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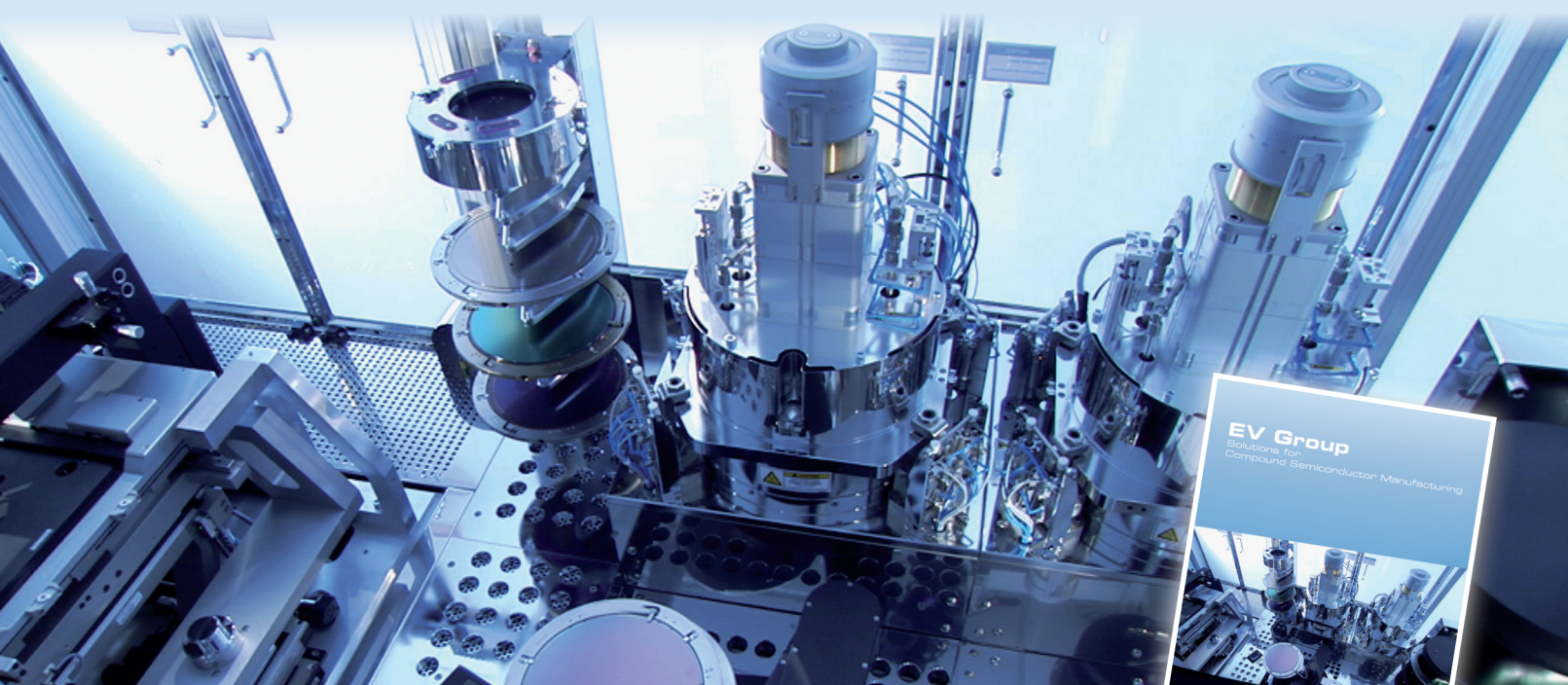
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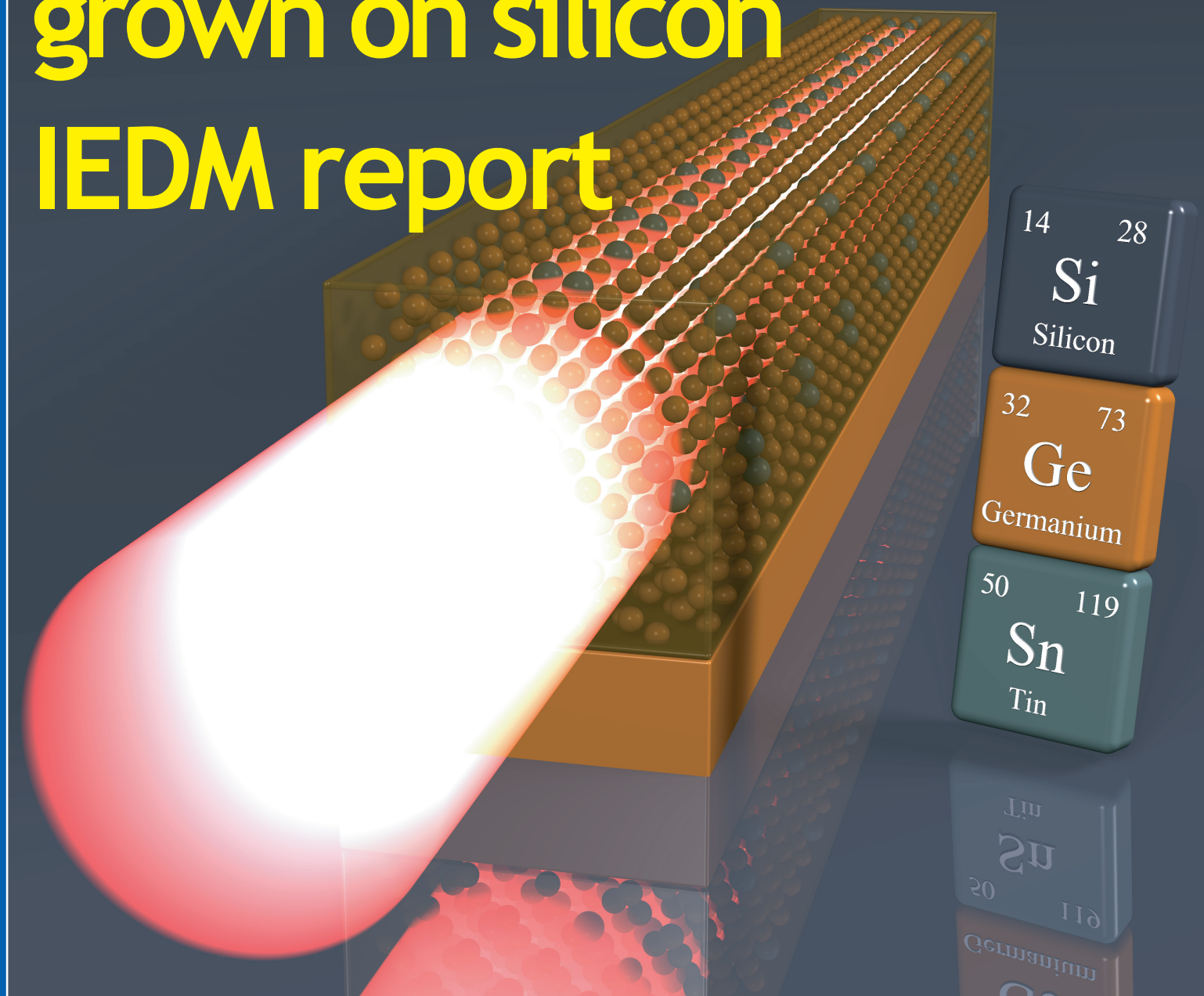
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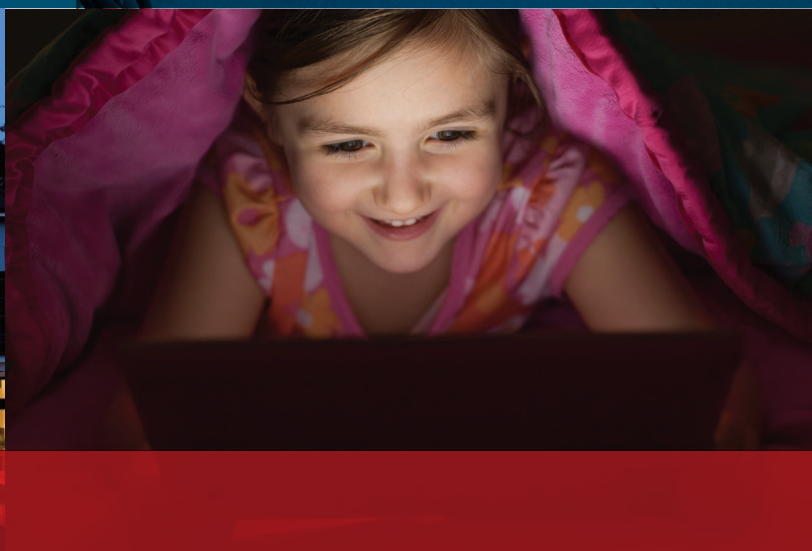


