, it is as high as $4.5\times10^{17}cm^3$ when the temperature is down to 100K. This reveals that the holes in the graded AlGaN layer are induced by polarization, because the polarization doping does not need thermal ionization energy to activate. The RT resistivity of the graded AlGaN layer is 0.6Ωcm, lower than that of the GaN layer (1.8Ωcm), indicating enhanced p-type conductivity in the graded AlGaN layer. Besides, as the temperature decreases, the resistivity of the graded AlGaN layer increases more slowly than that of the GaN layer.

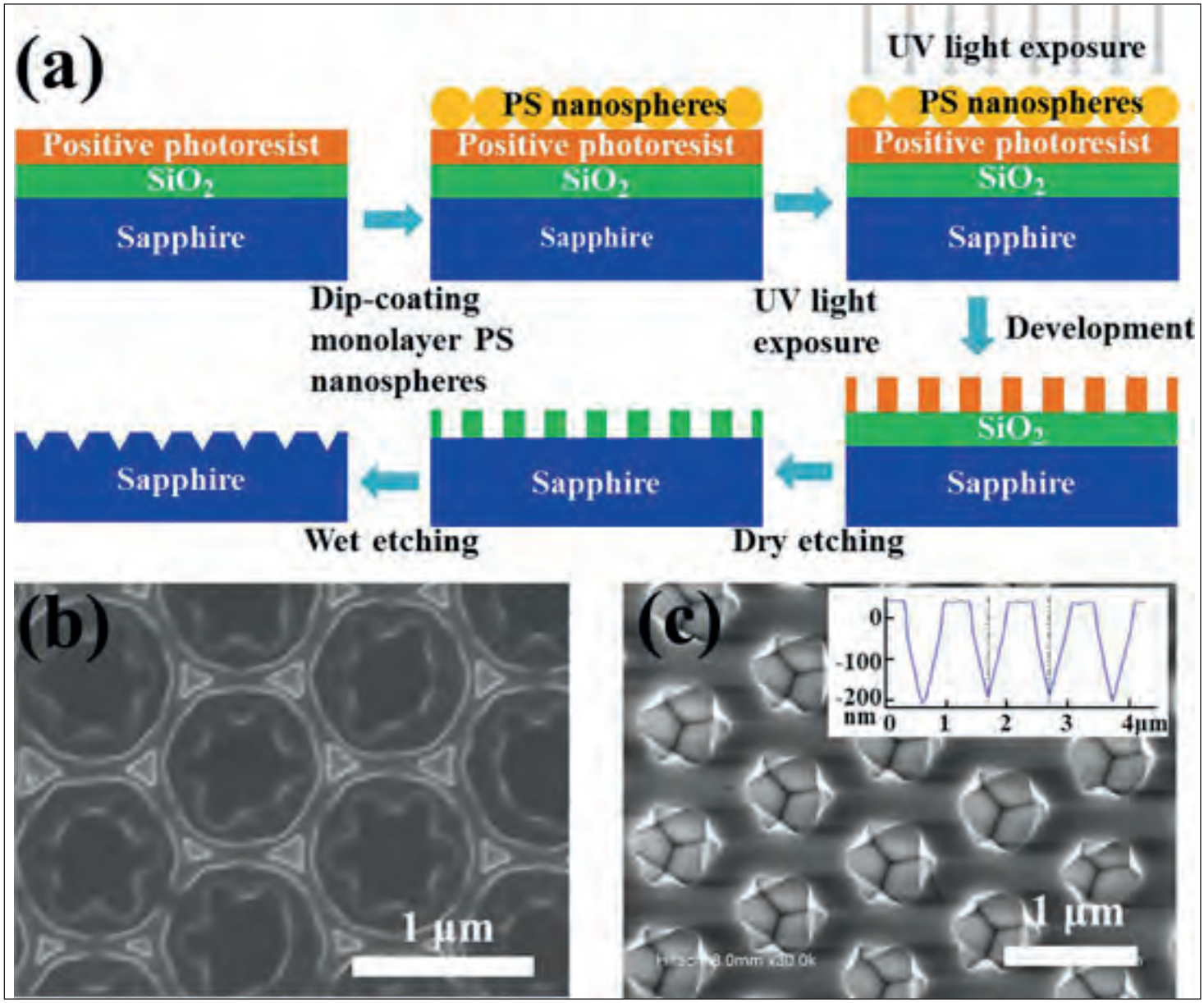


Figure 6. (a) Schematic of fabrication process flow to create nano-patterns on a sapphire substrate (NPSS). SEM images of the patterned photoresist (b) and wet-etched NPSS (c). Inset in Figure 6(c) shows line profile of patterns of NPSS by AFM measurement.

This p-type doping method overcomes the problem of high Mg activation energy in III-nitrides and paves the way for achieving high efficiency in wide-bandgap semiconductor light-emitting devices. The researchers studied the polarization-doped (0001)-oriented GaN-based LEDs by using APSYS software. The calculated results indicate that the electroluminescence (EL) intensity and the internal quantum efficiency (IQE) in the polarization-doped LEDs are enhanced significantly compared with the conventional LED due to the polarization-doped hole as well as the smooth valence band in the graded AlGaN layer, and consequently the enhanced hole injection. On the other hand, the efficiency droop in the polarization-doped LEDs is also improved compared with the conventional LED.

The influence of the degree of AlGaN gradation on polarization-doped LEDs has also been studied by the researchers. Because of the enhanced hole concentration caused by the increased degree of AlGaN gradation, the EL intensity and external quantum efficiency (EQE) of the polarization-doped LED are improved when x_0 is increased from 0.15 to 0.2. However, when x_0 is further increased to 0.25 and 0.3, the EL intensity and EQE are decreased due to the increased alloy scattering in the graded AlGaN and the larger strain in the MQWs, which reduce the hole injection and radiative recombination rate.

(Related publications: L. Zhang, et al. 'Three-dimensional hole gas induced by polarization in (0001)-oriented metal-face III-nitride structure', Applied Physics Letters 97, 062103 (2010); L. Zhang, et al. 'Theoretical study of polarization-doped GaN-based light-emitting diodes', Applied Physics Letters 98, 101110 (2011); L. Zhang, et al., Applied Physics Letters 98, 241111 (2011).)

AlGaN-based efficient DUV-LEDs on nano-patterned sapphire substrate

AlGaN-based UV-LEDs are promising for providing a good solution for SSL with high color rendering. It is also hoped that efficient deep UV LEDs would provide more energy-efficient compact solutions compared with existing fragile and hazardous mercury vapor lamps. Proposed applications of deep UV LEDs include disinfection, sensing, water purification, bio-medical, and communication. Key to achieving these aims is improved material quality.

Researchers at ISCAS have been developing nano-patterned sapphire substrates (NPSS), achieved with nano-sphere lithography (NSL), as a basis for the production of superior aluminium gallium nitride (AlGaN) semiconductor material for deep ultraviolet (UV) light-emitting diodes (LEDs) — see www.semiconductor-today.com/news_items/2013/AUG/LED_050813.html.

Sapphire patterning was achieved by photolithography through a mask consisting of polystyrene nanospheres that were then removed using deionized water (Figure 6). The pattern in the developed photoresist was transferred to an underlying hard mask layer of 200nm silicon dioxide using inductively coupled plasma (ICP) etch. Finally, the sapphire was wet etched using a mix of sulfuric and phosphoric acid solutions. The silicon dioxide was removed using hydrofluoric acid.

The pattern consisted of 230nm-deep concave triangular cones set in a hexagonal pattern of period 900nm. The unetched region between the cones was 400nm wide.

The growth of the UV LED epitaxial structure was through low-pressure metal-organic chemical vapor deposition (LP-MOCVD) with trimethyl-aluminium, trimethyl-gallium, and ammonia precursors, respectively, for the Al, Ga and N species. The structure began with 25nm of low-temperature 550°C AlN, before the whole 4μm AlN template was completed at 1200°C.

The AlN was found to coalesce after only 3μm. This is much sooner than other epitaxial layer overgrowth (ELOG) techniques using micro-stripe patterning that only coalesce after 10μm growth. Atomic force microscopy (AFM) over 5μm x 5μm fields gave a root-mean-square (RMS) roughness of 0.15nm. The AFM analysis also indicated a step-flow growth mode. X-ray analysis gave estimates for screw and edge dislocation densities of $1.6x10^7/cm^2$ and $1.2x10^9/cm^2$, respectively.

This AlN template material was used in further growth of the UV LED structure. The same structure was grown on flat sapphire with a 1μm AlN template layer. The n-AlGaN layer was found to have pure edge and mixed threading dislocation densities on NPSS and FSS substrates of ~$1.6x10^9/cm^2$ and ~$3.4x10^9/cm^2$, respectively. The reduced-density layer on NPSS was attributed to the higher-quality AlN template.

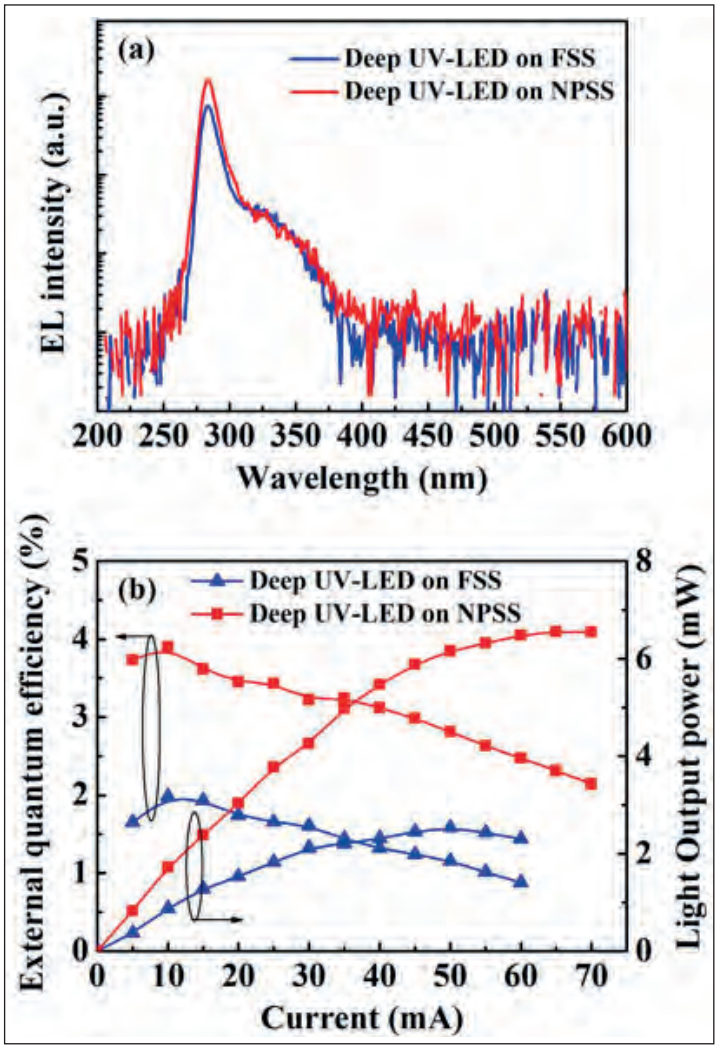


Figure 7. (a) EL spectra and (b) LOP-I-EQE curves of deep UV LEDs grown on NPSS and FSS.

Temperature-dependent photoluminescence studies at 10K and 300K suggested an internal quantum efficiency of 45% for the NPSS LED structure, compared with 28% for the FSS AlN template epitaxy.

The epitaxial materials were formed into 380μm x 380μm devices. The chips were flip-chip-mounted on silicon sub-mounts with gold-bump bonding. The majority of light in deep UV LEDs is expected to emerge through the sapphire substrate, since the p-GaN layer absorbs the radiation due to it having the narrowest bandgap in the structure. Device testing was performed with the sub-mounted chips attached to metal-core circuit boards with silver paste to improve heat dissipation.

The main EL peak occurred at 282nm with a weak shoulder peak near 330nm (Figure 7). It is thought that recombination in the electron-blocking layer was responsible for the shoulder peak. Hence, "further optimization of the electron-blocking layer is needed to suppress electron overflow into the p-cladding layer," the researchers write.

For the NPSS-based device, the light output power (LOP) at a current (I) of 20mA was 3.03mW, with EQE

of 3.45%. This was almost double that of the FSS-based LED. The saturation LOP for the NPSS LED was 6.56mW at 60mA current. The FSS device saturated at 2.53mW with 50mA injection.

Since the internal quantum efficiency does not account for all the improvement in performance, the light scattering at the AlN/NPSS interface reduces the total internal reflection and absorption in the p-GaN layer, and increases the photon's escape opportunity from the sapphire backside.

(Related publication: Peng Dong, et al. '282-nm AlGaN-based deep ultraviolet light-emitting diodes with improved performance on nano-patterned sapphire substrates', Applied Physics Letters 102, 241113 (2013).)

Summary

To summarize the above SSL R&D highlights, low-operating-voltage VLEDs, composite optical coatings, polarization-induced p-type doping and NPSS-based UVLEDs, are the epitome of endeavors by ISCAS in III-nitride LEDs. These innovations offer possible solutions for future LEDs targeted at general lighting. In future, SSL is expected to replace conventional lighting applications, such as incandescent and fluorescent lamps. All the research work at ISCAS is carried out with this aim. By combining the novel technologies developed at ISCAS, high-power white LEDs with efficiency above 180lm/W have been achieved. This value is much higher than the efficiency of incandescent and fluorescent lamps.

ISCAS' aim is focused not only on novel lab-level research but also on applying R&D results to the SSL industry. In fact, this has been done through Yangzhou Zhongke Semiconductor Lighting Co and Hunan HuaLei Optoelectronic Corp (two of the main Chinese LEDs companies). Yangzhou Zhongke Semiconductor Lighting Co's LED epitaxy technique came almost entirely from ISCAS on the firm's foundation several years ago, and it now has more than 50 MOCVD systems. For Hunan HuaLei Optoelectronic Corp, ISCAS contributed greatly to the firm's device processing. ISCAS has also performed collaborative research with many other Chinese LED companies, including Xiamen San'an Optoelectronics Co and Foshan Nationstar Optoelectronics Co. Through close collaboration with the firms, ISCAS has transferred its novel techniques to industry. It is now more concerned with LED reliability, lifetime prediction, standards, etc, and is confident in overcoming these issues. ■

http://english.semi.cas.cn

Improving LED efficiency through InN nanostructures

Bridging the green gap by using quantum confinement.

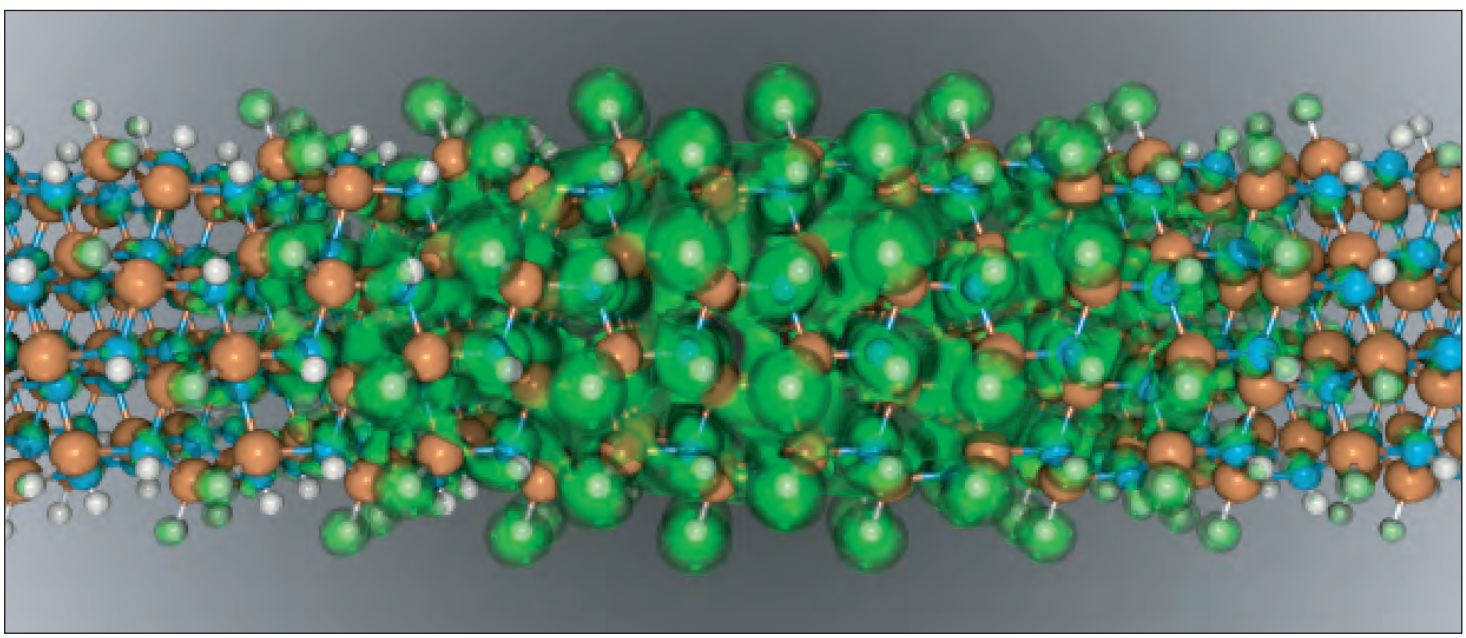
The US Department of Energy's National Energy Research Scientific Computing Center (NERSC) has conducted simulations showing that nanostructures half the width of a DNA strand could enhance the efficiency of LEDs. In particular, efficiency improvements were notable in the 'green gap' portion of the spectrum where efficiency in traditional LED is known to fall (Dylan Bayerl and Emmanouil Kioupakis 'Visible-Wavelength Polarized Light Emission with Small-Diameter InN Nanowires', published online on 14 February 2014, DOI: 10.1021/nl404414r; to be featured in the July issue of Nano Letters).

Using NERSC's Cray XC30 supercomputer 'Edison', Dylan Bayerl and Emmanouil Kioupakis in the University of Michigan's Department of Materials Science and Engineering found that indium nitride (InN), which typically emits infrared light, will emit green light if reduced to 1nm-wide wires. Moreover, just by varying their sizes, the nanostructures could be tailored to emit different colors of light, which could lead to more natural-looking white lighting while avoiding some of the efficiency loss that existing LEDs experience at high power. "Our work suggests that indium nitride at the few-nanometre size range offers a promising approach to engineering efficient, visible light emission at tailored wavelengths," says Kioupakis.