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First group-IV lasers grown on silicon IEDM report



Toyota road testing SiC devices • Ammono making 2" Si GaN
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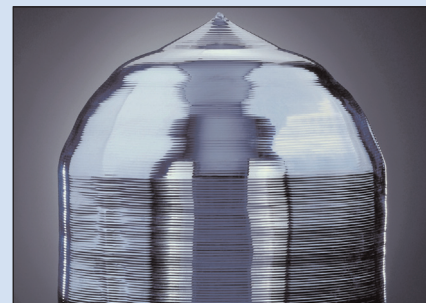
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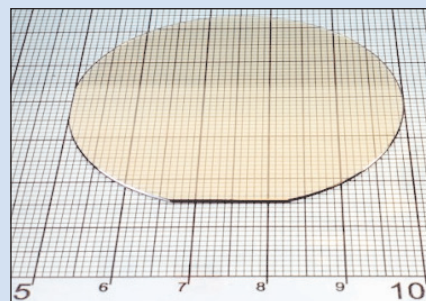
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COMPOUNDS & ADVANCED SILICON

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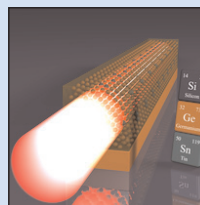
p22 Karlsruhe Institute of Technology is studying using SiC switches in power supplies, e.g. in float-zone growth of crystalline materials.



p29 Ammono has begun fabrication of 2" semi-insulating GaN substrates.



p40 Ichor Systems has had its new European head office opened by the Scottish Government Minister for Business, Energy and Tourism.



Cover: Germany's Forschungszentrum Jülich and Switzerland's Paul Scherrer Institute have presented what is reckoned to be the first semiconductor laser consisting solely of main group IV elements, namely direct-bandgap germanium-tin alloy grown on silicon. p56

New technology drives growth

On page 94 of this issue we give an overview of compound semiconductor-related research reported at December's IEEE International Electron Devices Meeting (IEDM) in San Francisco, focusing on developments in both power and high-speed electronics, along with optoelectronics. While most of these devices are based on nitride materials, the report also covers research into devices based on two-dimensional semiconductor materials such as layers of transition-metal dichalcogenide (TMDC) — e.g. molybdenum disulfide and diselenide (MoS_2 and MoSe_2) and tungsten disulfide and diselenide (WS_2 and WSe_2) — which have potential application for CMOS technology with dimensions of less than 7nm. These materials were also discussed by the likes of University of California Santa Barbara (UCSB) and Intel at the International Solid State Circuits Conference (ISSCC) in late February (to be covered next issue).

Regarding power electronics based on gallium nitride and silicon carbide, on page 10 market analyst firm Lux Research reckons that, as wide-bandgap materials such as GaN and SiC make inroads into the market share of incumbent silicon technology, their higher cost requires market-specific strategies to leverage the technology differentiation for applications such as automotive and solar inverter markets. Concerning SiC, on page 22 comes news that Toyota has begun year-long road testing SiC transistors and diodes in the power control units (PCUs) of a Camry hybrid prototype car, as well as in the voltage step-up converter of a fuel-cell-powered bus. On page 8, Strategy Analytics forecasts that revenue for GaN RF devices will grow at a compound average annual growth rate (CAAGR) of over 20% to nearly \$560m in 2019. In tune with this, Japan's Fujitsu has just begun mass production of Transphorm's GaN power devices for switching applications using an automotive-qualified CMOS-compatible, 150mm fab, while Japan's Yaskawa Electric has begun production of a PV inverter using a power conditioner based on a Transphorm GaN power module (see page 26).


These market developments for GaN-on-silicon should benefit start-ups such as Belgium-based III-nitride epitaxial material supplier EpiGaN, which is gearing up for GaN-on-Si and GaN-on-SiC demand by adding a chief marketing officer (see page 29). Meanwhile, in April Sumitomo Chemical will acquire the compound semiconductor materials business of Hitachi Cable, which produces GaN substrates and epiwafers (as well as GaAs epi) — see page 31.

Demand for GaN epi is also driving the recovery in orders of metal-organic chemical vapor deposition reactors, as LEDs are increasingly adopted for general lighting applications and as the corresponding higher-volume new-generation MOCVD systems of the two main suppliers Veeco and Aixtron achieve acceptance at the main LED makers. In particular, China's San'an ordered 50 new Aixtron AIX R6 systems last September, followed in fourth-quarter 2014 by 25 new Veeco EPIK700 systems (helping Veeco's total MOCVD orders to almost triple year-on-year) — see page 34–37.

Nevertheless, due to the LED-driven slowdown in MOCVD demand during the prior years (leading to Aixtron announcing 60 job cuts in January), Aixtron says it is continuing to invest in R&D to reduce its dependency on one product while creating new opportunities (citing power and logic as well as OLEDs). With Veeco launching its Propel Power GaN MOCVD system last November, it will be interesting to see how Aixtron taps these new, growing markets.

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Semiconductor Today covers the R&D and manufacturing of compound semiconductor and advanced silicon materials and devices

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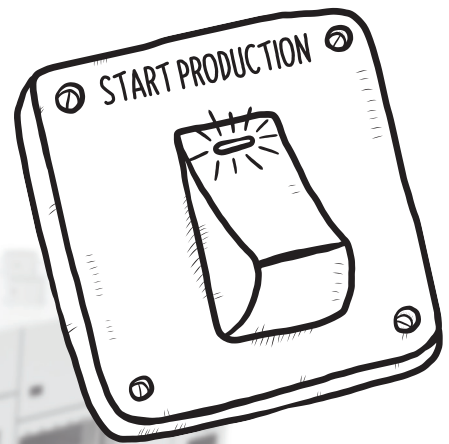
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LED lamp and luminaire shipments for commercial buildings to total 10.7 billion from 2014 to 2023

Lamp revenue to fall from \$18.5bn to \$12.8bn due to lifespan of LEDs

Unit shipments of LED lamps and luminaires are expected to total 10.7 billion from 2014 through 2023, according to the report 'Energy Efficient Lighting for Commercial Markets' from Navigant Research.

As new LED products have reached the market in the last few years, the technology has become increasingly competitive with the fluorescent lighting typically used in commercial applications, says the market research firm. While still more expensive, LEDs have been found to be more efficient and to offer a range of benefits, including improved color quality and better dimming.

"Long term, it's possible that LEDs could trigger a fundamental change in the way lighting is provided to commercial spaces," says senior research analyst Jesse Foote.

"The traditional lamp/luminaire model could be replaced by products that integrate the two, and even the concept of providing light through fixtures in the ceiling could shift, as flat and flexible LEDs allow for more creative designs that can be incorporated into other building materials and placed in non-traditional locations."

The use of LEDs in commercial applications is expected to be most apparent in retrofit projects, where older lighting is often replaced specifically to improve efficiency, according to the report. Although research indicates that only 15% of lamps sold to retrofit projects worldwide in 2014 were LED-based, that share is expected to grow to nearly 74% by 2023, potentially eliminating inefficient technologies like incandescent and halogen.

However, due to the much longer lifespan of LED lamps, Navigant expects overall revenue from lamp sales to decline in the coming decade, from \$18.5bn in 2014 to \$12.8bn in 2023.

To avoid this inevitable decline, lighting companies are broadening their focus from that of equipment suppliers by beginning to provide lighting controls and lighting services.

Just as the tech giants (e.g. Hewlett-Packard and IBM) of decades past had to make the shift from hardware to software and services, today's lighting giants are becoming providers of complete lighting solutions rather than just the physical elements that emit light, notes Navigant Research.

www.navigantresearch.com/research/energy-efficient-lighting-for-commercial-markets

Chip-on-board LED market to grow from \$1.5bn in 2014 to \$4.4bn in 2020, driven by directional and high-lumen applications

COBs to exceed 70% penetration in downlight, streetlight and high-bay

The market for chip-on-board (COB) LEDs and multi-chip array COBs will grow significantly from \$1.5bn in 2014 to \$4.4bn in 2020, including 40% growth from 2014 to 2015, according to the report 'The World Market for COB LEDs in General Lighting' from market research firm Strategies Unlimited.

Long-term growth is due mainly to the increased penetration of COBs into directional and high-lumen applications. "COBs have a better light distribution and design flexibility than other package types, which makes them more adapted to

applications where you need to direct light, need a large quantity of usable lumens, or both," comments research analyst Martin Shih.

The report offers insight into the total lighting market through 2020 by covering all applications of luminaires and lamps, including troffers, downlights, spotlights, street lights, high-bay, MR-16, reflectors, and other replacement lamps.

For a few years now, there have been many proponents that claimed mid-power packaged LEDs were going to supplant all other LEDs in lighting applications, says

Strategies Unlimited. The train of thought was that, since mid-power LEDs are cheaper, companies will just pack luminaires with more of these LEDs to get the desired lumen output. Strategies Unlimited has determined that this trend is shifting, as it is much easier to design certain luminaires with higher-power LEDs and as COB packages are coming down in price. "By 2020, we expect COBs to have a higher than 70% penetration rate in downlight, streetlight, and high-bay applications, to name a few," concludes Shih.

www.strategies-u.com

LED lighting market growing at 17.3% CAGR to 2019 while traditional lighting shrinks at 7.6% 2015 to be transitional year for LED lighting, says IHS

Whereas 2014 was a challenging year for lighting products (with most traditional technology suppliers reporting declining quarterly revenues for lamps and luminaires), many LED-only manufacturers saw their revenues rise, says market research firm IHS Technology. This trend is expected to continue, with lamp revenues forecasted to rise at a compound annual growth rate (CAGR) of 1.4%, from \$28.6bn in 2014 to \$29.9bn in 2019, consisting of LED revenue rising at a CAGR of 17.3% while that for traditional technology falls by 7.6%.

Traditional technology lamp makers have had to restructure their portfolios, as traditional lighting products are replaced by more lucrative LED lamp and luminaire products. At the same time, high growth rates for LED lamps are attracting lots of competition from low-priced Chinese manufacturers – margins have been squeezed and could continue to decrease. In fact, some manufacturers could be forced to leave the market altogether if they cannot find a way to compete at lower price points, says IHS Technology.