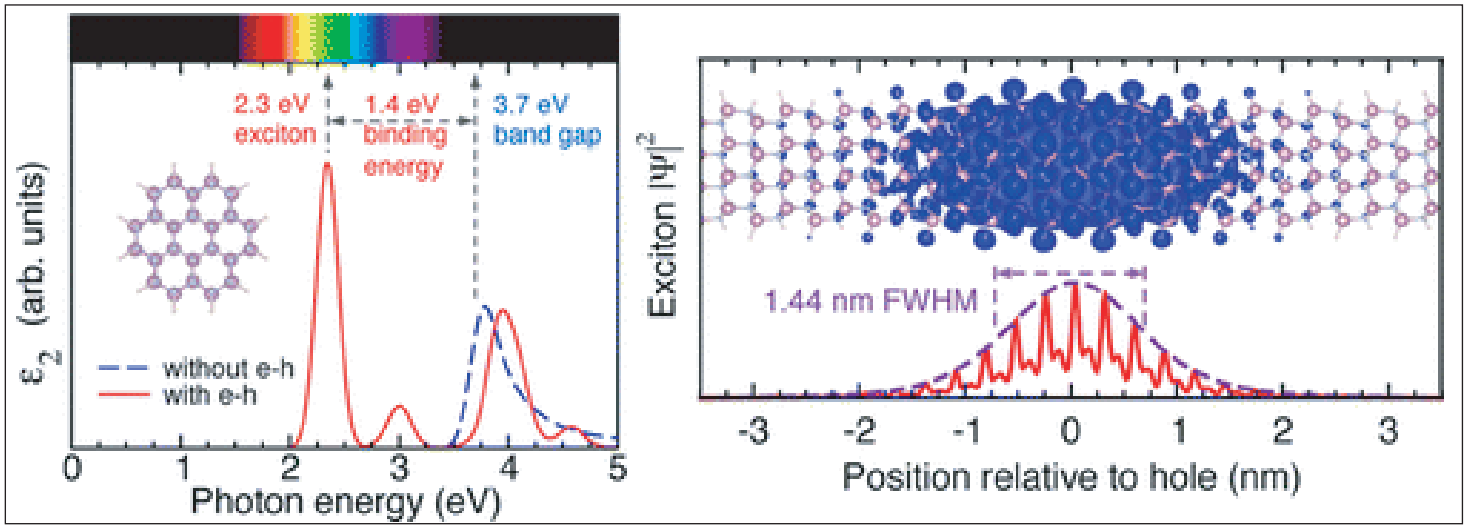
In existing multi-layered LED chips, the outer layers are doped with elements that create an abundance of electrons on one layer and too few (i.e. 'holes') on the other. When the chip is energized, the electrons and holes are pushed together, confined to the intermediate quantum-well layer where they are attracted to combine, shedding their excess energy (ideally) by emitting a photon.

At low power, nitride-based LEDs (most commonly used in white lighting) are efficient, converting most of their energy into light. But when the power is turned up to levels that could light up a room, the efficiency plummets. This 'efficiency droop' effect is especially pronounced in green LEDs, giving rise to the 'green gap'. Nanomaterials offer the prospect of LEDs that can be grown in arrays of nanowires, dots or crystals. The resulting LEDs could not only be thin, flexible and high-resolution, but efficient as well.

"If you reduce the dimensions of a material to be about as wide as the atoms that make it up, then you get quantum confinement. The electrons are squeezed into a small region of space, increasing the bandgap [the energy difference between electrons and holes]," Kioupakis notes. The photons emitted when electrons



This simulation of a 1nm-wide InN wire shows the distribution of an electron around a positively charged hole. Strong quantum confinement in these small nanostructures enables efficient light emission at visible wavelengths. (Visualization: Burlen Loring, Lawrence Berkeley National Laboratory)



Quantum confinement in 1nm-wide InN nanowires shifts optical emission to the visible range at green/cyan wavelengths and inverts the order of the top valence bands, leading to linearly polarized visible-light emission. It also leads to large exciton binding energies of 1.4eV and electronic band gaps in excess of 3.7eV.

and holes combine are hence more energetic. Since the bandgap determines the wavelength of the emitted light (and the wider the bandgap, the shorter the wavelength of light), quantum confinement hence produces shorter-wavelength light.

The bandgap energy for bulk InN is quite narrow (just 0.6eV), so it produces infrared light. In Bayerl and Kioupakis simulated InN nanostructures, the calculated bandgap increased, leading to the prediction that green light would be produced with an energy of 2.3eV. "If we can get green light by squeezing the electrons in this wire down to 1nm, then we can get other colours by tailoring the width of the wire," says Kioupakis. A wider wire should yield yellow, orange or red. A narrower wire, indigo or violet," he adds.

This bodes well for creating more natural-looking light from LEDs. By mixing red, green and blue LEDs, engineers can fine tune white light to warmer, more pleasing hues. The 'direct' method is not practical currently, because green LEDs are not as efficient as their blue and red counterparts. Instead, most existing white lighting comes from blue LED light passed through a phosphor (a solution similar to fluorescent lighting, and not much more efficient). Direct LED lights would not only be more efficient, but the colour of light they produce could be dynamically tuned to suit the time of day or the task at hand.

Using pure InN, rather than layers of alloy nitride materials, would eliminate one factor that contributes to the inefficiency of green LEDs: nanoscale composition fluctuations in the alloys. These have been shown to impact LED efficiency.

Also, using nanowires to make LEDs eliminates the problem of lattice mismatch between layers of different material in layered devices. "When the two materials do not have the same spacing between their atoms and you grow one over the other, it strains the structure, which moves the holes and electrons further apart, making them less likely to recombine and emit light," says Kioupakis. "In a nanowire made of a single material, you do not have this mismatch and so you can get better efficiency," he adds.

The researchers also suspect that the nanowire's strong quantum confinement contributes to efficiency by squeezing the holes and electrons closer together (a subject for future research). "Bringing the electrons and holes closer together in the nanostructure increases their mutual attraction and increases the probability that they will recombine and emit light," Kioupakis says.

While this result points the way towards a promising avenue of exploration, the researchers emphasize that such small nanowires are difficult to synthesise. However, they suspect that their findings can be generalized to other types of nanostructures, such as embedded InN nanocrystals, which have already been synthesised in the few-nanometres range.

NERSC's newest flagship supercomputer 'Edison' was instrumental in the research, says Bayerl. The system's thousands of compute cores and high memory-per-node allowed Bayerl to perform massively parallel calculations with many terabytes of data stored in RAM, making the InN nanowire simulation feasible. "We also benefited greatly from the expert support of NERSC staff," notes Bayerl. Burlen Loring of NERSC's Analytics Group created visualizations for the study. The researchers also used the open-source BerkeleyGW code, developed by NERSC's Jack Deslippe.

The work was supported as part of the Center for Solar and Thermal Energy Conversion, an Energy Frontier Research Center funded by the US Department of Energy's Office of Science. ■

www.nersc.gov
http://cs.lbl.gov
http://pubs.acs.org/doi/abs/10.1021/nl404414r

Enabling high-voltage InGaN LED operation with ceramic substrate

Better thermal conductivity reduces self-heating performance degradation, report Taiwan National Central University and Epistar.

Researchers associated with Taiwan National Central University and Epistar Corp are developing a method to transfer indium gallium nitride (InGaN) light-emitting diodes (LEDs) to ceramic aluminium nitride (AlN) substrates for high-voltage operation [Meng-Lun Tsai and Kun-Yu Lai, Appl. Phys. Express, vol7, p022103, 2014].

The ceramic substrate is more thermally conductive than the sapphire commercially used as a growth substrate for nitride semiconductor heterostructures. The higher thermal conductivity reduces self-heating effects, which negatively impact LED performance.

The high-voltage operation is enabled by connecting 16 electrically isolated sub-devices in series, reducing the injection current and thus delaying the efficiency droop that afflicts nitride semiconductor LEDs at increasing current.

The epitaxial material for the LEDs was grown on c-plane sapphire using metal-organic chemical vapor deposition (MOCVD). The layers consisted of a GaN buffer, n-GaN contact, InGaN/GaN multiple quantum well, p-AlGaN electron-blocking layer, and p-GaN contact. The electroluminescence wavelength was ~450nm (blue).

Fabrication began with deposition of a nickel/silver mirror on the p-contact layer, followed by titanium/aluminium/indium/gold/titanium for flip-bonding to the ceramic AlN substrate. The thermal conductivity of the substrate from Maruwa was 230W/m-K. The sapphire was then detached from the nitride layers by laser lift-off.

The HV-ceramic LEDs are formed by mesa etching down to the ceramic to create 4x4 cell arrays. The n-GaN surface was roughened with a potassium hydroxide wet etch. The purpose of roughening is to enhance light extraction by reducing the total internal reflection at the n-GaN surface due to its large refractive index contrast with air. The sidewalls of the cells were passivated with aluminium oxide. The cells were connected in series with a series of bridges and contacts made with chromium/gold metallization.

Similar devices were produced with transfer to silicon substrates. However, the series connection is difficult to achieve since the substrate is conductive. In view of this, the device consisted of one large cell rather than a 4x4 array to give a low-voltage LED (LV-Si).

Also, HV-sapphire devices were produced in unflipped 4x4 arrays on the original sapphire substrate. Indium tin oxide (ITO) was used as a transparent conducting layer on the p-GaN, followed by aluminium oxide sidewall passivation and the creation of chromium/gold metal bridges and contacts for HV LEDs. An aluminium-based mirror was created on the back-side of the sapphire substrate in an attempt to improve light

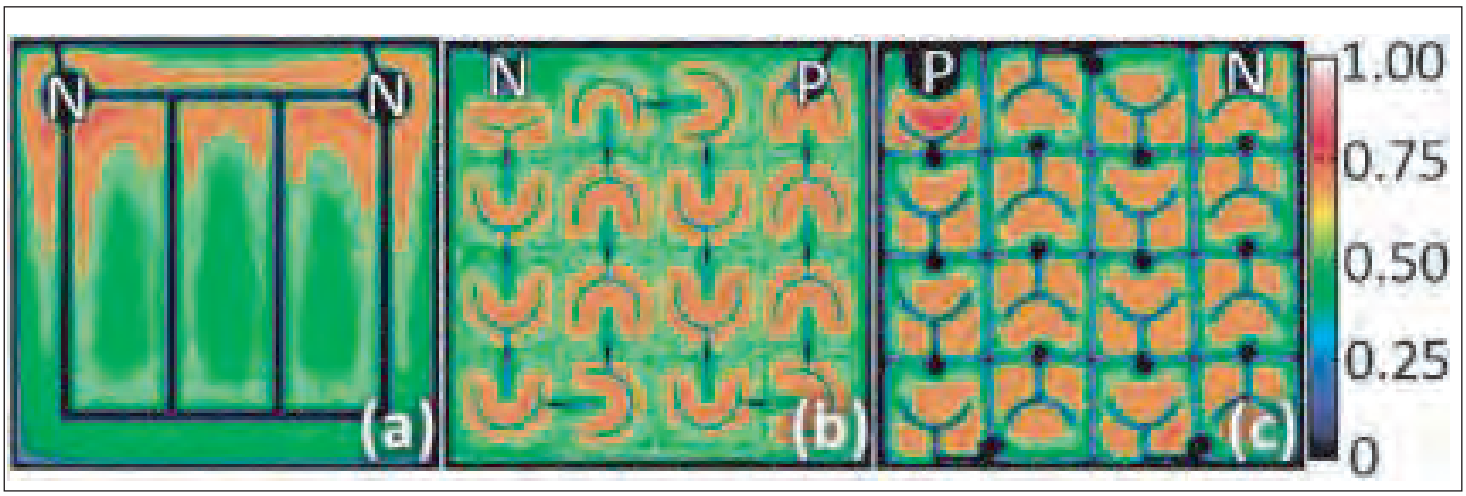


Figure 1. Normalized optical intensities of LEDs driven by current density of 76A/cm^2 for (a) LV-Si, (b) HV-sapphire and (c) HV-ceramic. P and N denote p-pad and n-pad, respectively.

extraction. The mirror was designed to have 99% reflectance in the blue region of the spectrum.

All the devices measured 45mil x 45mil (1.14mm x 1.14mm). With an injection current density of 76A/cm^2, the HV-ceramic device had much better current spreading (Figure 1). The flipped HV-ceramic LED benefited from the lower sheet resistance of the n-GaN window layer, compared with p-GaN. The LV-Si LED suffers from the difficulty of spreading over a wider area. The researchers estimate sheet resistance of the n-GaN window layer at 15Ω/square, compared with 40Ω/square for the p-GaN window of the HV-sapphire LED.

The operating voltage of the HV-ceramic LED is higher than that of the HV-sapphire device. This is attributed to the immature nickel/silver/p-GaN mirror contact, compared with the well developed ITO/p-GaN process. The researchers estimate the respective contact resistances at 8mΩ-cm^2 and 5mΩ-cm^2.

Tsai and Lai comment: "As the preparation of the Ni/Ag alloy is still under development, the operation voltage of the HV-Ceramic device is expected to be reduced once the fabrication parameters are further optimized."

Output power was measured in an integrating sphere with the LEDs packaged using metal core printed circuit board, but without encapsulation (Figure 2). The measurement stopped when saturation was reached. The HV-ceramic device did not reach saturation before 450A/cm^2. "Such a high operation current density of 450A/cm^2 is rarely found in the literature," Tsai and Lai say.

The saturation of HV-sapphire and LV-Si is mainly attributed to self-heating due to the poorer thermal conductivities of the substrates: 36W/m-K for sapphire, 150W/m-K for Si, and 230W/m-K for ceramic AlN. As the devices heat up, the higher temperature activates defects and increases thermal velocities. Both factors increase non-radiative recombination, reducing efficiency.

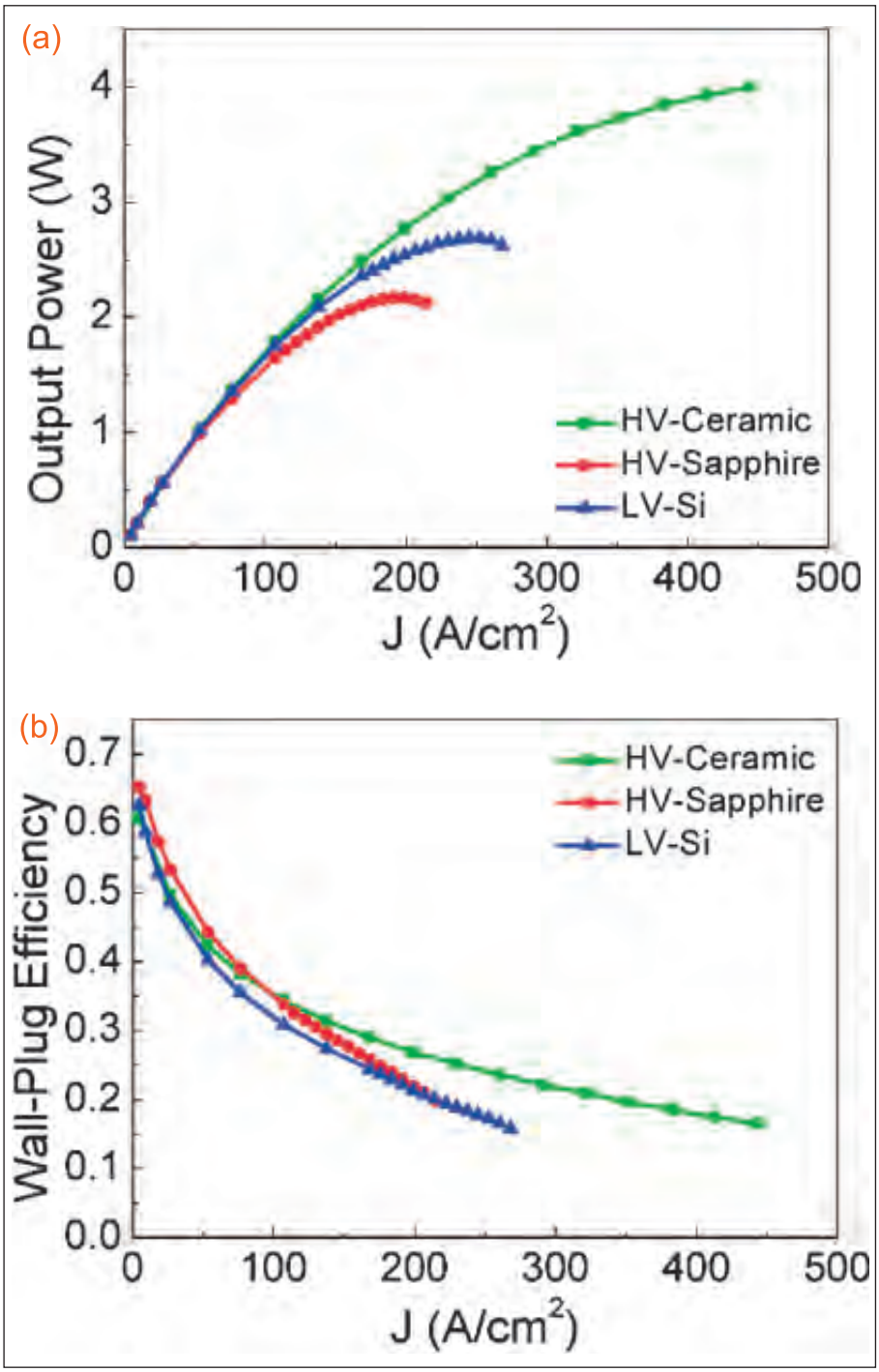


Figure 2. (a) Optical output power versus current density and (b) wall-plug efficiency versus current density for three types of LED.

The wall-plug efficiencies (WPE) at 210A/cm^2 are reduced from the peak values by 70%, 68% and 57%, respectively, for HV-sapphire, LV-Si and HV-ceramic. The WPE of HV-sapphire is slightly higher than the other devices at low currents due to a lower turn-on voltage as a result of the better ITO/p-GaN contact used.

The emission wavelength of the HV-ceramic device is more stable than the other devices. All the LEDs suffer from a blue-shift of about 1.5nm at low injection, due to screening at increased current/carrier densities of the quantum-confined Stark effect of the polarization-dependent electric fields in the structure. At higher currents, self-heating narrows the bandgap, leading to a red-shift.

Between 55A/cm^2 and 215A/cm^2, the respective red-shifts for HV-sapphire, LV-Si and HV-ceramic are 4.0nm, 1.5nm and 0.5nm. For HV-ceramic, the red-shift at 450A/cm^2 is less than 4nm. ■

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Author: Mike Cooke

Indium gallium nitride LEDs produced at 480°C

Japan researchers develop low-temperature process that could lead to low-cost manufacturing of nitride LEDs on large-area glass substrates.

Researchers in Japan have produced working indium gallium nitride (InGaN) semiconductor light-emitting diodes (LEDs) using a low-temperature (480°C) pulsed sputtering deposition (PSD) process [Eiji Nakamura et al, Appl. Phys. Lett., vol104, p051121, 2014].

The team from University of Tokyo and Japan Science and Technology Agency's CREST fundamental science program is working towards the production of nitride semiconductor LEDs on large-area glass substrates. While traditional GaN device production substrates of sapphire or even silicon are limited to less than 300mm diameter, glass panels are available in sizes of 2m x 2m and more.

However, glass softens above 500°C, well below the conventional metal-organic chemical vapor deposition (MOCVD) growth temperature of ~1000°C.

The Tokyo/CREST team has developed the PSD technique as a way to reduce growth temperatures: "The PSD growth technique has a unique feature of enhanced surface migration of growth precursors due to the pulsed supply of group III metals, which leads to a dramatic reduction in the growth temperature of nitride films."

All epitaxial layers were grown at 480°C on semi-insulating GaN templates on sapphire substrate. As is often the case with GaN-based devices, the difficult/critical part is finding a suitable methodology for creating p-type (hole) conduction through magnesium (Mg) doping.

Table 1. Carrier concentration and mobility of Mg-doped GaN films with different growth stoichiometries.

Growth condition	Carrier type	Carrier concentration ($/cm^3$)	Mobility (cm^2/V-s)
Ga-rich	n-type	$1.5x10^{19}$	42
Stoichiometric	p-type	$3.0x10^{17}$	3.1
N-rich	n-type	$4.7x10^{18}$	22

The PSD growth technique has a unique feature of enhanced surface migration of growth precursors

At such low growth temperatures, such layers can suffer from incorporation of donor-like native point defects and residual impurities. Tests on Mg-doped GaN on the template were first carried out to optimize the process to bring these problems under control (Table 1). The researchers found that they had to grow the layer under near stoichiometric conditions (i.e. with the gallium and nitrogen supply balanced) to achieve p-type conduction.

In addition, the p-GaN layer exhibited a "clear step and terrace structure" with a root-mean-square (RMS) surface roughness of 0.67nm, as determined by atomic force microscopy (Figure 1). The researchers suggest that the improvement in Mg-doping for near-stoichiometric GaN was due to the improved surface morphology and reduction in number of

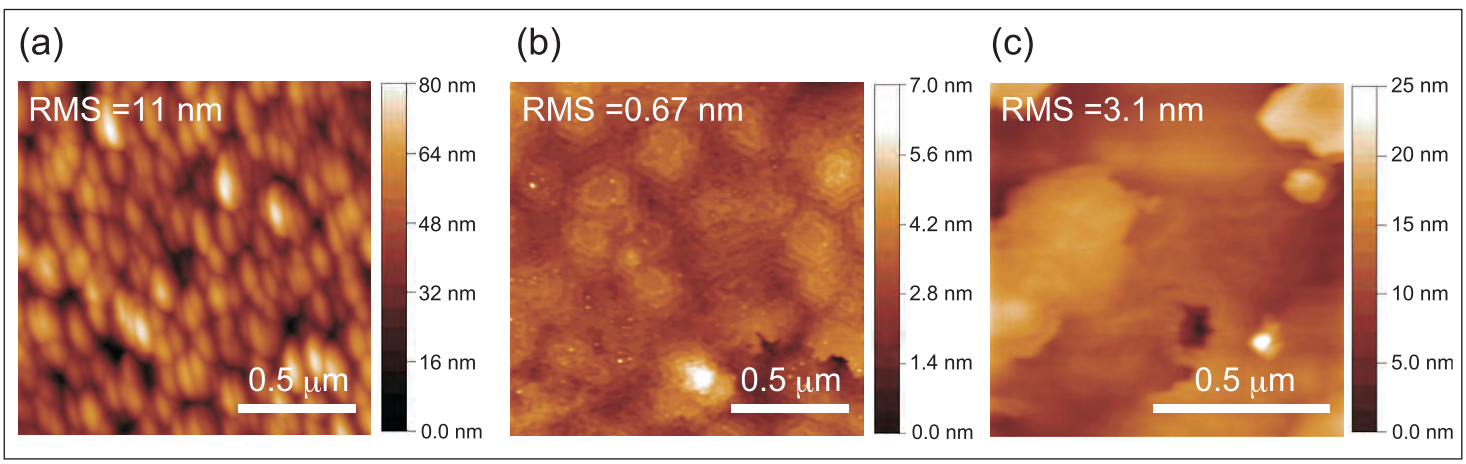

Figure 1. AFM surface images of Mg-doped GaN films grown at 480°C under (a) N-rich, (b) near-stoichiometric, and (c) Ga-rich conditions.

point defects. Temperature-dependent Hall measurements gave an activation energy estimate for the Mg acceptors of 153meV, comparable with values obtain in conventional high-temperature MOCVD.

Using these results, the researchers attempted to produce LEDs at 480°C with n-GaN, 30nm InGaN, and 300nm p-GaN layers. The indium content of the InGaN was determined to be 0.33, according to x-ray analysis. Temperature-dependent photoluminescence measurements gave a value of 24% for the internal quantum efficiency (IQE).

Current–voltage measurements showed "good" rectification with a –5V reverse bias current leakage of $3x10^{-5}$A. The clear orange electroluminescence emission wavelength was around 640nm (Figure 2).

Combining the results of this research and a recent demonstration of fabrication of nearly single-crystalline nitride-based LEDs on an amorphous substrate using a graphene buffer layer by the same team, the researchers hope to produce nitride-based LEDs on glass. ■

http://dx.doi.org/10.1063/1.4864283

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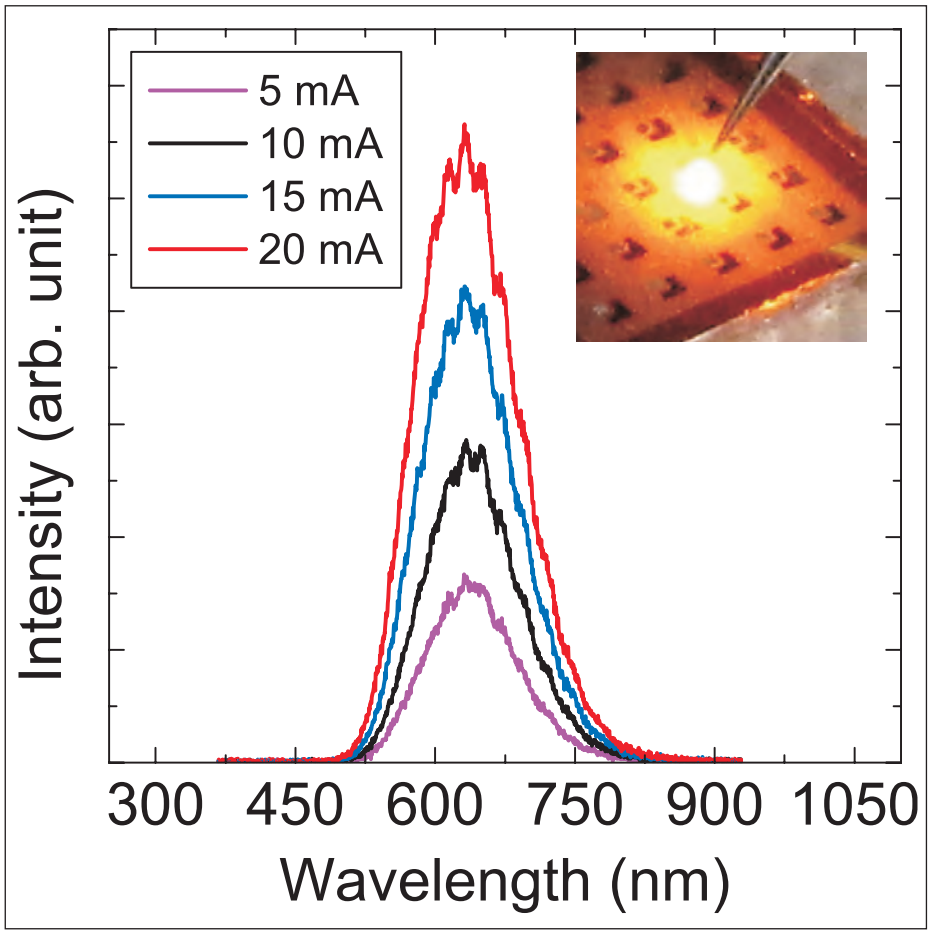


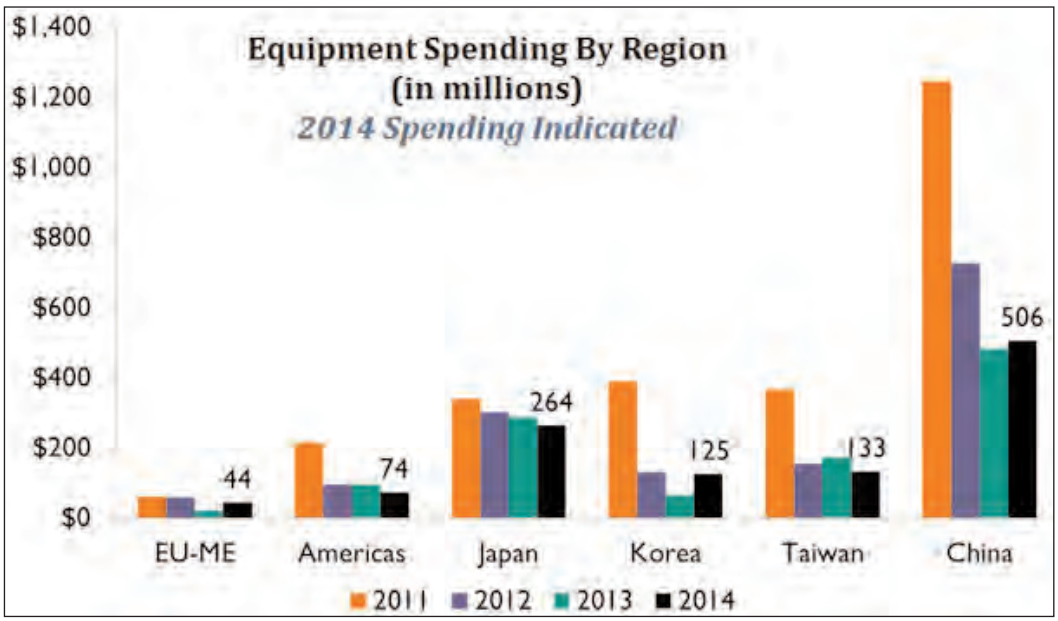
Figure 2. Electroluminescence spectra of LED structure grown at 480°C at forward currents from 5mA to 20mA. Inset: optical image of orange electroluminescence at forward current of 20mA.

LED investment to recover in light of solid-state lighting adoption

After two years of decline, LED epi/chip equipment spending is stabilizing in 2014 and will grow in 2015, says Clark Tseng of SEMI.

During the LED Taiwan and LED China events in March, participants were optimistic about the LED market outlook due to rising adoption for general lighting.

An early indicators is that LED chip makers and packaging houses in Taiwan are posting much stronger revenue growth in first-quarter 2014 compared to the same period last year. While the LED industry is eyeing soaring growth of the lighting market, the 'legacy' LCD panel backlight markets is actually performing admirably. For smartphone and tablet LCD panels, LED demand is driven by growing screen size, higher resolution, and better color reproduction. In terms of TV backlighting, even though LED backlight penetration has nearly reached 100%, the growth will still come from growing average TV screen size and the rise of Ultra HD 4K TV, which will consume more LED chips.



The LED illumination market is now in the fast growth stage of its product life-cycle. Some forecasts are predicting that LED lighting adoption will grow more than 50% annually over the next three years. Currently, the largest LED lighting market is retrofit lamps. Various vendors are aggressively pushing 40W/60W-equivalent LED bulbs to the market. With the banning of incandescent bulbs and the rise of environmental awareness, consumers are more willing to choose LEDs over other alternatives. Besides retrofit lamps, other major lighting markets — e.g. outdoor, retail & hospitality — are expected to drive further growth in the years to come. Both Government advocacy and consumers' adoption will be the locomotive of LED market growth.

From the LED makers' point of view, the competition has now swung from lumen per watt to lumen per dollar. Cost reduction has become the main priority to fight off price erosion and also to drive market demand. Migration to larger substrate size is one of those approaches to reduce chip cost. Although leading LED chip makers are in mass production on 4" and 6" substrates, the industry is now moving towards 6" and 8" gallium nitride-on-silicon production. Investment in GaN-on-Si LEDs and trial production is occurring worldwide, with companies in Japan, Korea and China the most aggressive in pursuing this technology. Other cost-reduction efforts can be found on epitaxy and substrate processes and in packaging, i.e. wafer-level packaging (WLP) LEDs, flip-chip LEDs, and other technologies.

In terms of epitaxy/chip investment, SEMI's data shows that, after two years of recession, the investment level is stabilizing in 2014. China is the region showing the strongest new investment and capacity additions (driven by leading chip makers in both Taiwan and China). Metal-organic chemical vapor deposition (MOCVD) is still the key cost factor in the epitaxy process, but other equipment categories such as lithography, etch, test and inspection are gaining momentum as far as optimizing productivity in order to lower costs. LED investment is unlikely to return to the level of 2010/2011 spending, but improvement is expected in 2015 with the increasing adoption of solid-state lighting (SSL). ■

www.semi.org/en/Store/MarketInformation/OptoLEDFabForecast

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Next investment cycle already begun in LED front-end equipment

Market to peak at nearly $580m in 2015, with MOCVD comprising more than 80%, forecasts Yole Développement.

Driven by the fanfare over (and over-estimation of) the LCD display market, the LED front-end equipment market experienced an unprecedented investment cycle in 2010–2011, driven mostly by metal-organic chemical vapor deposition (MOCVD) reactor shipments to new Chinese entrants who benefited from generous subsidies of the Chinese central and local governments in a bid to stimulate domestic chip production. Now, following a 18–24 month digestion period, the market is slowly recovering and will experience another investment cycle in 2014–2016, driven by demand for general lighting applications, according to the report 'LED Frond-End Equipment Market' from Yole Développement. However, this second cycle will be limited in value due to: improvements in equipment throughput and yields; increased competition; and potential consolidation in the industry.

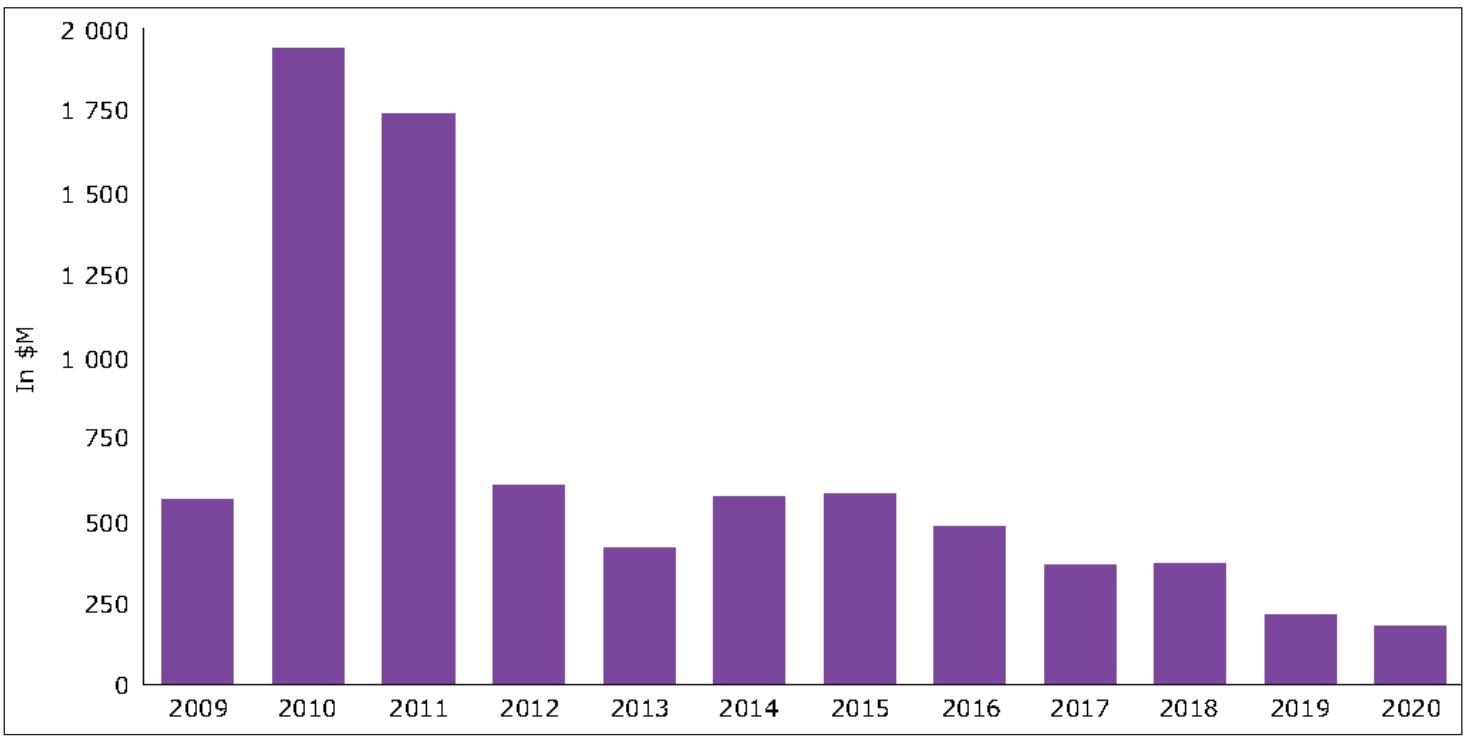
Indeed, LED makers initially relied on old semiconductor systems designed for other applications. However, now that the industry has reached a critical size, several LED-dedicated systems (which take into account the specificities of LED manufacturing) have been commercialized, notes Yole.

As a result, the equipment market will peak at nearly $580m in 2015, with MOCVD reactors representing more than 80% of business. The bulk of these are still being shipped to Chinese manufacturers or Taiwanese players transitioning to 4"-diameter wafers. Lithography, plasma etching, plasma-enhanced chemical vapor deposition (PECVD) and physical vapor deposition (PVD) equipment will follow a similar trend, Yole forecasts.

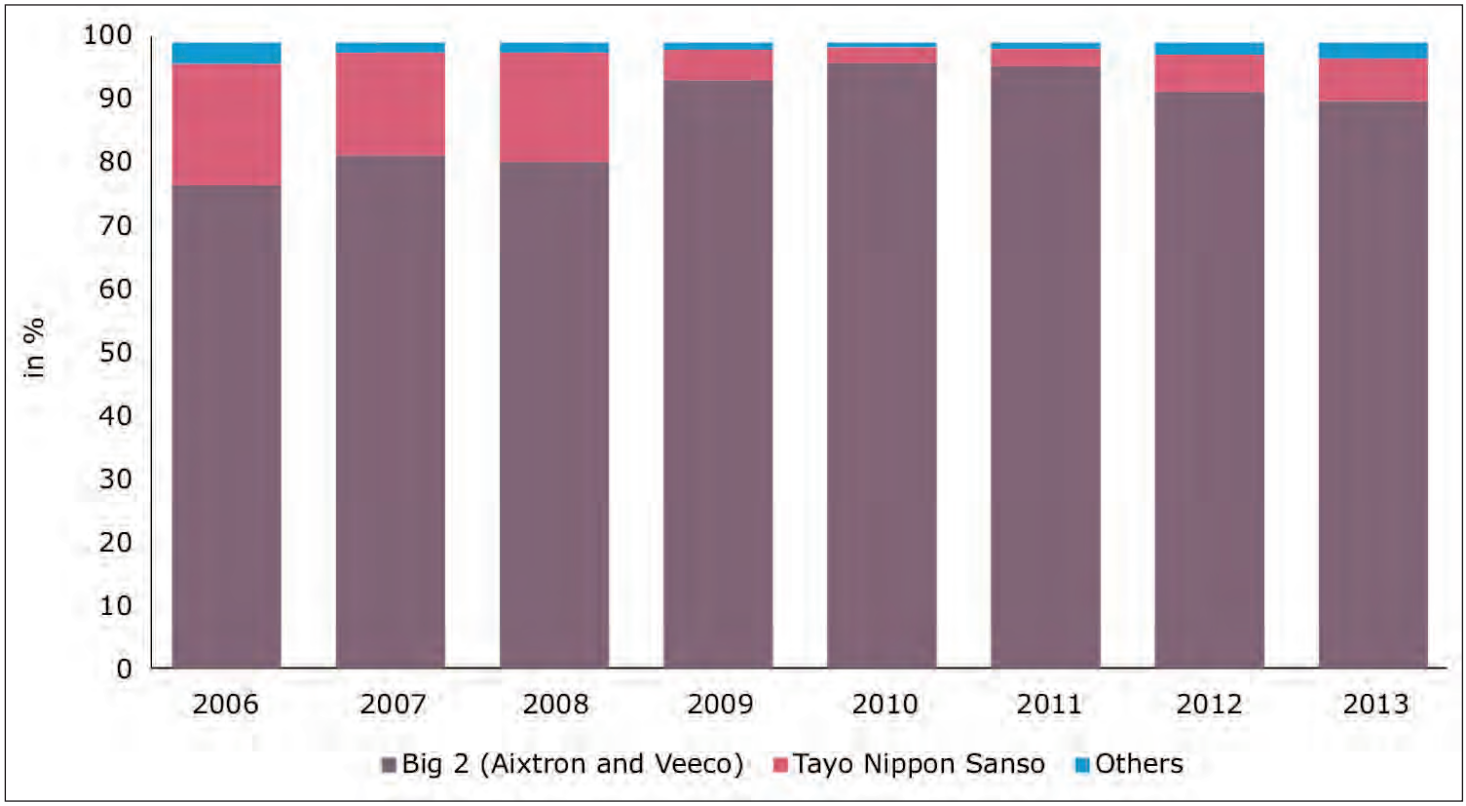
Different markets with different competitive landscapes

The LED epitaxy equipment market (MOCVD reactors) is very concentrated, under the control of the big three (Aixtron, Veeco and Taiyo Nippon Sanso) who represented nearly 97% of the market in 2013.