Currently, A-type LED replacement lamps – which replace the traditional technology A-lamps that are especially prevalent in the residential sector – comprise the majority of LED lamp shipments and revenue in North America, Latin America and Europe, Middle East and Africa (EMEA). An increasing number of manufacturers introduced T-type LED products last year, to address this large and growing market. According to the most recent IHS findings, 10.6 billion fluorescent units are currently installed in indoor commercial and industrial applications worldwide, accounting for about half of all lamps in this sector; however, LED penetration has yet to surpass 1%.

In the past, there was little incentive for building owners to swap fluorescent tubes with T-type LEDs, as the high **Some manufacturers could be forced to leave the market altogether if they cannot find a way to compete at lower price points**

initial cost of the LED products and relatively small efficiency gains over fluorescent tubes meant a low return on investment. However, new and more efficient products are now entering the market, creating a large potential market for LED-integrated luminaires. For example, Cree released a 150lm/W LED troffer with a 100,000 hour lifetime last year, which could reduce energy consumption by 70%.

Technology advances have also led to products that provide a better colour rendering index (CRI) and a more pleasant colour temperature, which is important to retailers and other end-users who require high-quality light, says IHS. Lighting manufacturers have also begun embracing the Internet of things (IoT), producing smart light bulbs that can be controlled from a smartphone, play music or have integrated smoke detectors and security cameras. Introducing lighting products like these is one way that manufacturers are differentiating themselves in this increasingly crowded market, notes the market research firm.

www.ihs.com

Packaged LED providers diversifying into module market

Leading suppliers of LED components are increasingly diversifying, in order to produce LED modules and light engines, according to the latest Research Note from market analyst firm IHS Inc, whose 'Next Generation Lighting' report projected that the combined market for LED modules and light engines in lighting applications would reach \$1.3bn in 2014.

Many companies, known in the past only as packaged LED providers, have expanded their product offerings, and are now also supplying LED modules. The com-

petition in this market is particularly diverse, not only because suppliers are located all over the world, but also because of competition from companies with backgrounds in power devices and other backgrounds, adds IHS.

These suppliers are moving into the module market, in order to diversify their portfolio and protect against component LED profit margins potentially falling further, as the packaged LED market becomes increasingly commoditized, says IHS. With Chinese companies beginning to gain market share,

companies in the West and Korea (among others) are moving up the supply chain to minimize the effects of this competition. With modules and light engines becoming more common, there is a growing trend for lighting companies to purchase LED modules, rather than component-packaged LEDs, in order to shorten and simplify the supply chain. However, in-house production by lighting companies is still common and will remain so, reckons IHS.

<https://technology.ihs.com/512171/next-generation-lighting-2014>

Silicon photonics market to grow at nearly 28% compound annual growth rate to \$497.5m by 2020

The silicon photonics market is expected to increase at a compound annual growth rate (CAGR) of 27.74% from 2014 to \$497.53m by 2020, according to the report 'Silicon Photonics Market — Global Trends and Forecasts to 2014 — 2020' from MarketsandMarkets Inc.

Silicon photonics is being implemented by various companies in their product portfolios due to features such as high-speed data transfer and the integration of large data into a small device. With the help of silicon photonics, products such as optical waveguides, modulators, and photo-detectors can be integrated within a single device, providing a smaller form factor.

In particular, wavelength division multiplexer filters (WDMF) and silicon optical modulators (SOM) have the highest share in the North American market currently. Thus, this shows that WDMF and SOM products in the silicon photonics market have great potential to grow over time.

The silicon photonics market is dominated by the North American region in terms of market size. Growing demand to transfer data as well as government funding in silicon photonics are motivating firms to launch silicon photonics products in the North American market, says the market research firm. However, the Asia-Pacific (APAC) region has been growing at the highest CAGR.

In terms of the competitive landscape, the market is witnessing new product launches and large-scale collaborations, as well as agreements and partnerships across the value chain, with a number of tier-one players around the globe, notes the report.

The report lists the major players in the silicon photonics market as Intel, Japan's Hamamatsu Photonics, Finisar, IBM and Luxtera in the USA, Swiss-based ST Microelectronics, 3S Photonics in France, and Oclaro, Mellanox Technologies and Infinera in the USA.

www.marketsandmarkets.com/Market-Reports/silicon-photonics-116.html

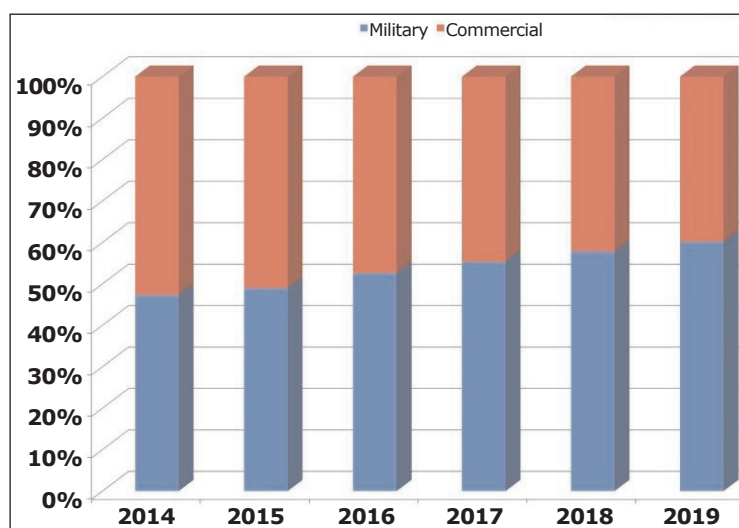
GaN RF device market to grow at 20% CAAGR to nearly \$560m in 2019

Revenue for gallium nitride (GaN) RF devices in both military and commercial applications will grow at a compound average annual growth rate (CAAGR) of more than 20% to nearly \$560m in 2019, according to the Strategy Analytics Advanced Semiconductor Applications (ASA) spreadsheet model, forecast and outlook report 'GaN RF Market Update: 2014–2019'.

Specifically, military applications accounted for slightly less than 50% of total GaN RF device revenue in 2014, but strong growth in all areas — particularly the communications segment — will propel this to 60% market share in 2019.