Comparatively, the lithography, plasma etching, PECVD and PVD equipment markets are much more fragmented, with several players battling to enlarge



LED front-end equipment revenue (MOCVD, lithography, dry etching, PECVD, PVD).



LED MOCVD reactor supplier market share (2006–2013).

their market share. For example, the top three suppliers of LED lithography equipment represented nearly 70% of the market in 2013, with the remaining 30% divided between more than 10 competitors.

Yole says that this situation is due to the specificities of the different LED front-end manufacturing process steps:

- LED epitaxy is quite specific and requires dedicated tools supplied by companies that have developed strong expertise.
- Other LED front-end manufacturing processes can use older or refurbished semiconductor systems designed for other applications. Also, with the growth of the LED industry, suppliers of LED-dedicated systems have also appeared. This has further fragmented these markets, now both traditional semiconductor equipment suppliers and new LED-dedicated equipment suppliers compete.

Increased competition in MOCVD, but no impact on market structure

The LED epitaxy equipment market has always been of central interest to equipment manufacturers due to the high average selling price (ASP), strong profitability, and large market volume (compared with other equipment sectors).

Since 2010, following the explosion of the LED TV market, more than 20 players (mostly from Asia) have tried to enter the MOCVD reactor market, but without real success: in 2013, these new suppliers represented only 3% of the market share (up only +2% compared with 2010).

This situation has arisen for two main reasons:

- New entrants have missed the first two LED growth cycles (small-display and large-display applications) that allowed leaders to build their expertise and their networks (sales offices, training centers etc). Even the big players in semiconductor equipment manufacturing, such as Applied Materials, did not achieve access in these markets.
- Revenue collected during the 2010–2011 investment cycle (totaling more than $2bn for MOCVD reactors, with more than 90% going to Aixtron and Veeco) allowed those firms to slash ASPs and initiate a price war to lever further market-entry barriers.

The current LED front-end industry is driven largely by cost reduction (as technological evolutions are reaching their saturation point), notes Yole. The main strategy developed by a new MOCVD reactor supplier is to focus on reducing cost of ownership (CoO), for example through a new heating system, new gas flow design, increased automation, etc. However, even if this is the best strategy to adopt, Yole does not expect new entrants to make a big gain in market share in future, as the finances and expertise of the big two suppliers far surpasses any of their competitors.

Yole concludes that, in the short term, only two types of suppliers (outside of the big three) will survive:

- suppliers that develop collaborations with some big LED makers;
- Chinese suppliers that are able to scrape together bits and pieces of the huge local market.

www.i-micronews.com

Sapphire core prices to resume rise in Q2–Q3/2014; wafer prices to rise slightly in Q2

Prices to stabilize by end-2014 then start falling in late 2015 as cost structure improves.

The sapphire industry recently ended an 18-month period of depressed pricing and achieved $936m in revenue for wafer products, according to the report 'Sapphire Market 2014' from Yole Développement.

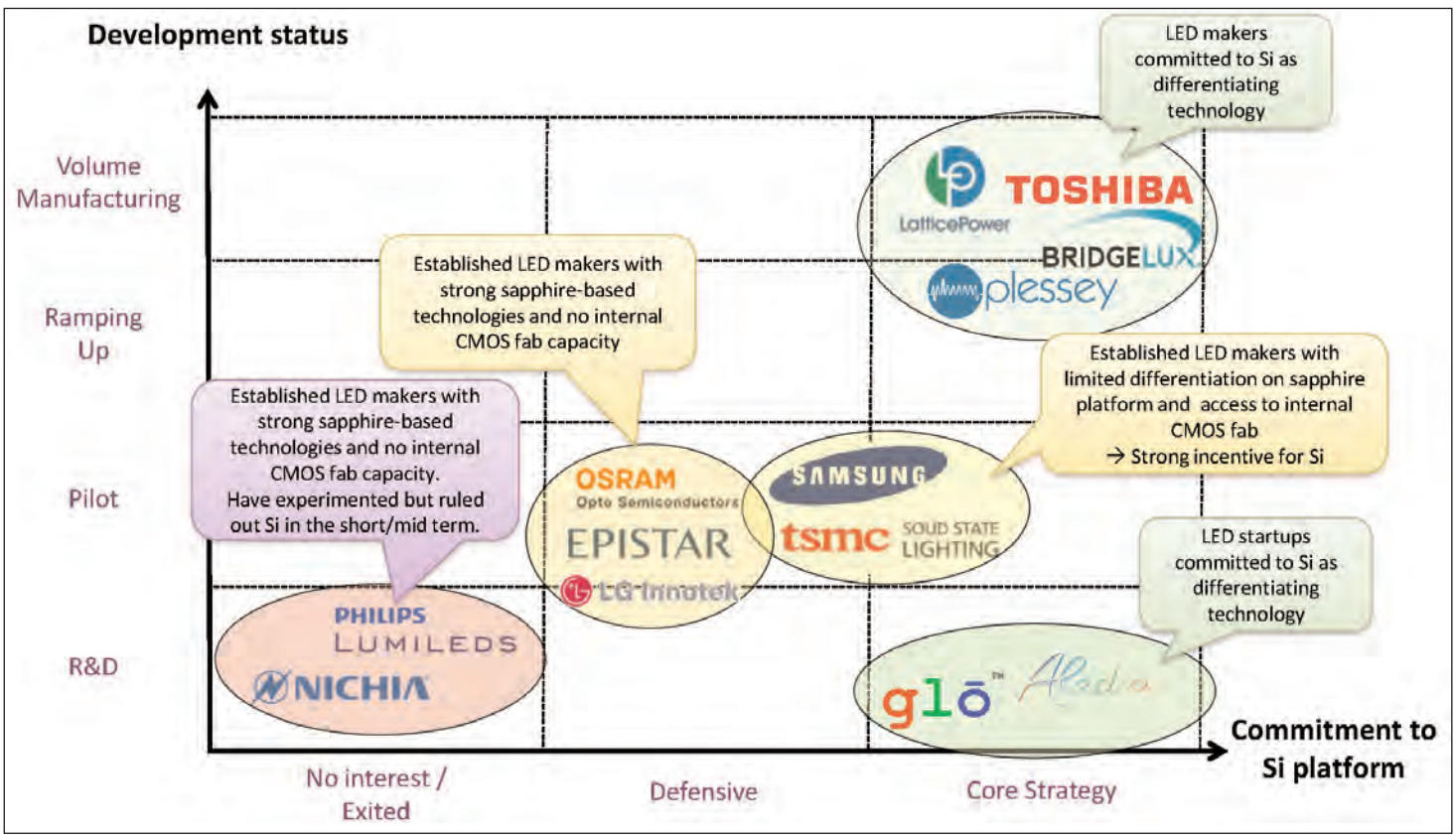
Recovery was helped by an increase in LED demand due to growing adoption in general lighting and a resilient LCD backlight market. But the saving grace was new consumer electronic (CE) applications: camera lens and fingerprint reader covers, mostly driven by Apple in 2013, notes Yole.

Overall, the growth in wafer demand will be enough to justify a capacity increase toward the end of 2014. For the longer term, Yole has analysed opportunities of alternative LED substrates — i.e. gallium nitride (GaN) and silicon (Si) — but concluded that sapphire will retain more than 90% of the market through 2020.

After almost 2 years of losses, core prices increased by more than 50% in 2013; tier-1 sapphire vendors are finally selling at prices close to breakeven costs.

After a short pause, Yole expects the upward trend to resume through Q2 and Q3/2014. However, leading vendors' interests are not to increase prices above levels that would allow tier-2 competitors to generate a profit as well. Yole therefore expects prices to stabilize by the end of this year.

Due to strong competition, last year wafer finishing firms did not pass the higher material costs on to their customers. Wafer prices remained stable in 2013 but will rise slightly in Q2/2014, forecasts Yole. For patterned sapphire substrates (PSS), which now dominate (with a penetration rate of 85%), prices could increase faster as supply currently falls short of demand in Taiwan. This will continue until leading suppliers increase capacity and emerging players in China ramp up and enter the supply chain later in 2014, forecasts Yole. Overall, sapphire prices should stabilize by the end of 2014 and start decreasing again in late 2015 as the industry keeps improving its cost structure, reckons Yole.

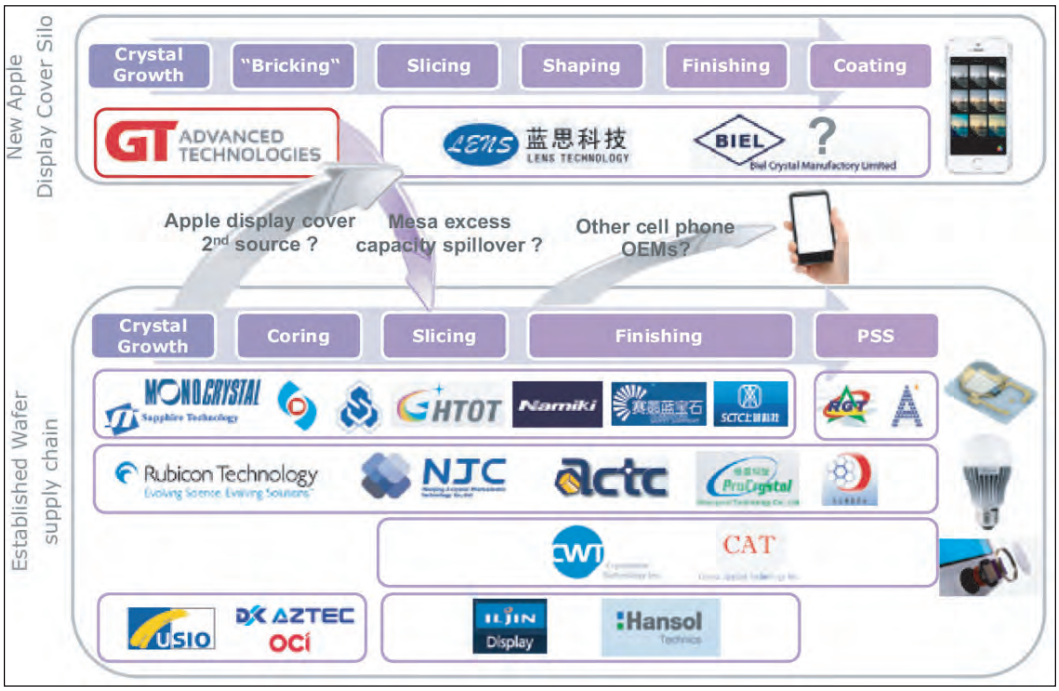


Apple could transform industry in 2014

Sapphire has been used for years in various luxury cell phones. In 2013 Yole indicated that adoption in more accessible models could start in 2014. This just happened with the introduction by Gionee of the first 'non-luxury' (<$1000) smartphone to feature a sapphire display cover. If adopted by leading cell-phone OEMs for their flagship models, total sapphire demand could increase by up to 2x by the end of 2014 and 20x by the end of the decade, reckons Yole.

On 4 November, Apple and GT Advanced Technologies Inc (GTAT) of Nashua, NH, USA (a provider of polysilicon production technology as well as sapphire and silicon crystal growth systems and materials for the solar, LED and electronics markets) announced a partnership to set up a large sapphire manufacturing plant in Mesa, AZ, USA. Yole says that it has analysed the deal and concludes that, exiting 2014, the plant could reach a capacity equivalent to more than twice the world's current capacity. Demand for home buttons and camera lens covers is expected to increase in 2014 and 2015 but, even with aggressive forecasts for smart watches (and assuming that Apple uses sapphire for its own model, which Yole doesn't believe it will), the firm could still tap into the existing supply chain to procure the sapphire it needs. It is hence difficult to justify this $1bn investment unless new applications needing a lot of sapphire come to market. From its analysis, Yole considers cell-phone display covers to be the most likely outlet for this capacity.

Yole modeled the Mesa operations and believes that the plant will make sapphire slabs that will then be sliced and polished by Apple subcontractors in China. The simulated slab cost of $6.40 per part would enable a $17 cost per finished display cover, with a path for under $13 ASP in the mid-term. The plant could deliver an equivalent of 42 million display covers in 2014 and more than 85 million in 2015, it is reckoned.



Possible future crossovers in supply chain for wafers and display covers.

Sapphire industry to benefit, but not all will win

With display applications, total revenue from polished sapphire products could rise at a compound annual growth rate (CAGR) of 50% through 2018 and exceed $5bn. Sapphire is now a strategic material for Apple that it will use as an element of differentiation versus Samsung and other competitors, says Yole. With the Mesa plant, Apple is creating its own supply chain, sheltered from any risk of shortage or price increase. But a second source is needed. Yole therefore expects other sapphire makers to increase capacity and join the Apple supply chain in the next few months.

There is still a risk associated with the unprecedented ramp up that GTAT and its suppliers have committed to. Even a few months from its targeted full-capacity operation, Apple could still walk away from the project. In addition, sapphire needs to deliver its promises of stronger displays. Bloggers can be creative in their ways to destroy phones and, if initial reports do not show a noticeable improvement in breakage rates, it will create a negative perception of the technology, notes Yole.

The impact of Apple's commitment to sapphire is positive for the industry, the market research firm reckons. It brings a lot of visibility to sapphire and could spur new applications. But we must guard against the notion that everybody will benefit, says Yole: 2014–2015 will be good for those with efficient cost structures that position themselves in the supply chain. Shortages might occur if other cell-phone OEMs decide to use sapphire as well. Their volume needs will be too small to justify an Apple-like investment, so they will tap into the existing supply chain; even a small percentage of adoption will lead to vast amounts of sapphire per the industry standards.

Now that the deal is sealed, it is in the interest of other sapphire vendors that GTAT and Apple succeed, thinks Yole: the Mesa plant provides unprecedented economies of scale and expertise in high-volume sapphire manufacturing. If Apple was to use less sapphire than anticipated, GTAT might flood the market with unused capacity at very competitive prices. The report thus thoroughly analyzes the impact on the sapphire industry and the supply chain.

www.yole.fr

Marked advancement in sapphire crystal quality from improved process control

John Ciraldo of Rubicon Technology discusses how sapphire substrate producers need to continually improve quality to keep up with advances in LED technology.

Synthesized sapphire material has been widely adopted by industry for many applications due to its broad range of favorable properties. For example, as one of nature's hardest materials, sapphire has been frequently utilized for optical applications in environments where abrasion and subsequent wear have proven problematic for softer materials, e.g. glass. However, by far the largest adoption of sapphire has been for the LED market, particularly for the application of gallium nitride (GaN)-based devices.

While sapphire generally presents the best lattice match to GaN of any widely available and optically transparent substrate material, achieving a very high-quality GaN film at the GaN/sapphire interface still presents challenges. This is due in part to the lattice mismatch between the two materials, but is exacerbated by defects in the sapphire crystal that directly impact the quality of the epitaxial layers in LED devices. Defects such as surface bubbles, dislocations, and impurities are widely known within the industry to be problematic in LED applications where, for example dislocations in the substrate can be replicated in the epitaxial overgrowth. Moreover, in many LED applications sapphire is part of the structure of the final LED device, with the consequence that the optical properties of the sapphire affect the LED efficiency.

Although the quality of available sapphire material has improved over time, it has struggled to keep up with the advances in LED technology. As LED producers continue to push the limits of power and efficiency in their devices, substrate quality becomes an increasingly important consideration. As a result, substrate producers need to continue to innovate and find new ways to enhance their material.

Rubicon Technology takes a holistic approach to improving the quality of its sapphire (Raja Parvez, 'Vertical integration streamlines sapphire production', Compound Semiconductor March 2013, p50–55). For example, rather than relying on outside vendors for high-quality sapphire precursors, Rubicon has brought much of the refinement in-house, providing tighter control of purity levels. Vertical integration extends through proprietary furnace technology and crystal growth methodology to patented tools for precise crystal orientation, a high-precision polishing platform, and large-diameter custom patterning capability. By controlling every aspect of the process, Rubicon maintains greater consistency and uniformity and has earned a reputation for overall sapphire material quality.

The use of x-ray diffraction (XRD) rocking curves is often employed to evaluate the quality of single-crystal materials. This technique is highly sensitive to strain, particularly in the case of single-crystal material, which is represented by a broadening in the rocking curve peak. Common causes of strain within the crystal include dislocations, vacancies, and bubbles (i.e. macro-scale vacancies within the bulk crystal). Thus, by evaluating the full width half maximum (FWHM) value of a rocking curve, one can obtain detailed information about the quality of a crystal. With the help of Dr Albert Macrander and Dr Naresh Kujala, rocking curve data was obtained at The Advanced Photon Source at Argonne National Laboratories for multiple sapphire samples. Included in the study were standard Rubicon sapphire, as well as commercially available sapphire material from other vendors. The results of this study can be found in Figure 1. As can be seen, material from Rubicon shows a greater overall intensity with a significantly narrower peak, both of which are indicators of superior crystal quality. Moreover, the peaks from Rubicon's material show a higher symmetry, indicative

Although the quality of available sapphire material has improved over time, it has struggled to keep up with the advances in LED technology. Substrate producers need to continue to innovate and find new ways to enhance their material

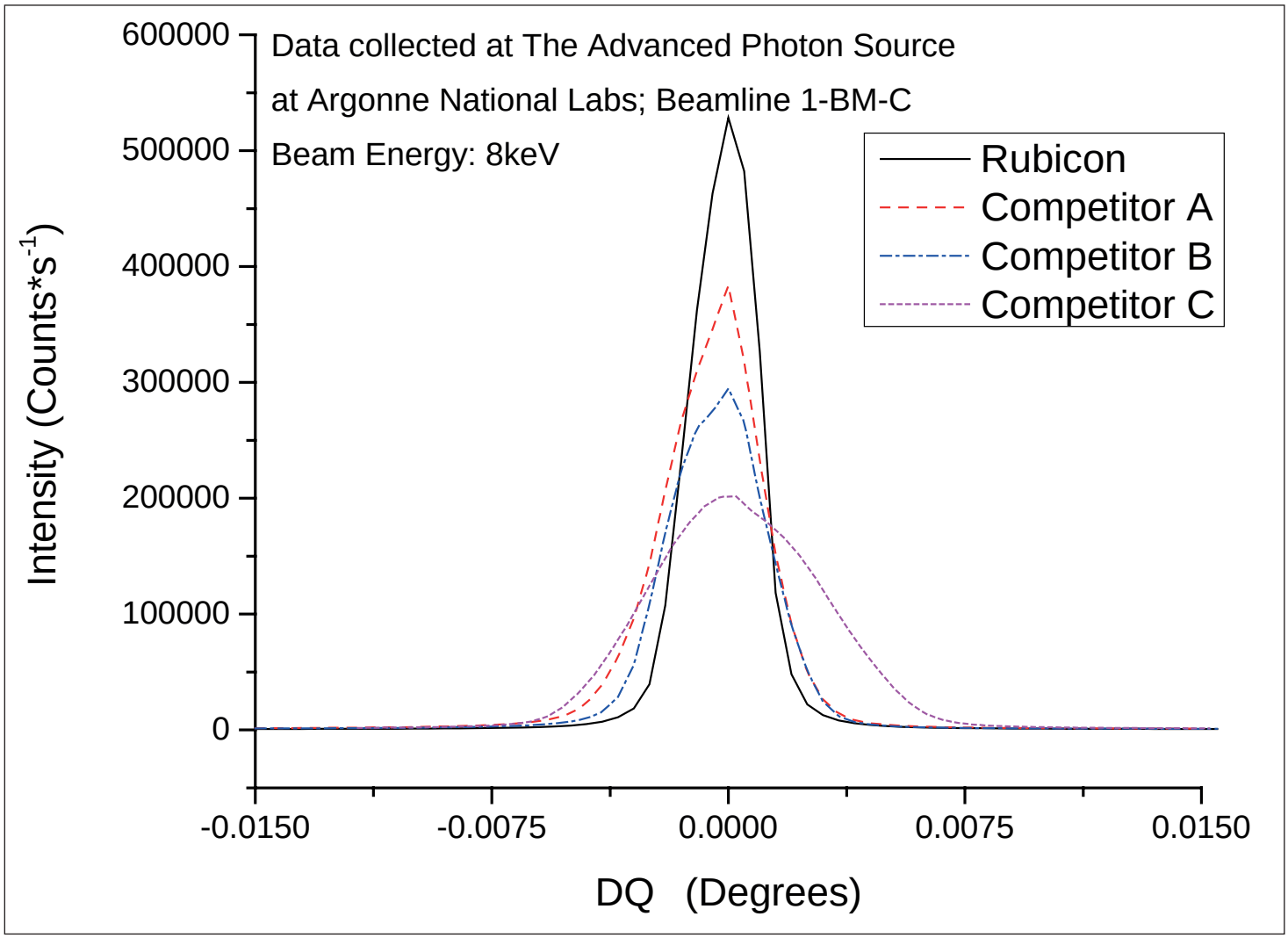


Figure 1: X-ray rocking curve of c-plane sapphire material. The Bragg reflection of the sapphire was for the (0006) reflection, which occurred at a Bragg angle of 21°. The synchrotron x-ray beam had been preconditioned with a Si(111) x Si(111) double crystal monochromator. Intensity recorded via pin-diode.

of a very low stress gradient within the material. FWHM values for each sample can be seen in Table 1.