"Military applications for RF GaN devices are expanding quickly," notes Asif Anwar, director in the Strategic Technologies Practice. "We anticipate broad adoption of GaN RF devices in radar, communications and EW [electronic warfare] applications will fuel impressive revenue growth."

Also, while military applications continue to experience strong



GaN RF device revenue share: military and commercial.

growth in GaN device usage, commercial applications for the technology are finally seeing widespread adoption.

The biggest uptick in commercial adoption in 2014 came from wireless infrastructure, says Strategy Analytics. This will remain the largest commercial segment, but decreasing LTE macro-cell deployments in China and a shift to small-

cell architectures will dampen the revenue growth rate.

"It is an interesting time in the GaN RF device market," comments Eric Higham, service director, Advanced Semiconductor Applications. "Wireless and CATV/broadband infra-

structure PA [power amplifier] applications have taken root and we are seeing initial adoption in other commercial applications," he adds. "Price reduction is still a central theme [as GaN technology looks to capture more market share from LDMOS and GaAs technology] and some initiatives could prove to be very disruptive in the future."

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Apple matches Samsung as largest smartphone vendor in Q4/2014, as total shipments grow 31%

Samsung's market share falls year-on-year from 29.6% to 19.6%

Global smartphone shipments grew 31% annually from 290.2 million units in fourth-quarter 2013 to a record 380.1 million in fourth-quarter 2014, according to the latest research from Strategy Analytics.

"An impressive 1.3 billion smartphones were shipped worldwide in 2014 [up 29.6% from 0.99 billion in 2013], with very strong growth seen last year in emerging markets such as China, India and Africa," notes Linda Sui director at Strategy Analytics.

Apple's shipments grew 18% from 51 million in Q4/2013 to 74.5 million in Q4/2014, taking a record 19.6% market share (up from 17.6%).

"Apple's new iPhone 6 and 6 Plus models are proving wildly popular in China, USA and Europe," comments executive director Neil Mawston.

Apple tied with Samsung to become

the largest smartphone vendor for the first time since Q4/2011.

Samsung's 19.6% market share (74.5 million shipments) is down from 29.6% in Q4/2013 (86 million shipments). "Samsung continues to face intense competition from Apple at the higher end of the smartphone market, from Huawei in the middle tiers, and from Xiaomi and others at the entry-level," notes Mawston.

"Samsung may soon have to consider taking over rivals, such as Blackberry, in order to revitalize growth this year," he adds. However, Samsung remained the number-one smartphone player globally on a full-year basis in 2014.

Lenovo merged officially with Motorola to capture 6.5% smartphone market share (level year-on-year, with shipments up from 18.8 million in Q4/2013 to 24.7 million

in Q4/2014), taking third position.

"Lenovo is hoping to leverage Motorola's famous brand to drive global scale this year and to offset some of Lenovo's recently weakening smartphone growth at home in China," says Strategy Analytics' director Woody Oh.

Huawei's shipments grew by 45% from 16.6 million in Q4/2013 to 24.1 million in Q4/2014, taking a 6.3% market share (up from 5.7%) in fourth place. "Huawei is expanding rapidly online in China and through retailers across Africa, enabling it to become an emerging powerhouse in developing markets." Adds Oh.

The report 'Apple Becomes World's Largest Smartphone Vendor in Q4 2014' is published by the Strategy Analytics Wireless Smartphone Strategies (WSS) service.

www.strategyanalytics.com

Strategy a key differentiator as more efficient GaN & SiC power electronics enter market

Power electronics based on gallium nitride (GaN) and silicon carbide (SiC) have the potential to greatly improve efficiency. However, since these materials are higher cost, companies need market-specific strategies in order to succeed as these new wide-bandgap (WBG) materials claim market share from silicon-based semiconductors, says Lux Research in its report 'Strategic Playbook for Power Electronics: Lessons from the IC Sector Evolution' (part of the Lux Research Energy Electronics Intelligence service).

Car makers would succeed by playing the role of an 'integrator' by vertically integrating upstream in the value chain to power modules, while a GaN or SiC developer would do well to pursue a strategy as 'technology disruptor' offering core technology expertise to solar inverter makers and incumbent

system integrators like ABB, reckons Lux Research.

"Fast-growing markets like automotive and solar inverters are unforgiving when it comes to players without strong business and strategy," notes analyst Pallavi Madakasira (lead author of the report). "Start-ups trying to address these opportunities need to forge partnerships and collaborations – companies like Transphorm and GaN Systems that have done so are best-positioned for success," she adds.

Lux Research analysts evaluated the value chain in GaN and SiC power electronics to identify strategies for the automotive and solar inverter market. Their findings include the following:

● Integrators face low risk

Car makers could integrate upstream through acquisition to include power modules and

inverter/converter manufacturing. Such acquisitions will allow car makers to own drive-train design and to lower overall costs.

● Tech differentiation is critical

A vertically integrated GaN/SiC device or module player is well positioned in the solar value chain. The core technology differentiation that such a firm offers will be critical for incumbent solar inverter makers like SMA and Fronius, and something that system integrators like ABB do not have the competencies for.

● Other players need to be nimble

Suppliers of substrates, packaging materials and thermal materials will need to customize. Staying nimble and planning for an increased number of specialized device makers in the power electronics value chain will be critical to their overall success.

https://portal.luxresearchinc.com/research/report_excerpt/18580

Smartphone sales grow 23% to over 1.2bn units in 2014

Unit sales growth to slow to 14% in 2015

Global smartphone revenue grew 20% year-on-year to a record \$115bn in fourth-quarter 2014 as unit sales rose 19% to almost 346 million (totalling over 1.2bn in full-year 2014), according to market research firm GfK.

In Q4/2014, all regions saw year-on-year growth, in terms of both units and value, except for developed APAC (Asia-Pacific), where subsidy changes in Korea negatively affected these already very mature markets. The Latin America market saw the highest growth, with revenue growing 37% to about \$10bn and unit sales up 43% year-on-year to 36 million units (and up 59% for full-year 2014).

China will remain the biggest market in terms of both unit and value sales for the foreseeable future. However, growth slowed dramatically in second-half 2014. During Q4, smartphone unit sales were flat year-on-year, although the value of units sold rose by 21% to \$28bn, the highest ever quarterly figure.