In addition to collecting rocking curve data, the unique capabilities of Argonne's Advanced Photon Source also allows for x-ray topography data to be collected on the single-crystal material. X-ray topography is used for the imaging of lattice defects, which can be seen as streaks in the topography images. Thus, x-ray topography produces data that is comparable to traditional etch pit density (EPD) techniques via wet etch. However, unlike EPD, x-ray topography has the advantages of being non-destructive, and sensitive to sub-surface defects as well as purely surface defects.

Again with the help of Dr Albert Macrander and Dr Naresh Kujala, x-ray topography images were taken on each of the three competitor materials used for rocking curve data, as well as the same standard Rubicon wafer used for the collection of rocking curve data. Each topographic image represents an area of approximately 5.5mm wide x 3.5mm high. Streaks observed in topographic images represent lattice defects. Dark regions represent high densities of lattice defects (i.e. 'tangles'). Dark or light spots within the images are artifacts from the system setup and are not related to the samples themselves. The sample from competitor C shows a very high density of lattice defects, including a large band of extremely high defect density. Competitor sample A is comparatively much better, but still demonstrates a significant amount of defects. Competitor sample B is similar in defect density to Competitor sample A. The final image is of the Rubicon material. While, as is to be expected, some lattice defects are present in the Rubicon sample,

Table 1: FWHM values for Gaussian fits of x-ray rocking curve data from Figure 1.

Sample	FWHM (arc-seconds)
Rubicon	8.712
Competitor A	12.881
Competitor B	14.110
Competitor C	22.710

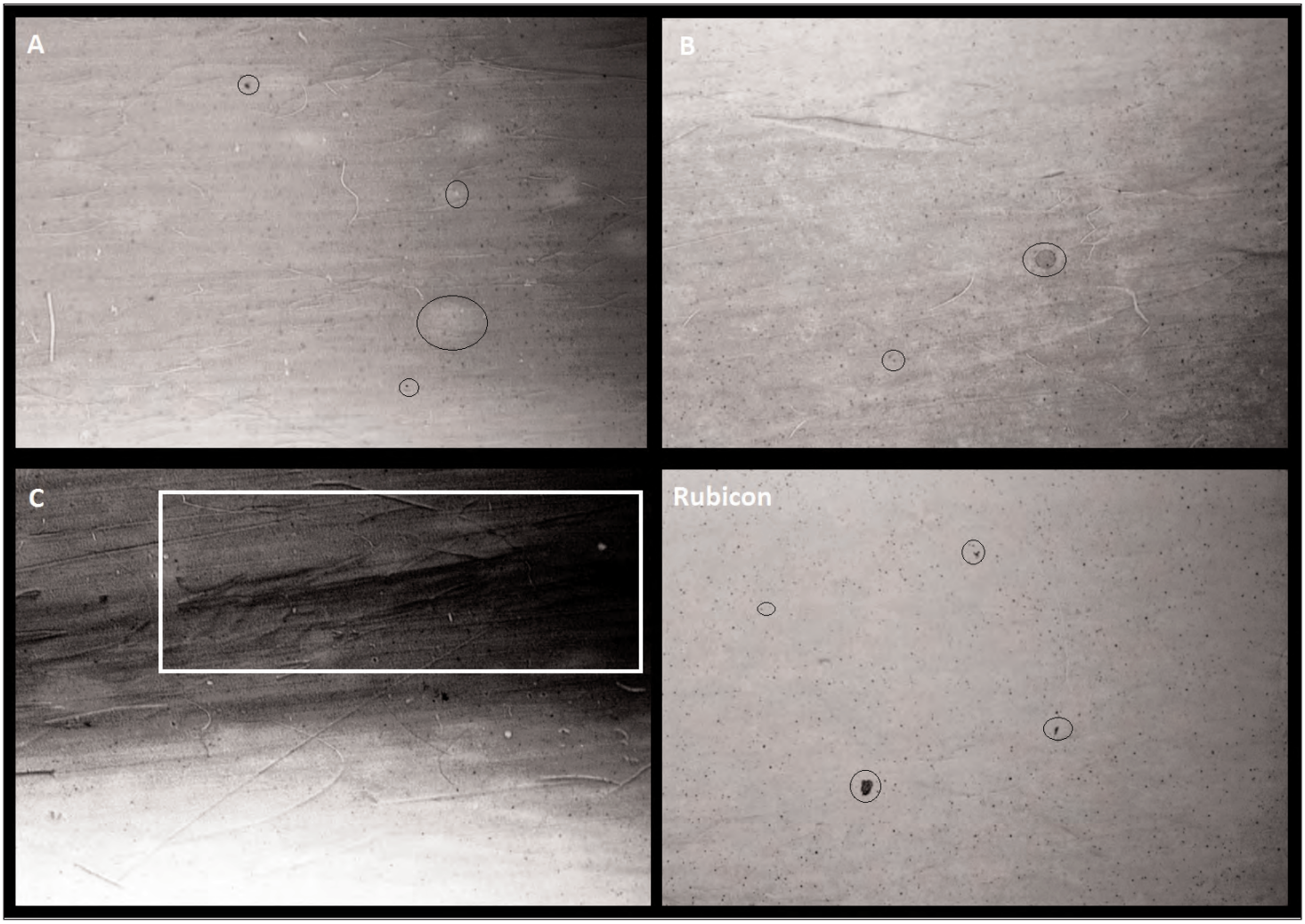


Figure 2: X-ray topography images of c-plane sapphire. Light and dark spots (such as those circled) are artifacts from imaging and developing and are unrelated to crystal structure. Boxed-in region is an example of a tangle, or large band of defects.

they are quite sparse, and the defect density is clearly much lower than that of any of the competitor material (as indicated by the lack of obvious streaks). It is noteworthy that the defect density of each material shows a strong correlation with the FWHM values from Table 1. While this is not surprising, this correlation helps to validate each individual measurement. Lastly, it should be noted that, while only one Rubicon sapphire sample was presented for this study, several Rubicon samples, each randomly selected from stock, were studied with similar results.

Single-crystal sapphire has been available for industrial applications for some time. While no other material is as useful as sapphire for GaN-based LEDs (due to superior lattice and optical properties), available sapphire has historically been associated with high defect densities and poor crystalline quality compared with some other widely available semiconductor materials. As the quality of the semiconductor substrates has a direct impact on the quality of epitaxial films deposited on the substrate, improvements in crystallinity are paramount to improvements in epitaxial devices, such as LEDs. This relationship is particularly important for more sensitive applications such as high-brightness LEDs, where a push toward greater efficiency and higher output power are key for competitive advantage and essential for continued cost reduction and overall industry growth.

By exercising more control over the production of our sapphire material through a vertically integrated approach, Rubicon Technology has demonstrated vast improvements in the overall quality of sapphire crystals that make them much more suited to advanced applications, including high-efficiency LEDs. As demonstrated through various techniques of x-ray characterization, Rubicon has confirmed the ability to produce sapphire crystal of a significantly higher quality than has previously been possible by any large-scale producer of sapphire crystals. ■

Acknowledgements

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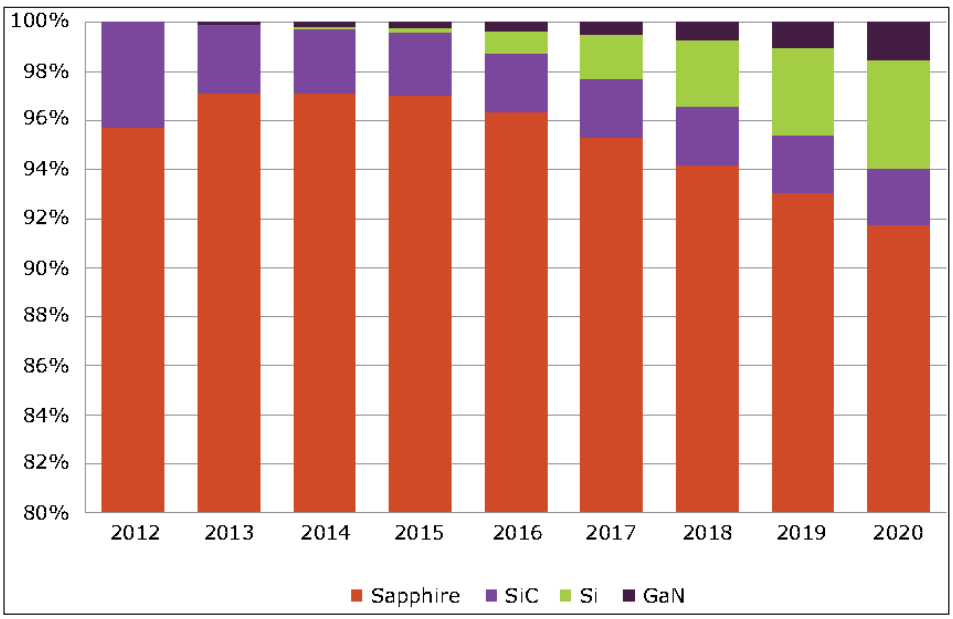
GaN-on-silicon enabling GaN power electronics, but to capture less than 5% of LED making by 2020

Power electronics firms to buy epiwafers if price keeps falling, but LED firms to make own epiwafers for mass production.

Gallium nitride (GaN)-on-sapphire is the existing mainstream technology for LED manufacturing, but GaN-on-silicon technology has naturally appeared as an alternative to sapphire in order to reduce cost. However, a cost simulation by market analyst firm Yole Développement indicates that the differential in silicon substrate cost is not enough to justify the transition to GaN-on-Si technology. The main driver is the ability to manufacture on 6" or 8" wafers in existing, depreciated CMOS silicon fabs, according to the firm's new report 'GaN-on-Si Substrate Technology and Market for LED and Power Electronics', which reviews GaN-on-Si technology growth, challenges and solutions.



Penetration rate of various LED substrates.

Despite potential cost benefits for LEDs, the mass adoption of GaN-on-Si technology for LED applications remains unclear. Opinions regarding the chance of success for LED-on-Si vary widely in the LED industry from unconditional enthusiasm to unjustified scepticism, says Yole. Almost all major LED makers are researching GaN-on-Si, but few have made it core to their strategy and technology roadmap. Among the proponents, only Lattice Power, Plessey and Toshiba have moved to production and are offering commercial LED-on-Si.

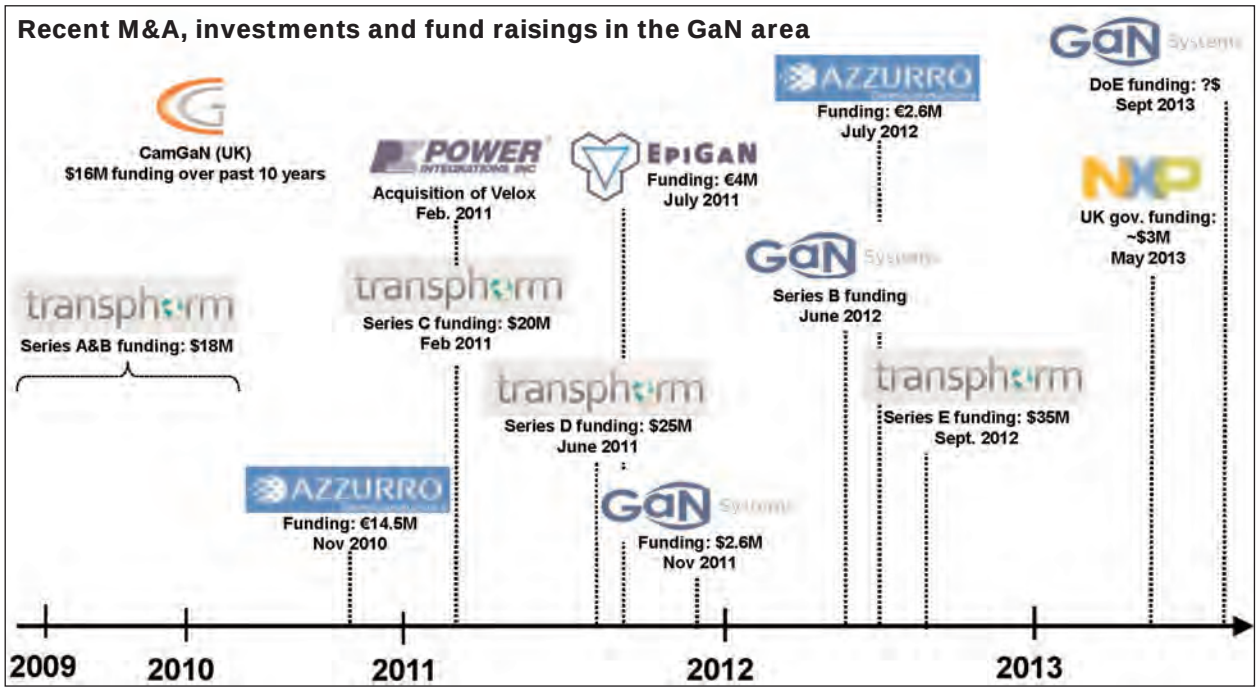
Yole believes that, although significant improvements have been achieved, there are still some technology hurdles to be overcome (performance, yields, CMOS compatibility). "We consider that, if the technology hurdles are cleared, GaN-on-Si LEDs will be adopted by some LED manufacturers, but will not become the industry standard," the firm says. "We expect that silicon will capture less than 5% of LED manufacturing by 2020."

GaN-on-Si to be widely adopted for power electronics

The power electronics market addresses applications such as AC-to-DC or DC-to-AC conversion, which is always associated with substantial energy losses that increase with higher power and operating frequencies. Incumbent silicon-based technology is reaching its limit and it is difficult to meet higher requirements, says Yole. GaN-based power electronics have the potential to significantly improve efficiency at both high power and high frequencies while reducing device complexity and weight. Power GaN is therefore emerging as a substitute to silicon-based technology. However, currently power GaN remains at an early stage and represents just a tiny portion of the power electronics market.

"We are quite optimistic about the adoption of GaN-on-Si technology for power GaN devices," says Yole. GaN-on-Si technology has brought to market the first GaN devices. In contrast to the LED industry, where GaN-on-sapphire is main stream and presents a chal-

lenging target, GaN-on-Si will dominate the GaN-based power electronics market because of its lower cost and CMOS compatibility, adds the firm. Although GaN-based devices remain more expensive than Si-based devices today, the overall cost of GaN devices for some applications is expected to be lower than silicon devices three years from now, according to some manufacturers.



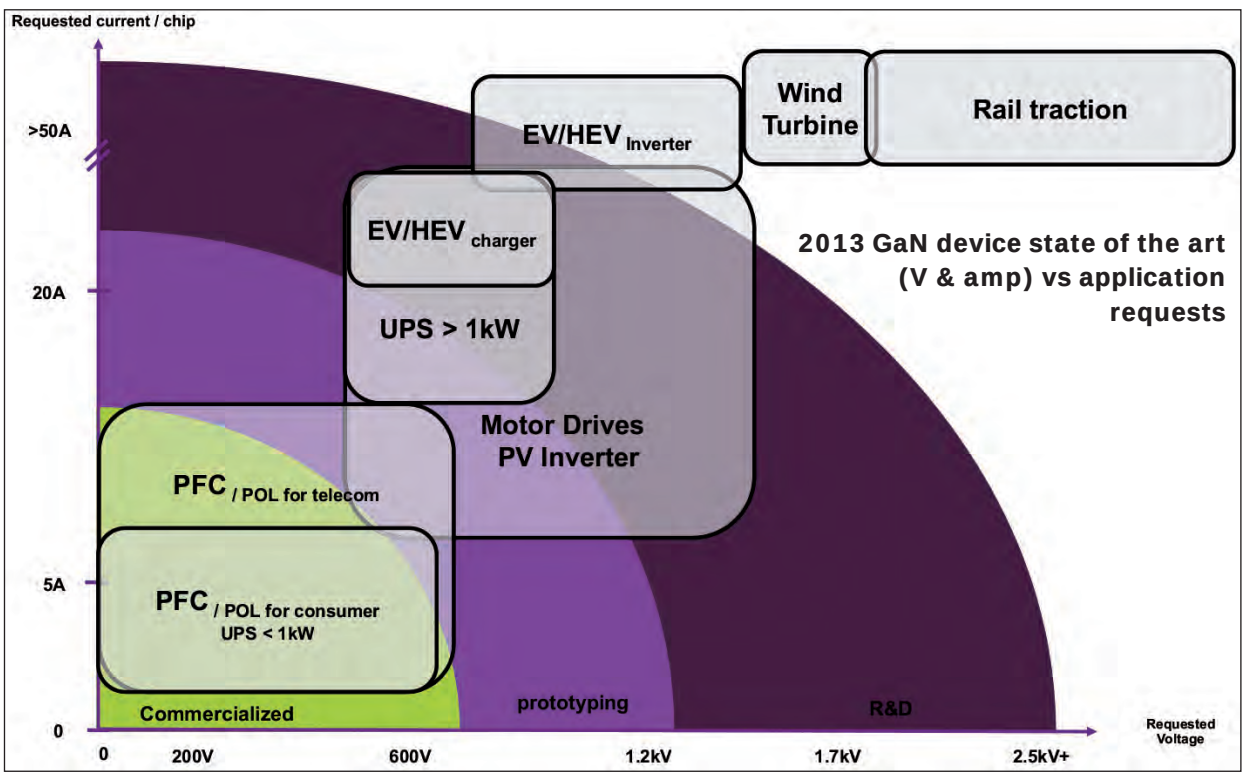
"In our nominal case, GaN-based devices could reach more than 7% of the overall power device market by 2020," forecasts Yole. GaN-on-Si wafers will capture more than 1.5% of the overall power substrate volume, representing more than 50% of overall GaN-on-Si wafer volume, subject to the hypothesis that 600V devices will take off in 2014–2015.

Epi: buy it or make it? Which will dominate?

To adopt GaN-on-Si technology, device makers have a choice between buying epiwafers or templates on the open market or buying metal-organic chemical vapour deposition (MOCVD) reactors and making epiwafers themselves. Today, there is a limited number of players selling either epiwafers or templates or both on the open market. These players comes from Japan, USA and Europe. "We have not observed an absolute dominance from one region," says Yole.

As perceived by device makers, each business model has its pros & cons in terms of intellectual property (IP), technology dependence, R&D investments, and time. "According to our analysis, we do not expect to see a significant template/epiwafer business emerge for LEDs, and consider that LEDs makers would prefer making their epiwafers internally for mass production," says Yole. For the power electronics industry, opinion is divided, it adds. "We consider that buying epiwafers could work as long as the price of the epiwafer on the open market keeps decreasing," the market research firm concludes.

www.i-micronews.com/upload/Rapports/Yole_GaN-on-Si_March_2014_Report_launch.pdf



Direct growth of III-V quantum dot lasers on silicon

UCSB and IQE demonstrate record-performance 1.3μm InAs QD laser grown on silicon as a competitive alternative to wafer bonding.

University of California Santa Barbara (UCSB) and epiwafer foundry IQE Inc have developed 1.3μm-wavelength indium arsenide (InAs) quantum dot (QD) lasers grown on silicon (Si) with "record performance" [Alan Y. Liu et al, Appl. Phys. Lett., vol104, p041104, 2014].

The researchers write: "The device performances reported here indicates that direct growth of III-V lasers on silicon with quantum dot active regions is a competitive alternative to wafer bonding lasers grown on native substrates. Such epitaxial approaches not only provide a lower barrier to entry for silicon photonics devices through potential large-scale growth, but would also take advantage of the many benefits inherent to quantum-dot-based optoelectronics, yielding performance characteristics that are difficult to achieve in quantum well devices".

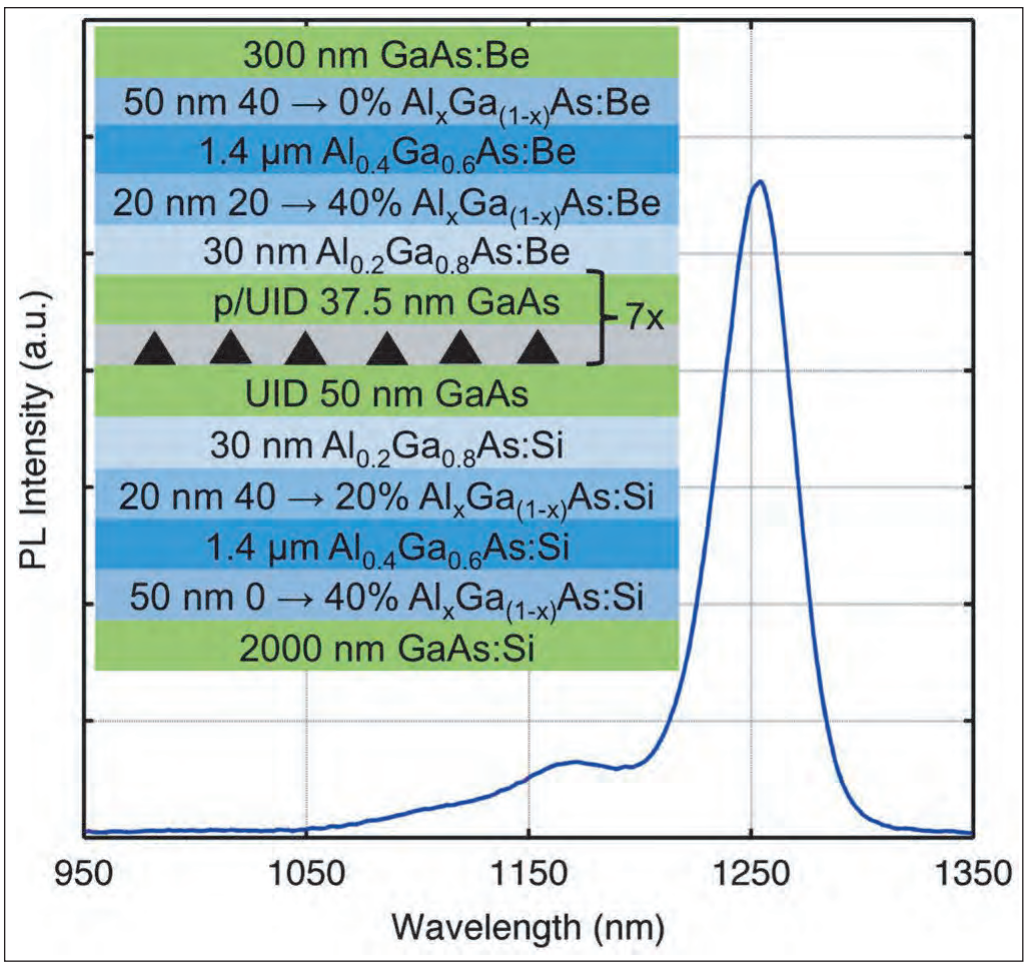


Figure 1. Room-temperature photoluminescence spectrum of the InAs quantum dots grown on Ge-on-Si substrates. Inset: layer structure of the GRINSCH InAs quantum dot lasers.

Up to now, most demonstrations of the integration of electrically driven lasers with silicon photonic waveguides etc have used wafer bonding techniques to combine III-V and Si technologies. Silicon photonics and III-V lasers are used in optical communications. Direct growth of III-V materials is challenging and requires careful process control to achieve low defect densities.

The researchers comment that III-V quantum dot lasers "have proven to be less sensitive to non-radiative defects than their quantum well counterparts due to carrier localization within individual dots."

The quantum dot laser structures were grown on germanium-on-silicon (Ge-on-Si) substrates using molecular beam epitaxy (MBE). The 150mm-diameter (100) silicon substrates, miscut 6° in the [111] direction, were prepared with chemical vapor deposition (CVD) of 500nm Ge.

The initial MBE included a thermal anneal to create bi-atomic step arrays for nucleation of epitaxial gallium arsenide (GaAs). This enabled the growth of mirror-like layers with reasonable dislocation densities. The GaAs growth was carried out at 600°C, giving a 1μm combined nucleation and buffer layer. The dislocation density was estimated at ~10^8/cm^2 on the basis of transmission electron microscopic (TEM) analysis.

The substrate was then diced into smaller 'virtual GaAs substrates' before the laser material (Figure 1) was grown, based on two graded-index separate-confinement heterostructures (GRINSCHs) around the active quantum dot layers. The 7-period quantum dot

layers consisted of InAs dots in 8nm $In_{0.15}Ga_{0.85}As$ quantum wells separated by 37.5nm GaAs barriers. Some devices included p-type beryllium doping in the GaAs barriers.

Conventional ridge-waveguide lasers were produced with gold-germanium/nickel/gold n-contacts and titanium/platinum/gold n-contacts. Plasma-enhanced chemical vapor deposition (PECVD) silicon dioxide was used for electrical isolation. The facets were polished and then the rear facet was coated with 95%-reflection material. Some devices also included silicon nitride coating on both facets, applied before the reflection material on the back facet.

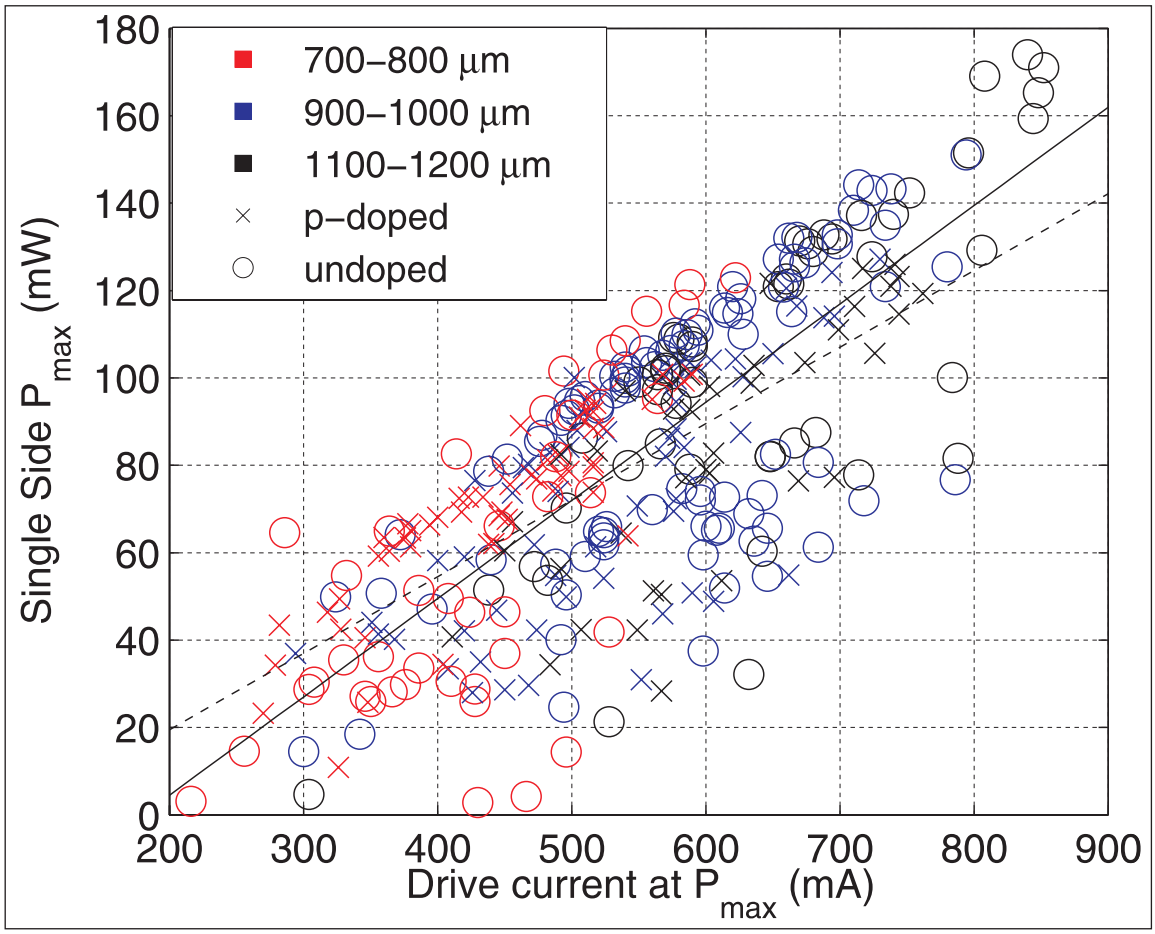


Figure 2. Maximum CW output power at 20°C (both p-doped and undoped) versus corresponding drive current. The solid and dashed lines are best fits for undoped and p-doped devices with slopes of 22.52 and 17.52 W/A, respectively.

At 20°C, the continuous wave (CW) threshold current and peak output power of a 937μm x 4μm device with polished facets and undoped barriers were 16mA and 50mW, respectively. The emission spectrum peaked around 1250nm wavelength, matching the peak in photoluminescence measurements.

The maximum CW lasing temperature was 110°C. Pulsed current measurements in the 20–110°C range gave a threshold current characteristic temperature (T_0) of 43K. Pulsed measurements avoid self-heating effects.

The researchers comment: "We note that the quantum dot laser grown on Ge had nearly the same threshold as a reference laser grown on GaAs, indicating high material quality."

An 1130μm x 10μm device with silicon nitride facet coatings and undoped barriers had a maximum power output of 176mW in CW operation, "the highest reported for telecom lasers on silicon", according to the researchers. At 150mA, the maximum single-side wall-plug efficiency was 18% and the differential efficiency 37%.

Devices with p-doped barriers in the active region had similar characteristics. An 1155μm x 4μm with polished facets had a threshold current of 21mA and maximum output power of almost 54mW at 20°C. The T_0 characteristic was 143K for the range 20–40°C and 41K for the range 40–120°C.

A second kink in the light output power versus current characteristic above the threshold kink for the device at 70°C and above was attributed to the "onset of dual-state lasing with the excited state, commonly reported for InAs quantum dot lasers where gain and carriers are not fully clamped at threshold." In fact, the ground-state lasing is quenched above 100°C in pulsed operation and at 80°C for CW. Excited-state lasing continues up to 119°C and 130°C for CW and pulsed operation, respectively.

The researchers comment: "This is the highest CW lasing temperature for lasers on silicon, exceeding the previous record of 105°C reported for a 1.3μm AlGaInAs quantum well hybrid silicon laser."

Averaged over 330 devices, the slope efficiencies at 20°C were 22.5W/A and 17.5W/A, for devices with undoped and p-doped barriers, respectively.

The CW output power level of 176mW and lasing temperature up to 119°C "are the highest reported for lasers on silicon," according to the researchers. ■

http://dx.doi.org/10.1063/1.4863223

Author: Mike Cooke

Combining low on-resistance with high breakdown voltage

IEMN and EpiGaN demonstrate AlN/GaN/AlGaN transistor with record combined 1.9kV breakdown and 1.6mΩ-cm^2 specific on-resistance.

Institute of Electronic, Microelectronic and Nanotechnology (IEMN) in France and EpiGaN nv in Belgium have claimed a record combination of specific on-resistance and breakdown voltage for a double heterostructure field-effect transistor (DHFET) using a gallium nitride (GaN) channel and aluminium nitride (AlN) barrier on silicon (Si) substrate [Nicolas Herbecq et al, Appl. Phys. Express, vol7, p034103, 2014].

The team tackled leakage problems from substrate conduction by locally removing silicon from beneath critical parts of the device to achieve a breakdown voltage of 1.9kV with a specific on-resistance of 1.6mΩ-cm^2.

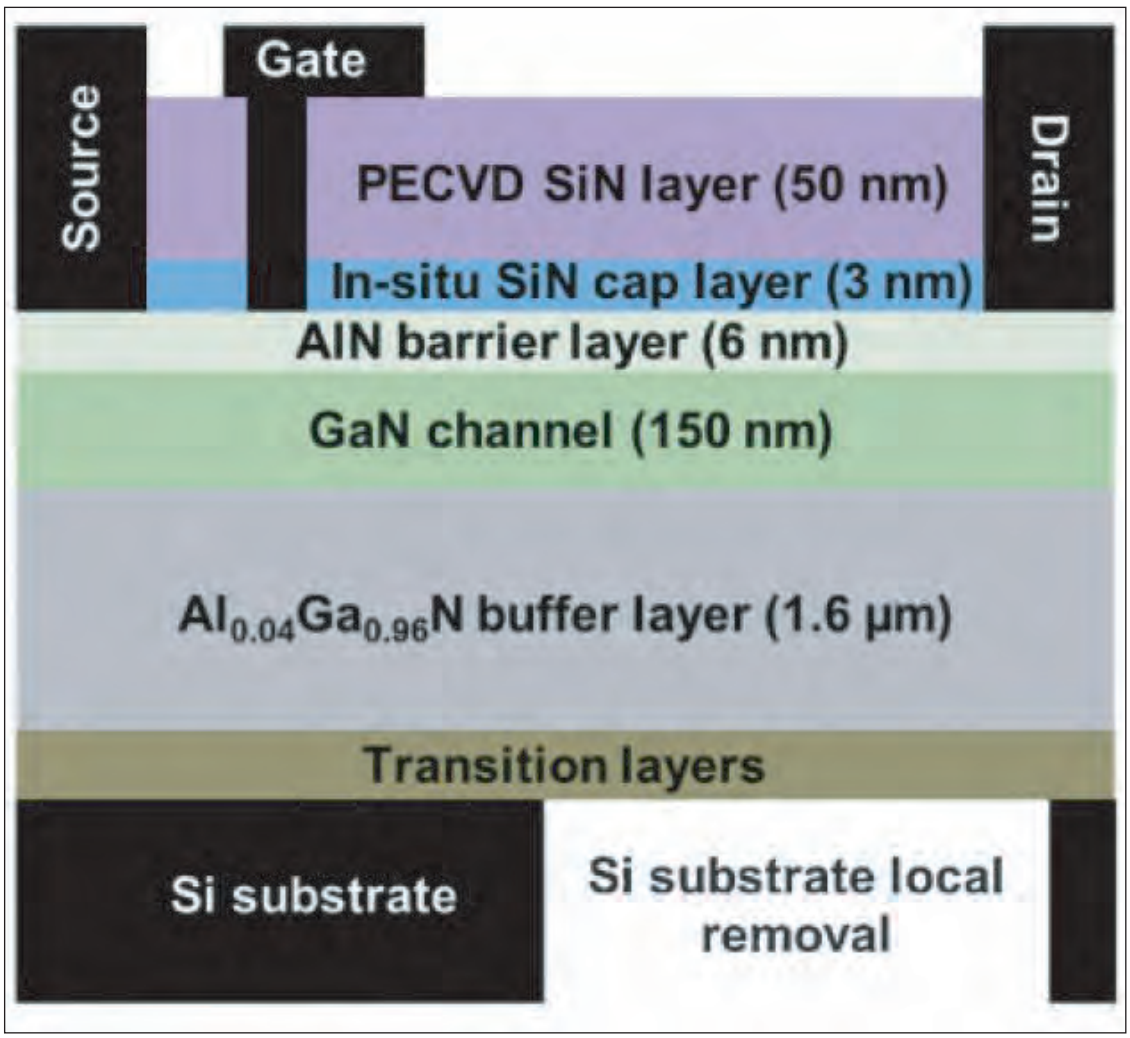


Figure 1. Schematic of AlN / GaN / AlGaN DHFET with local substrate removal.

The epitaxial nitride semiconductor layers for the transistor (Figure 1) were grown by metal-organic chemical vapor deposition (MOCVD) on 4-inch silicon (111) substrates. The 3nm silicon nitride (SiN) layer produced in-situ in the MOCVD reaction chamber provided early passivation and also prevented strain relaxation and increased surface robustness.

The use of an AlN barrier gave a high electron carrier density of 2.3x10^{13}/cm^2 with mobility 990cm^2/V-s. The sheet resistance was 280Ω/square. The device included an AlGaN back-barrier/buffer to further improve breakdown performance by reducing leakage.

The transistor fabrication began with titanium/aluminium/nickel/gold ohmic contact formation on the AlN layer after etching through the cap layer. The contact metals were annealed at 875°C. The devices were isolated with nitrogen implantation.

Fabrication continued with plasma-enhance chemical vapor deposition (PECVD) of 50nm SiN. The gate was

formed by etching through the SiN to the AlN layer with a low-damage low-power sulfur hexafluoride (SF_6) plasma and then depositing nickel/gold as the gate metal. The gate was 1.5µm long and 50µm wide. The gate–source spacing was 1.5µm. The distance between the gate and drain electrodes varied from 2µm up to 15µm. The gate was extended 0.75µm in the drain direction to create a field-plate.