"The increase in the value of units sold in China, despite the recent plateauing of unit sales, is due to consumers' rapid adoption of higher-priced smartphones with larger screen sizes," says Kevin Walsh, director of Trends and Forecasting at GfK. "This is a trend seen in most markets and GfK global data shows that the 5–5.6 inch segment grew by more than 130% year-on-year in Q4/2014 and by nearly 150% in the full year," he adds. "In 2015, we forecast this segment to become the dominant screen-size band, surpassing 4–4.5 inch for the first time."

All other regions - except for North America and Developed APAC - saw a decrease in the average selling price (ASP) in Q4/2014. Looking ahead, all regions will grow in unit terms in 2015, but growth rates will slow significantly from 2014, forecasts GfK.

	Units sold (in millions)			Sales value (in billions US\$)		
	Q4 2013	Q4 2014	% Change	Q4 2013	Q4 2014	% Change
Latin America	25.1	36.0	43%	7.2	9.9	37%
Central & Eastern Europe	16.7	21.5	29%	4.5	5.1	12%
North America	43.6	57.0	31%	18.4	25.1	36%
Emerging APAC	30.4	41.8	37%	6.4	7.6	18%
Middle East & Africa	27.9	37.8	35%	8.7	10.8	25%
Western Europe	35.1	40.0	14%	15.6	17.2	10%
China Units	95.0	95.1	0%	23.5	28.3	21%
Developed APAC	18.1	17.3	-4%	10.9	10.9	0%
Total global units	292.0	346.5	19%	95.3	114.8	20%

Source: GfK Smartphone sales based on point-of-sale (POS) tracking in 90+ markets © GfK 2015

	Units sold (in millions)			Sales value (in billions US\$)		
	FY 2013	FY 2014	% Change	FY 2013	FY 2014	% Change
Latin America	68.7	109.5	59%	20.6	31.4	52%
Central & Eastern Europe	50.9	69.8	37%	15.1	17.2	14%
North America	139.1	177.6	28%	58.2	71.8	23%
Emerging APAC	96.9	149.9	55%	22.3	28.4	27%
Middle East & Africa	99.8	135.2	35%	32.3	39.4	22%
Western Europe	115.4	128.0	11%	52.2	55.8	7%
China Units	359.0	392.8	9%	90.1	99.0	10%
Developed APAC	68.3	65.1	-5%	39.6	38.1	-4%
Total global units	998	1,228	23%	330.4	381.1	15%

Source: GfK Smartphone sales based on point-of-sale (POS) tracking in 90+ markets © GfK 2015

"The slowdown forecast for 2015 is due to developed markets reaching saturation point," says Walsh. As a result, global smartphone unit growth will be only 14% this year, down from 23% in 2014. "We forecast emerging regions to drive growth in 2015 as smartphones

the Middle East & Africa. Both regions still have significant room for growth as consumers migrate from feature phones and existing smartphones to trade up to a bigger screen, says the market research firm.

www.gfk.com

further penetrate lower price points," he adds. GfK forecasts that smartphone price bands above \$150 will see a decline in market share. At the next level down (\$100–150), sales will remain stable, but it is the cheaper smartphones priced below this point that will gain share.

The most resilient two regions in 2015 — both forecast to grow by 33% in unit terms — are Emerging APAC and

Anadigics' quarterly sales rebound by 10.6% to \$20.9m

Refocusing on Infrastructure to drive EBITDA break-even by mid-2015

For full-year 2014, broadband wireless and wireline communications component maker Anadigics Inc of Warren, NJ, USA has reported revenue of \$86.3m, down 36% on 2013's \$134.2m. Mobile revenue more than halved, from \$98m to \$47.1m, while Infrastructure grew 8.3% from \$36.2m to \$39.2m.

For fourth-quarter 2014, revenue was \$20.9m, down 42% on \$36.3m a year ago but rebounding by 10.6% from the low of \$18.9m last quarter.

In particular, Mobile revenue was \$11.2m (53% of total revenue), more than halving from \$25m a year ago but rebounding by 26% from \$8.8m last quarter (when there was an expected decline in sales of legacy products plus inventory reductions in the sales channel). "In accordance with our strategic plan, we continue to selectively engage mobile applications with products that provide our customers with unique value," says chairman & CEO Ron Michels. "In doing so, our mobile revenue - particularly in Wi-Fi [about two-thirds of Mobile revenue] - remains strategic to our plan," he adds. In addition to expected seasonal strength, growth was driven by design wins that entered production during second-half 2014, including Wi-Fi front-end modules in both the LG G3 Beat and Huawei Ascend Mate 7 smartphones (announced in late November).

Overall in Q4/2014, there were three greater-than-10% customers (Huawei, Samsung and distributor Alltech) and three customers in the 5-10% range (with a solid representation from Infrastructure).

Infrastructure revenue was \$9.7m (47% of total revenue), down on \$10m last quarter and \$11.3m a year ago, due to continued inventory reductions in the firm's sales channel that masked higher sales from distribution partners to end-customers during the last two quarters. "Lowering inventory is a

positive for working capital efficiency and cash but weighs slightly on our reported gross profit margin," notes executive VP & chief financial officer Terry Gallagher.

Gross margin rose from 16% last quarter to 18.7% in Q4 (above the expected 18%), driven by increased revenue, a more favorable product mix within Mobile, and continued expense improvements from the firm's restructuring. This more than offset the continuing light capacity utilization (up from 30% last quarter, but still only 35%) resulting from the ongoing inventory reduction.

In Q4/2014, research & development (R&D) and selling & administrative (S&A) operating expenses fell by a better-than-expected 2.7% from \$8.7m last quarter to \$8.5m, driven by efficient R&D investments (cut by 4.8%, from \$5.2m to \$5m), while S&A expenses were flat at \$3.5m. For second-half 2014, operating expenses were \$17.2m, down 38% on \$27.7m in second-half 2013.

On a non-GAAP basis, net loss for Q4/2014 was \$4.7m (\$0.05 per share), cut from \$5.7m (\$0.07 per share) — the third consecutive sequential improvement of \$0.02 per share — and \$8.4m (\$0.10 per share) a year ago. Full-year net loss has been cut further, from \$44.7m (\$0.55 per diluted share) to \$27.8m (\$0.32 per diluted share).