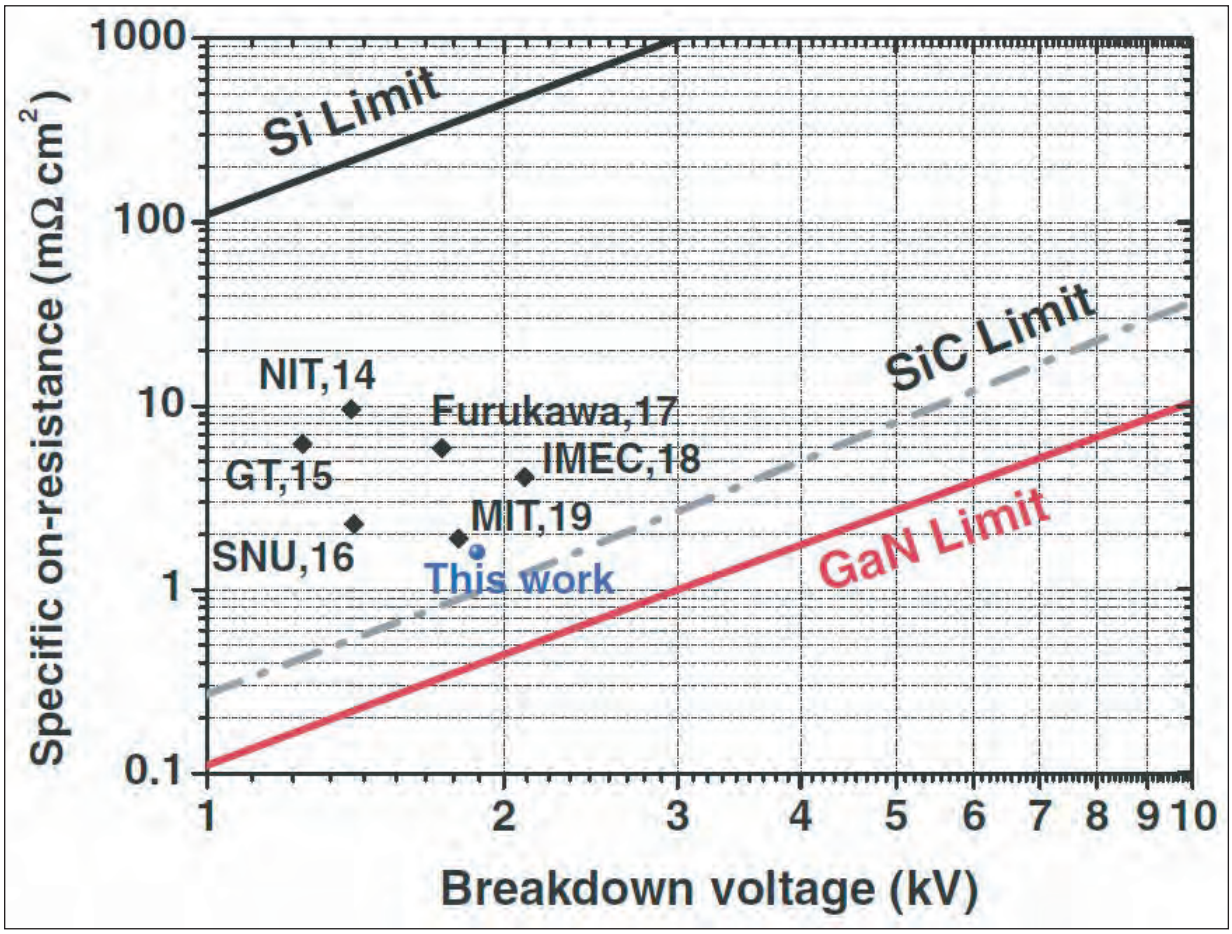


Figure 2. Benchmarking of specific on-resistance versus breakdown voltage of GaN-on-Si transistors rated above 1kV.

The backside processing involved thinning and polishing the silicon substrate down to 230µm, followed by local deep reactive-ion etch to the AlGaN buffer layer using the 'Bosch process' on a Surface Technology Systems tool. The Bosch technique involves a sequence of passivation and etch steps, which results in reproducible vertical walls and allows high aspect ratios to be achieved.

The local etch removed material around the drain contact. One potential drawback of the removal of material is degradation of thermal dissipation. The trenches were 20µm wide, extending over the gate–drain region.

The DC performance of the devices with local backside etching did show reduced performance in terms of maximum drain current and peak transconductance. In devices with 15µm gate–drain spacing, the maximum drain current without local Si removal was 0.7A/mm. This was reduced 28% to 0.5A/mm with silicon removal. These values corresponded to specific on-resistances of 1.3mΩ-cm^2 and 1.6mΩ-cm^2 for the devices without and with silicon removal, respectively. The researchers attributed the difference to self-heating effects due to inadequate thermal dissipation with local silicon removal. High temperature reduces channel mobility in GaN-based devices.

Both devices had a low off-state current less than 10µA/mm, despite the lack of gate insulation.

Three-terminal breakdown voltage measurements were carried out in a 'deep pinch-off' state with the gate at –5V. The breakdown current of 1mA/mm was used. The breakdown voltage for both types of device increased linearly with gate-drain distances up to 8µm. Beyond 8µm, the breakdown for devices without substrate removal saturated at around 750V. The limitation is attributed to the electric field reaching down through the thin buffer (~1.8µm) and effecting conduction through the substrate.

With local substrate removal, the breakdown voltage continued to increase linearly to 1.9kV with a gate–drain distance of 15µm. The device compares well with 'state-of-the-art' in terms of high breakdown voltage and low specific on-resistance (Figure 2).

The researchers believe the technique could be used to extend the gate-drain spacing to ~30µm, allowing 3kV blocking to be reached with less than 5mΩ-cm^2 specific on-resistance. Gate insulation would reduce leakage further. The team also suggests that a thick dielectric trench fill with, for example, AlN, could reduce self-heating effects. ■

http://iopscience.iop.org/1882-0786/7/3/034103/article

Author: Mike Cooke

Vertical GaN transistor with 1.6kV blocking voltage

Threshold voltage of +7V provides normally-off behaviour, making Toyoda Gosei device feasible for automotive power applications.

Researchers at Japan's Toyoda Gosei Co Ltd have achieved a blocking voltage of 1.6kV for a vertical gallium nitride (GaN) metal-oxide-semiconductor field-effect transistor (MOSFET) structure [Tohru Oka et al, Appl. Phys. Express, vol7, p021002, 2014].

"To our knowledge, the blocking voltage is the highest ever reported for vertical GaN-based transistors on free-standing GaN substrates," the researchers write. Previous vertical GaN transistors have achieved blocking voltages up to 1kV. Vertical Schottky barrier and pn diodes have achieved blocking voltages of up to 2kV.

At the same time, the threshold voltage of +7V provides normally-off behavior, as required for automotive power semiconductor applications, which normally need thresholds greater than +3V to prevent erratic performance with false triggers due to noise etc. Such threshold voltages are difficult to achieve with lateral GaN transistor structures.

The epitaxial structure for the transistor (Figure 1) was grown using metal-organic chemical vapor deposition (MOCVD) on a commercial free-standing n^+-GaN substrate with dislocation density of 3–4x10^6/cm^2. The added layers were 15µm n^--GaN and 1µm p-GaN, capped with 0.2µm n^+-GaN.

The fabrication of the 150µm x 300µm rectangular transistors began with a chlorine-based inductively coupled plasma etch for mesa isolation, and for 2µm-wide p-body contact and 2µm-wide gate trench recessing. The gate electrode insulation was provided by atomic layer deposition (ALD) of silicon dioxide (SiO_2).

The 2µm-wide p-body electrodes were palladium. The source-drain metals were titanium/aluminium, annealed at 550°C in nitrogen for 5 minutes to give ohmic contacts. The 6µm-wide source electrode was stacked on the p-body electrode to reduce the cell pitch to 15µm. The gate electrode and other wiring metals were aluminium-based.

The isolation mesa was passivated with 100nm of ALD of aluminium oxide (Al_2O_3). A 600nm dielectric interlayer of SiO_2 was applied with plasma-enhanced chemical vapor deposition (PECVD).

A source-connected field-plate was constructed using the wiring metal to reduce electric fields at the edge of the pn junction around the isolation mesa wall by

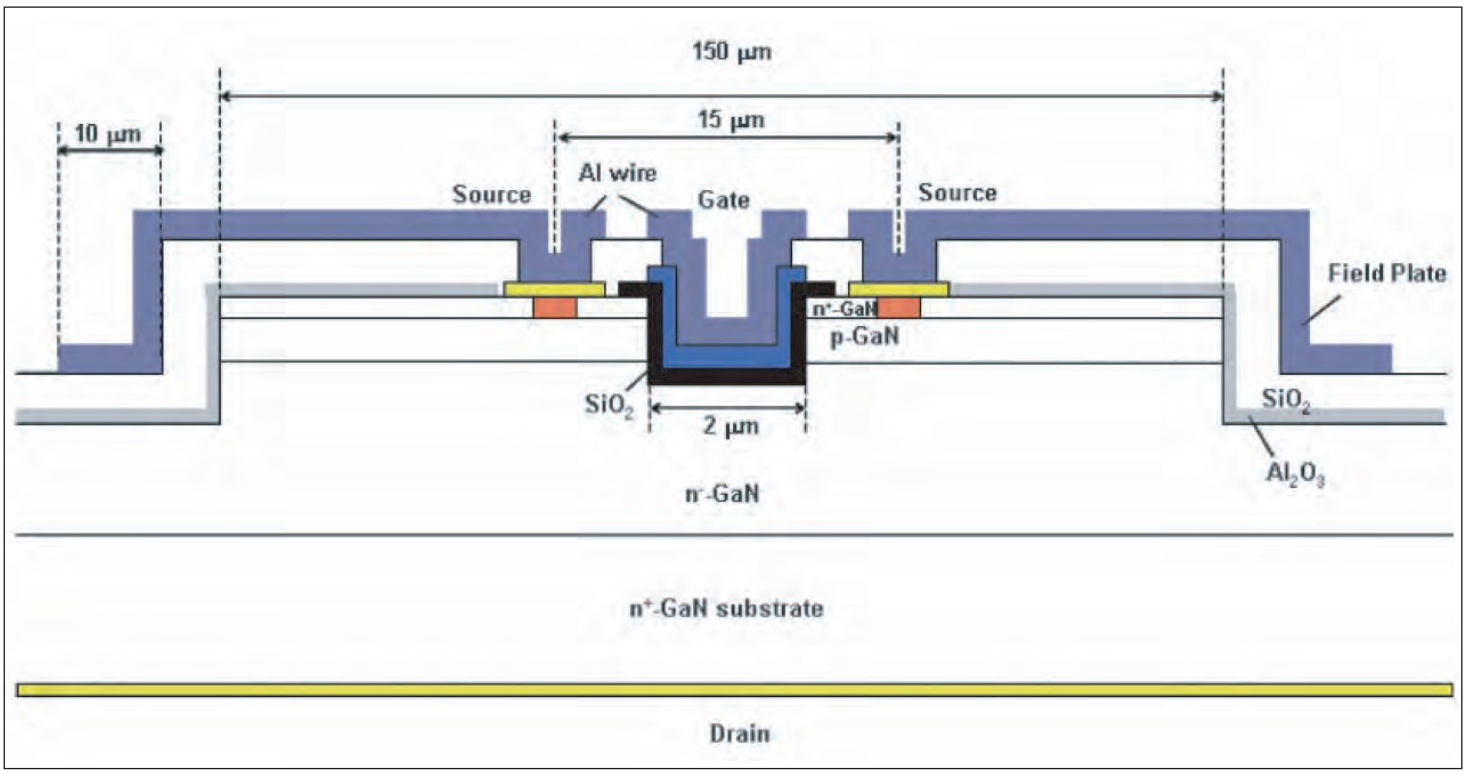


Figure 1. Schematic cross-section of trench MOSFET with field-plate edge termination.

reducing potential bunching. The plate extended 10µm beyond the base of the isolation mesa.

The researchers estimate that the transistor area includes about 10^3 dislocations and that the active transistor area was $1.5x10^{-5}cm^2$. The gate width was 2µm x 100µm.

The specific on-resistance based on the active area was $12m\Omega\text{-}cm^2$ at 50V gate potential and 0.5V drain bias. Although this value is larger than for lateral AlGaN/GaN transistors, the researchers believe that miniaturization should result in a much smaller on-resistance while maintaining the breakdown characteristics. The gate current leakage was below the limit of the researchers' measurement setup.

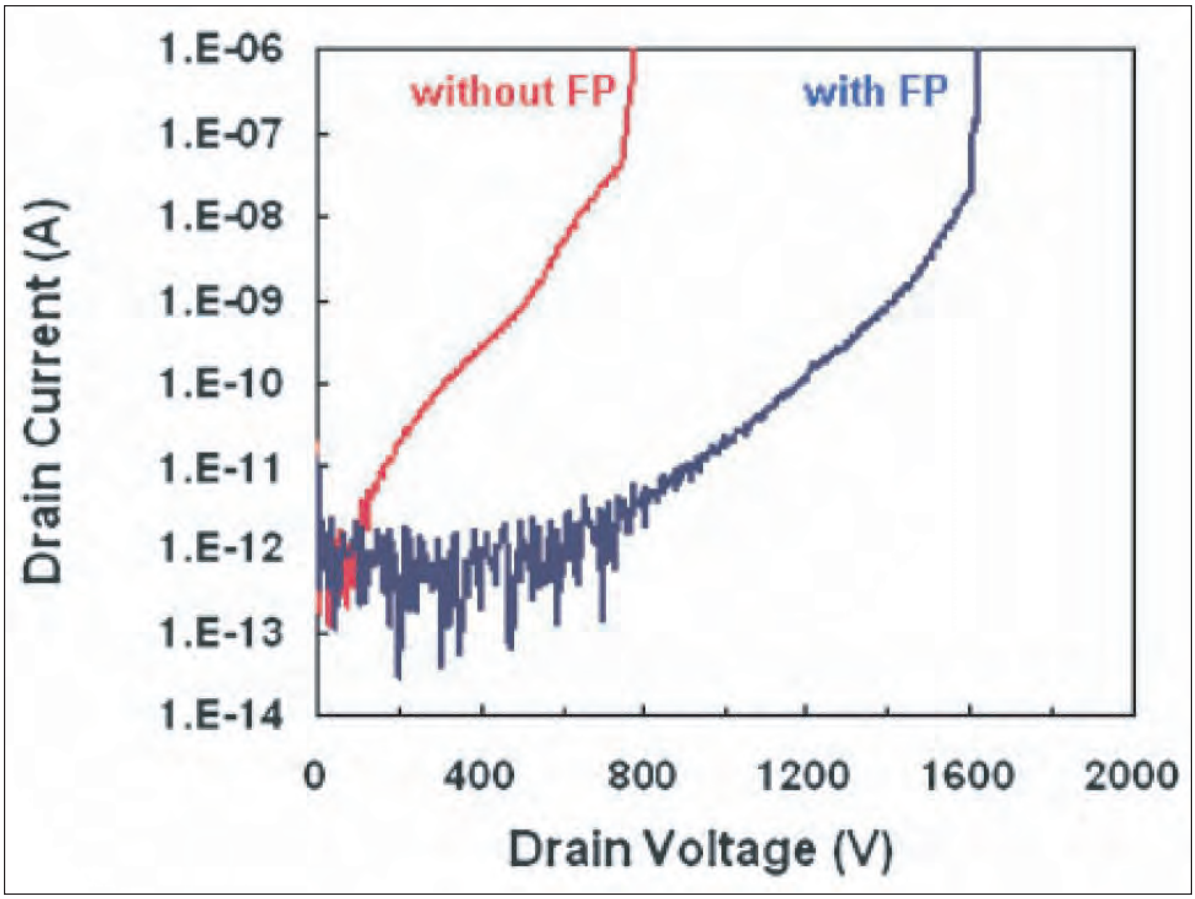


Figure 2. Off-state current-voltage characteristics for MOSFETs without and with field-plate edge termination.

The threshold voltage of the device was +7V, indicating normally-off enhancement-mode behavior. The researchers point out that this is far short of the estimated value of +57V, based on the p-type magnesium doping concentration, gate dielectric thickness and gate electrode work-function. The team is investigating the discrepancy, which could be due to insufficient activation of the p-type doping and/or etch-related damage of the gate trench: the activation problem could be related to hydrogen incorporation; the etch process could result in nitrogen vacancies at the gate trench surface.

The off-state (0V gate) blocking voltage was measured by increasing the drain bias in steps of 5V and seeking the point at which the drain current increased by an order of magnitude between steps (Figure 2). A MOSFET without field-plate broke down at 775V. The device with field-plate edge termination achieved a 1605V breakdown.

The gate current in the measurements remained below the measurement limit of the researchers' equipment. The researchers believe that the off-state leakage could be improved with optimization of the field-plate design. ■

http://apex.jsap.jp/link?APEX/7/021002

Author: Mike Cooke

Direct growth of graphene on aluminium nitride on silicon

Graphene grown on AlN templates on silicon substrates show potential for larger-area lower-cost application to CMOS and GaN-based devices.

Researchers in France have developed a technique to directly grow graphene on aluminium nitride (AlN) crystalline templates on silicon substrates [A. Michon et al, Appl. Phys. Lett., vol104, p071912, 2014].

Up to now, attempts to use graphene in conjunction with III-V semiconductor devices have generally used graphene grown on copper foil that is then transferred to the target application. Another technique to grow graphene is to anneal silicon carbide (SiC) substrates at ~1200°C, driving out the silicon from the surface and leaving the carbon atoms in a graphene structure.

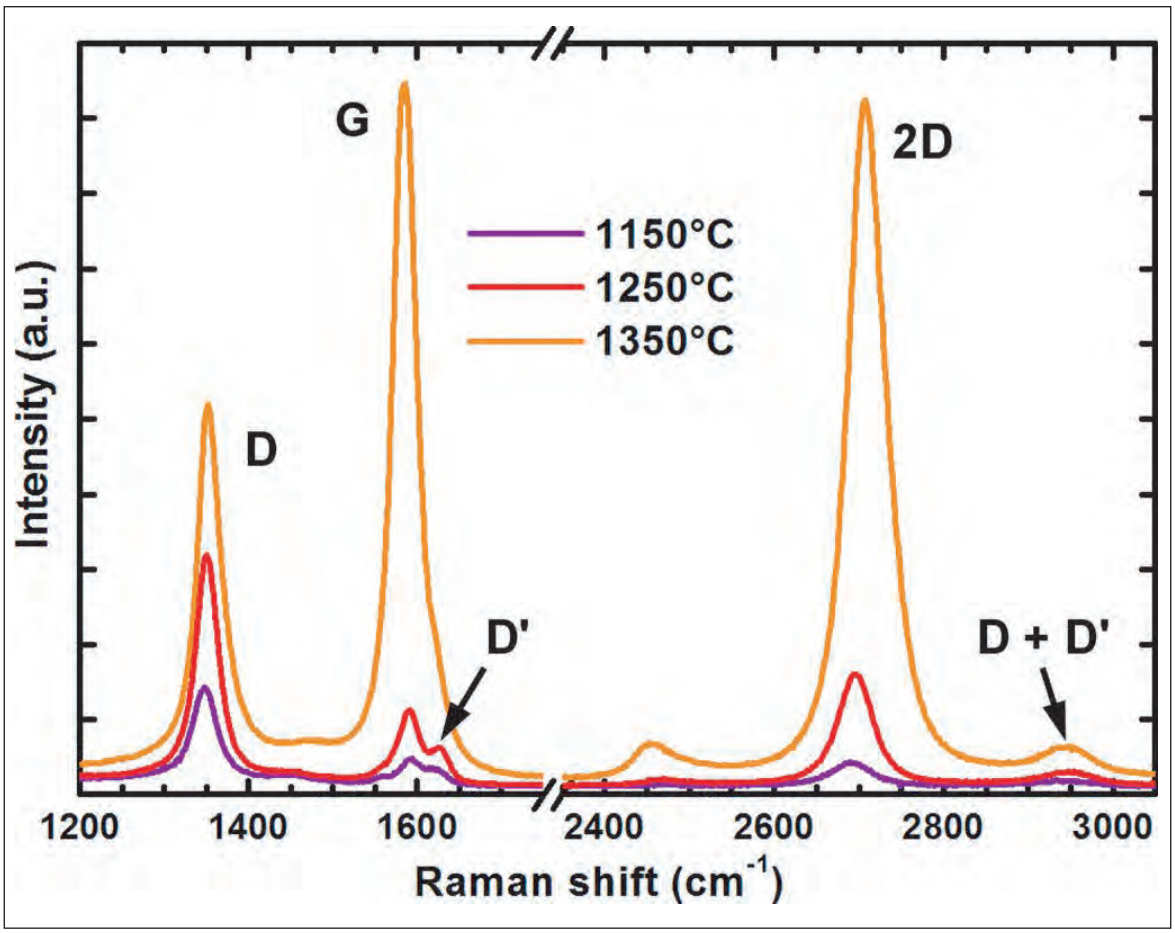


Figure 1. Raman spectra of off-axis AlN/Si(111) templates after graphene growth.