Likewise, earnings before interest, taxes, depreciation and amortization (EBITDA) loss has improved further, from \$4.9m a year ago and \$3.2m last quarter to \$2.1m, "evidence that our strategic restructuring and focus on Infrastructure markets is working", says the firm.

Capital investment was basically zero for a second consecutive quarter (compared with \$1.3m a year ago) and just \$0.75m for full-year 2014 (versus \$6.5m for full-year 2013). During the quarter, cash and cash equivalents rose from \$13.5m to

\$18.4m. However, excluding \$4m drawn under the firm's \$10m credit facility, net cash was \$14.4m (up \$4.9m on last quarter, due to the continued improvements in EBITDA performance, a further decrease in working capital, and the sale of \$1.3m in excess capital equipment). This is also \$4.7m higher than at the end of Q2/2014, when Anadigics started its strategic shift to infrastructure. "We are exceeding our targeted \$25m in annualized savings and we increased our net cash by approximately \$4.7m, against the headwind of EBITDA losses and restructuring cost during second-half 2014," notes Michels.

"The benefits of our new business model are evident in our improving metrics, including cash efficiency and expanding gross margin," says Gallagher.

"We have made remarkable progress since we announced our strategic restructuring late last June, and in virtually all aspects outperformed our stated objectives in the second half of 2014," says Michels. "Infrastructure is taking the leadership position in the company with strength across all of our key target markets, and we believe the company is well positioned for success," he adds.

"For each of our targeted infrastructure markets, maximizing spectral efficiency or bits per second per hertz is critical to delivering a rich user experience. For our part in this broader challenge, Anadigics has developed core technology to optimize RF power, current consumption and linearity," says Michels. "In CATV, we launched 16 new products in the second half of 2014 and we are very pleased with the engagements they are driving at OEMs worldwide," he adds. "We are positioned for a new customer expansion in key markets such as China with C-DOCSIS and anticipate solid revenue growth in 2015. Our rate of growth will depend on

► continued deployment of existing DOCSIS equipment, DOCSIS 3.0 equipment and the ramp of new DOCSIS 3.1 and the shape of the crossover between the two. Our design-win penetration is strong and, pending further clarity from key customer deployments, we now estimate a growth rate in 2015 to be approximately 30-50% over that in 2014," continues Michels.

For first-quarter 2015, Anadigics expects a less-than-typical sequential decline in revenue of only 10-13%, as the normal seasonal decrease in Mobile revenue will be offset by significant growth in Infrastructure revenue (to over 50% of total revenue) with channel inventory now closer to targeted levels. "With new designs and projects moving into production during 2015, we expect this trend will con-

tinue and should result in a year-end revenue split that is approximately 75% Infrastructure and 25% Mobile," says Michels.

Despite the drop in revenue in Q1/2015, driven by the higher mix of Infrastructure products and slightly improved factory utilization, gross margin is expected to improve sequentially (for a fourth consecutive quarter) by about 400 basis points (and to continuing improving through 2015). Operating expenses are expected to be roughly flat (with the expense base - particularly R&D investments - well aligned with the growth plan). Anadigics is not anticipating any material sales of excess capital equipment in Q1. "Cash usage will be slightly higher than our anticipated EBITDA loss due to a small forecasted increase in working cap-

ital," expects Michels. Nevertheless, Anadigics expects further improvement in EBITDA loss.

"Our existing net cash, in concert with the improved cash efficiency of our new operating model, provides us with adequate resources to realize cash flow positive operations," believes Gallagher. "With an expanding infrastructure product mix, we believe we can deliver EBITDA breakeven results [by mid-2015] at about \$20m in total revenue with factory utilization approximating 40%," he adds.

"Our \$10m line of credit with Silicon Valley Bank increases our flexibility to fund working capital needs in support of anticipated revenue growth," says Michels. "We have adequate capital resources to carry us through EBITDA breakeven and beyond."

Anadigics regains NASDAQ listing compliance

Anadigics has received a letter from The NASDAQ Stock Market that included a compliance determination that the firm has regained compliance with NASDAQ Listing Rule 5450(a)(1), which requires that listed securities maintain a minimum closing bid price of \$1 per share. Anadigics'

common stock will therefore maintain its listing on the NASDAQ Global Select Market.

As previously announced, on 11 August 2014 the firm received a letter from NASDAQ notifying it that it did not comply with the \$1 minimum closing bid price requirement for continued listing. The

firm was given 180 days (until 9 February) to regain compliance.

The stock subsequently maintained a closing bid price of at least \$1 per share for 10 consecutive business days, from 26 January to 6 February, enabling Anadigics to regain compliance.

www.anadigics.com

Anadigics' elects ServCo CEO to board of directors

Richard B. Kelson, chairman, president & CEO of strategic sourcing and supply chain management firm ServCo LLC, has been elected to Anadigics' board of directors. Paul Bachow is stepping down from the board after more than two decades of service.

Anadigics says that Kelson is a recognized finance and supply chain management leader, having held several positions at Alcoa Inc (one of the world's most successful metals companies). Most notably, Kelson served as chairman's counsel until he retired in 2006, executive VP & chief financial officer from 1997 to 2005, and general counsel from 1994 to 1997. Institutional

Investor magazine named him 'Best CFO in Metals and Mining' in 2004 and 2005. He is also a recipient of two of CFO Magazine's global CFO Excellence Awards.

"We conducted an exhaustive search to find a leader whose experience, knowledge, and values will further expand our board's breadth and depth of talent," says Anadigics' chairman & CEO Ron Michels. "With an extensive public company and private equity background, Rick brings to Anadigics vast financial, legal and supply chain expertise that we believe will be invaluable."

Kelson is a member of the board of directors of PNC Financial Services Group, MeadWestvaco Corp, and

Commercial Metals Corp. He was previously operating advisor with private equity fund manager Pegasus Capital Advisors from 2006 to 2010.

Paul Bachow has served on Anadigics' board since 1993 and was most recently chairman of the audit committee. With his departure, Harry Rein has been elected chairman of the audit committee and Kelson will join the committee as its financial expert. Kelson has also been elected as a member of the compensation & HR committee. He will serve out the remainder of Bachow's term and remain in office through the firm's Annual Shareholder meeting, when he will stand for re-election by the shareholders.