Recently, techniques have been developed for molecular beam epitaxy (MBE) and chemical vapor deposition (CVD) of graphene on silicon carbide and sapphire. The technique developed at CRHEA-CNRS, L2C-CNRS/Université Montpellier 2, and NOVASiC could open up graphene for applications using larger-area and lower-cost production such as for CMOS or for gallium nitride (GaN)-based light-emitting devices and power/high-speed electronic devices.

The AlN template layer was grown using MBE on Si(111) substrates. Monolayer nucleation was performed at 650°C. The temperature was raised to 920°C for the main AlN growth. The target thickness of the template layer was 200nm. The researchers find that their process results in less than $2x10^{11}/cm^2$ dislocation density with ~30nm crystal grains.

The template material was diced into $1cm^2$ samples. The graphene was grown in a resistively heated hot-wall CVD system designed for SiC epitaxy. The carbon source was propane (0.17%) in hydrogen/nitrogen (50%/50%) carrier. The carrier gas composition was a balance to avoid the AlN etching effect of hydrogen and the island formation found with high nitrogen concentration. The islands are thought to consist of aluminium droplets. The graphene growth pressure

and time were 800mbar and 6 minutes, respectively. Various growth temperatures – 1150°C, 1250°C and 1350°C — were explored.

Atomic force microscopy (AFM) and low-energy electron diffraction (LEED) analysis suggested that graphitic material grown on 2° off-axis templates gave better results than material using on-axis templates.

Raman spectroscopy on off-axis samples showed the presence of defects, especially at lower growth temperatures (Figure 2). The Raman measurements gave estimates of the number of graphene layers as between 1 and 3 for the low-temperature growth (1150°C and 1250°C) and 10 for the high-temperature process (1350°C). The crystallite sizes were around 5-6nm for the lower-temperature growth processes, but around 30nm at 1350°C. The crystallite size at 1350°C seems to be limited by the crystal grains of the AlN templates. The peak shifts of the Raman spectrum indicate a compressive strain in the graphene layers.

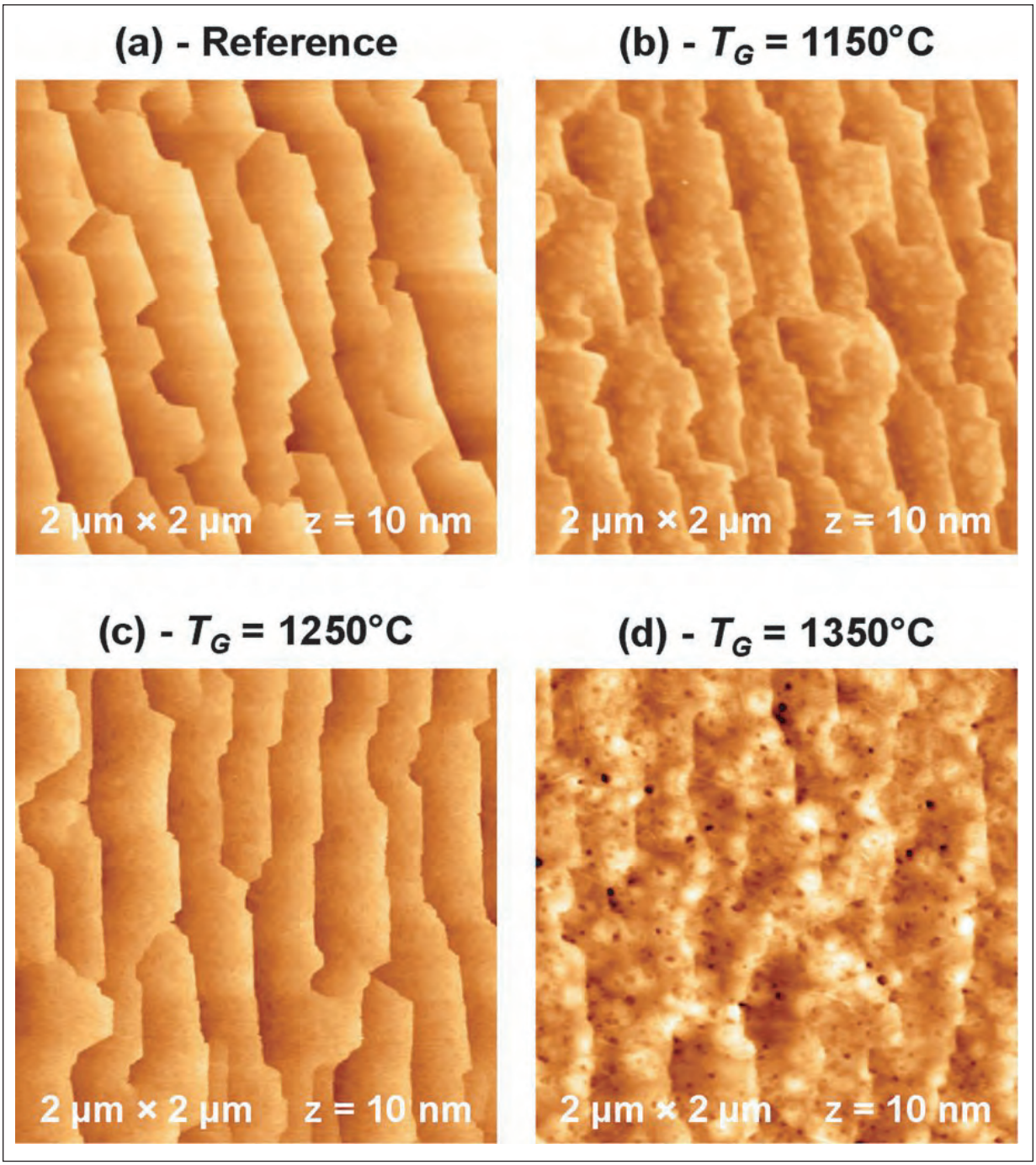


Figure 2. AFM views of off-axis AlN/Si(111) templates after annealing (a) and after graphene growth at 1150°C (b), 1250°C (c) and 1350°C (d).

LEED patterns also suggested some rotational disorder, which can be at least partly attributed to up to 6° rotation of the crystal structure between the grains of the underlying AlN. AFM images of the higher-temperature sample revealed pitting (Figure 2), probably due to an increased etching effect of the hydrogen.

The researchers suggest that "high-quality graphene could be grown on bulk AlN substrates, thanks to a lower density of defects and to the possibility to grow graphene at temperatures above the silicon melting point."

The researchers also suggest that the process could be used to provide a graphene layer to protect against etching in high-temperature annealing of AlN or other nitride films. "This may be useful for thermal treatment of nitrides films to increase crystalline quality or to activate doping after ion implantation," they write. ■

http://dx.doi.org/10.1063/1.4866285

Author: Mike Cooke

Selective III-V re-growth multi-gate transistor boosts performance

Sweden's Lund University reports record cut-off frequency and maximum oscillation frequency for III-V multiple-gate MOSFETs.

Lund University has developed multi-gate (MuG) III-V metal-oxide-semiconductor field-effect transistors (MOSFETs) with a cut-off frequency of 210GHz and a maximum oscillation frequency of 250GHz, "the highest of any reported III–V multiple-gate MOSFET" [Cezar B. Zota et al, IEEE Electron Device Letters, published online 12 February 2014]. The researchers see potential post-10nm complementary metal-oxide-semiconductor (CMOS) logic and high-frequency applications.

The high performance was achieved by creating fins through selective area re-growth processes that avoided etching of the III-V material. Etch processes, particular those that are plasma-based, cause surface damage that reduces carrier mobility and hence impairs performance.

Thin stripes of hydrogen silesquioxane (HSQ) on iron-doped (100) indium phosphide (InP) substrates were patterned using electron-beam lithography (Figure 1a). The stripes were aligned with the [001] crystal direction. The HSQ material was cured at 350°C.

Metal-organic vapor phase epitaxy (MOVPE) was used to create channels on the InP of 3nm InP followed by 15.5nm of indium gallium arsenide ($In_{0.53}Ga_{0.47}As$) (Figure 1b). The growth temperature was 500°C. The III/V precursor ratio was 94. The fins expanded by about 5nm in width compared with the spacing between the HSQ stripes due to

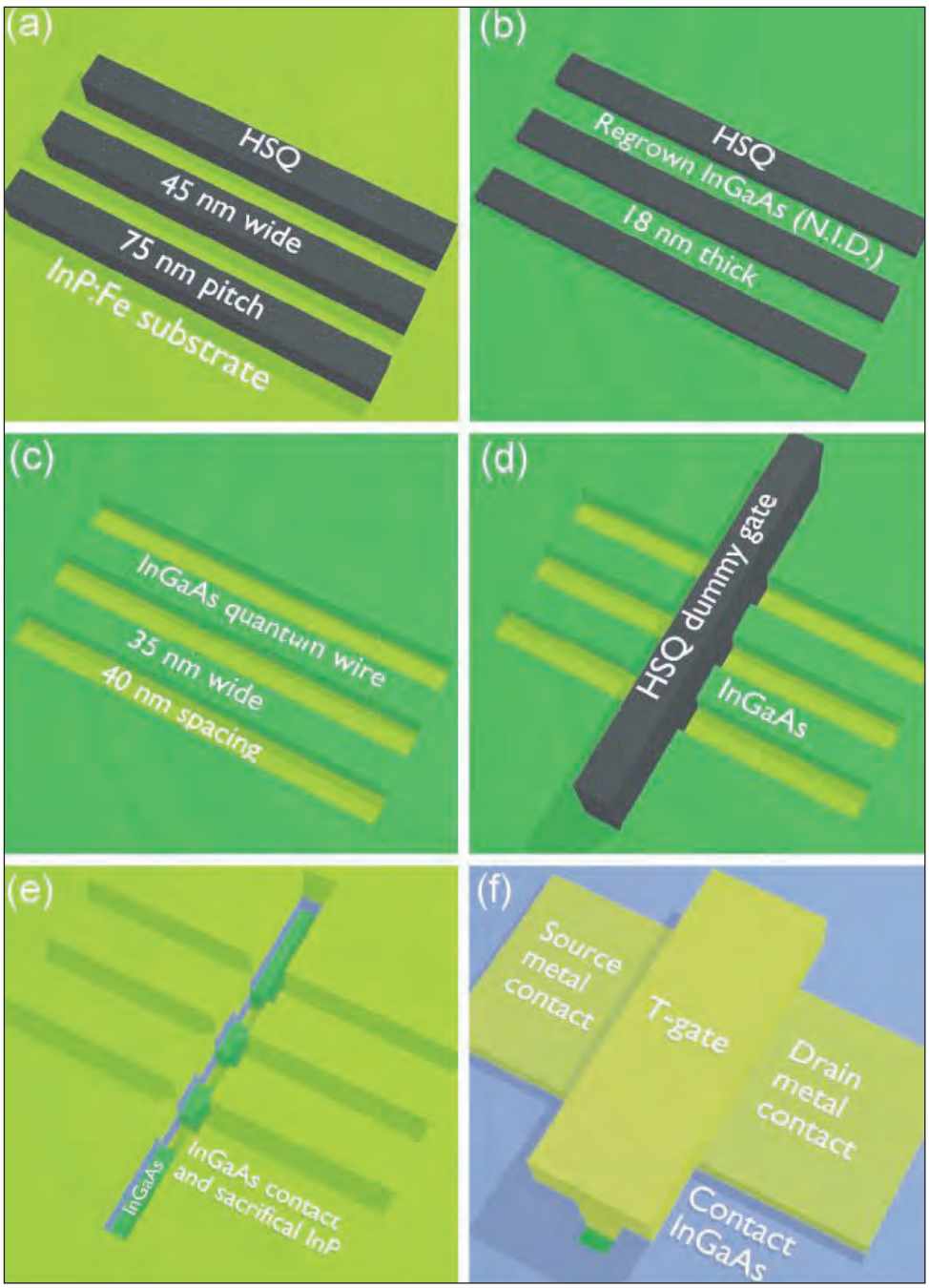


Figure1. Schematic of process flow. In fabricated devices, fins were at 45° relative to gate.

mask overgrowth (Figure 1c). The HSQ was removed with a (wet) buffered oxide etch.

A second re-growth step was prepared with the placement of an HSQ strip across the fins as a [110] dummy gate aligned 45° with respect to the fins (Figure 1d). The 45° angle was chosen to give the optimal facets for crystal re-growth, minimizing mask overgrowth. The deposition of 25nm $In_{0.53}Ga_{0.47}As$ and 15nm $In_{0.63}Ga_{0.37}As$ contact layers was followed by 90nm InP as a sacrificial support layer (Figure 1e).

The HSQ was removed and the samples were treated by immersing in 10% diammonium sulfide ($(NH_4)_2S$) solution for 20 minutes.

The gate oxide fabrication consisted of atomic layer deposition (ALD) of 5 cycles of aluminium oxide (~0.5nm, 300°C) and 55 cycles of hafnium dioxide (~5.5nm, 100°C). The palladium/gold T-gate was formed using electron-beam lift-off lithography. Thermal evaporation at 30° allowed deposition of titanium/palladium/gold source–drain contacts under the gate (Figure 1f).

The transistors were isolated from each other using the gate and source-drain contacts as self-aligned masks for wet etching of the channel and contact layers.

The peak transconductance ($g_{m,max}$) with a 32nm gate length was 1.67mS/µm at 0.5V drain bias. The maximum drain current at the same bias was 1.11mA/mm.

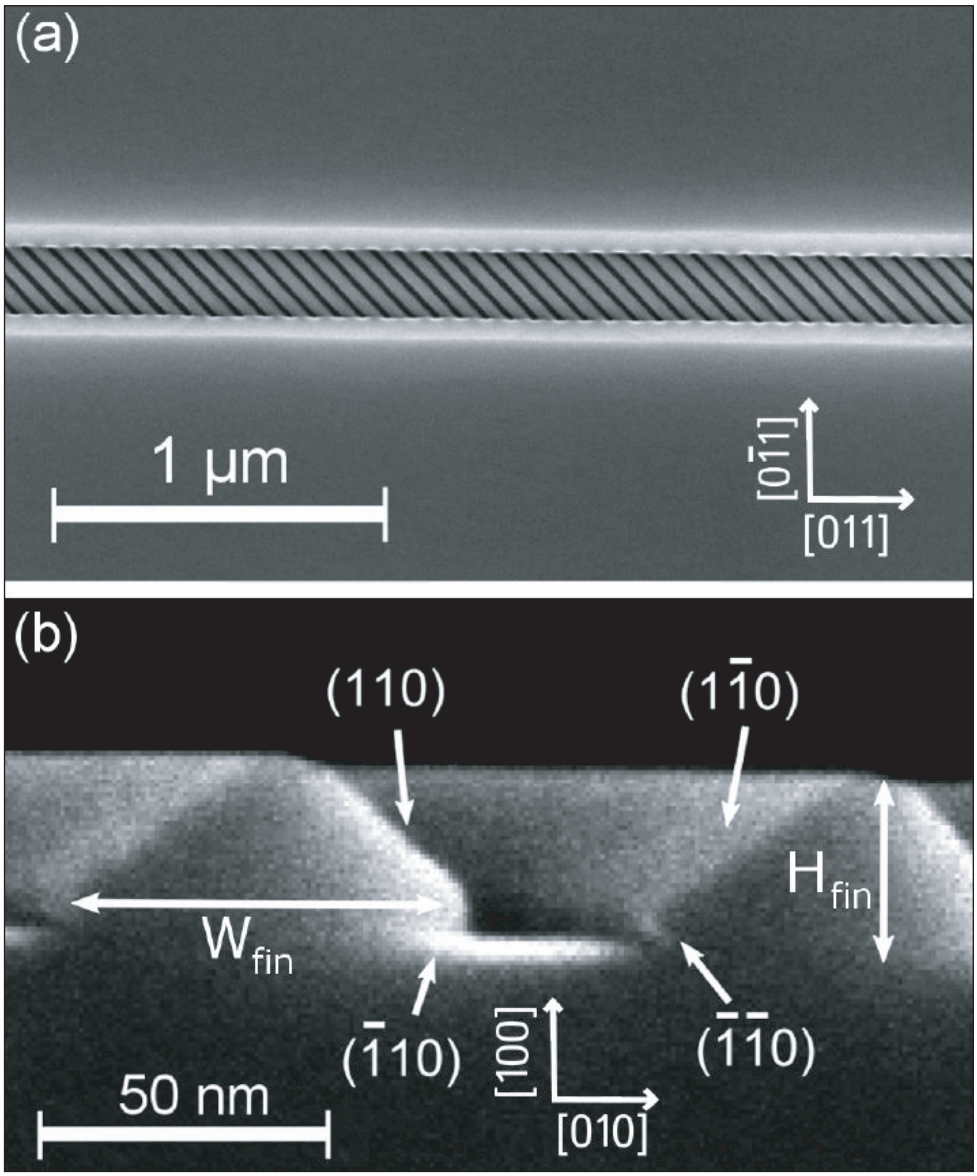


Figure 2. (a) Scanning electron micrograph (SEM) of device after second re-growth step. Shown are fins constituting the channel, as seen through gate-opening in sacrificial InP and highly doped InGaAs contact layers. (b) Cross-sectional SEM of 60nm-wide fin, with crystal planes denoted.

The researchers comment: "This is the highest reported g_m calculated from I_{DS} for any III-V multiple-gate MOSFET. We attribute these good values to the selectively re-grown channel and contacts, as well as the gate-last process."

The corresponding on-resistance was 270Ω-µm and threshold voltage was estimated at +0.09V. A 48nm-gate-length MuFET had a gm,max 1.48mS/µm at 0.5V drain.

A long gate length of 200nm allowed the device structure to achieve a low subthreshold swing (SS) of 85meV/decade and drain-induced barrier lowering (DIBL) of 88mV/V at 0.05V drain bias. At the higher 0.5V drain bias, the SS increased to 103mV/dec. The on/off ratio within a 0.5V window at 0.5V drain with 100nA/µm off-current was $1.5x10^3$. The SS for a 32nm gate length was 185mV/decade at 0.5V drain.

Radio-frequency measurements between 40MHz and 67GHz gave a cut-off frequency (f_T) estimate of 210GHz and maximum oscillation (f_{max}) of 250GHz; "the highest of any reported III-V multiple-gate MOSFET, though below the records for planar III-V MOSFETs", according to the researchers. The good performance is attributed to suppressed parasitic gate capacitance.

The poor SS in the short-channel/gate-length devices could be improved by etching the underlying InP to create gate-all-around structures or by using InAlAs back-barriers to reduce leakage effects. ■

http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6739081

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6 Deposition equipment

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