Qorvo reports combined RFMD–TriQuint December-quarter revenue up 33% year-on-year to \$742m

Qorvo Inc, a provider of core technologies and RF solutions for mobile, infrastructure and aerospace/defense applications, has reported December-quarter financial results for both RF Micro Devices Inc of Greensboro, NC, USA and TriQuint Semiconductor Inc of Hillsboro, OR, USA, following the merger of the two firms on 1 January. Combined revenue was \$742m, up 16.9% on \$634.8m last quarter and 33% on \$556.2m a year ago.

Individually, for fiscal third-quarter 2015 (ended 27 December 2014), RFMD's revenue was \$397.1m, up 9.5% on \$362.7m last quarter and 38% on \$288.5m a year ago.

On a non-GAAP basis, gross margin has risen further, from 39.7% a year ago and 48% last quarter to 49.3%. Likewise, net income has risen further, from \$36.4m (\$0.13 per diluted share) a year ago and \$90m (\$0.30 per diluted share) last quarter to \$108.4m (\$0.36 per diluted share, exceeding the guidance of \$0.33 per diluted share).

For TriQuint, fourth-quarter 2014 revenue was \$344.9m, up 26.8% on \$272.1m last quarter and 28.8% on \$267.7m a year ago.

On a non-GAAP basis, gross margin

has risen further, from 37.2% a year ago and 46.6% last quarter to 48.8%. Likewise, net income has risen further, from \$26.4m (\$0.16 per diluted share a year ago and \$51.4m (\$0.28 per diluted share) last quarter to \$89.6m (\$0.48 per diluted share, exceeding guidance of \$0.40–0.45).

For both RFMD and TriQuint, revenue, gross profit, operating income, operating margin and earnings per share were all quarterly records.

Strategic highlights during the quarter are listed as follows:

- starting shipments of LowDrift and NoDrift high-performance filters (delivering what is claimed to be unmatched temperature stability to solve challenging band coexistence problems);
- securing the first major design win for optical applications in the high-growth data-center market;
- capturing multiple power amplifier (PA), switch and filter design wins on the two leading 4G chipsets for the China market;
- leveraging broad strength in gallium nitride (GaN) products for the defense market, highlighted by significant design wins in shipboard

and land-based international radar programs;

- beginning volume production of RF Fusion integrated RF front-end solutions for a flagship smartphone anticipated in 2015;
- releasing what is claimed to be the highest-efficiency 5GHz WiFi PA for customer premises equipment (CPE) applications; and
- winning a contract (funded by the US Department of Defense) to enhance design and manufacturing capabilities for the Spatium family of high-power, solid-state GaN-based amplifiers, targeting traveling wave tube (TWT) amplifier replacements.

For the March 2015 quarter, Qorvo expects revenue of \$615–625m, gross margin of 46–48% and diluted EPS of \$0.80–0.90.

"Our March 2015 quarterly guidance implies year-over-year revenue growth of greater than 40%," notes Qorvo's chief financial officer Steve Buhaly. "Our expectations are to outpace the industry growth rate of 10–15% and achieve our target operating model of 50% gross margin, 20% operating expenses, and 30% operating margin," adds president & CEO Bob Bruggeworth.

www.qorvo.com

Qorvo announces \$200m share repurchase program

Qorvo's board of directors has authorized the repurchase of up to \$200m of the firm's outstanding

common stock.

The main objective of the share repurchase program is to reduce

dilution from issuances relating to employee equity awards and the employee stock purchase program.

Former RFMD CFO Priddy retires from Qorvo

Qorvo's executive VP of administration Dean Priddy plans to retire at the end of the current fiscal year.

Priddy's career in technology began at Analog Devices Inc and includes 23 years at RFMD and Qorvo. Prior to being as executive VP of administration of Qorvo, he was chief financial officer of RFMD since 1997.

"Dean's contributions over the past 23 years have played a vital

role in guiding RFMD to its many successes and, ultimately, in the creation of Qorvo," comments Qorvo's president & CEO Bob Bruggeworth. "Most recently, Dean and his team assembled the foundation for Qorvo to capture at least \$150m in cost synergies, and we believe the projects are in place for Qorvo to exceed our goals. Dean's many contributions have extended

into nearly every aspect of our organization," he adds.

"At Qorvo, we have assembled an exceptional team empowered to execute to our value capture plan, and I'm confident in our team's ability to exceed our stated synergy goals," says Priddy. "The foundation is set, the funnel is filled, and Qorvo is positioned exceptionally well for continued success," he believes.

Qorvo's new RF filters boost data throughput and longer battery life for 4G smartphones

Qorvo Inc of Greensboro, NC and Hillsboro, OR, USA, a provider of RF solutions for mobile, infrastructure and aerospace/defense applications, has announced several new high-performance RF filters that provide faster data throughput and longer battery life for next-generation 4G smartphones and other mobile devices. The latest additions to Qorvo's fast-growing line of premium filters leverage the firm's proprietary filter technologies to optimize efficient use of limited spectrum.

"The global transition to 4G is just beginning, and higher filter performance is a critical enabler in LTE and TD-LTE solutions," says Eric Crevis-ton, president of Mobile Products. "Qorvo is uniquely positioned to capitalize on the growing need for highly specialized filtering solutions, given our filter technology leadership, broad product portfolio, systems-level expertise, and high-volume manufacturing scale," he reckons.

Industry analysts forecast robust demand for high-performance filters. "Smartphones with more LTE bands and carrier aggregation for higher

data rates are pushing OEMs to use more high-performance RF filters and duplexers," says Christopher Taylor of Strategy Analytics. "We expect the total market for standard and premium RF filters in cellular devices to grow above 25% per year from 2014 to 2019," he adds.

Qorvo says that, as performance requirements tighten and RF complexity increases, its proprietary LowDrift and NoDrift filter technologies can solve the industry's most challenging LTE system and chipset problems. "LTE-Advanced will usher in more sophisticated carrier aggregation and MIMO techniques in the years ahead," says Glen Riley, general manager of Filter Solutions. "Qorvo is redefining filter performance in small form factors and achieving unmatched temperature stability to extend battery life, improve insertion loss, limit service disruptions and reduce dropped calls," he adds.

The five new filters are as follows:

- the 1.1mm x 0.9mm x 0.5mm 885067 Wi-Fi/LTE coexistence filter with LowDrift BAW technology

(for WLAN);

- the 1.8mm x 1.4mm x 0.73mm TQQ1007 LTE duplexer with Low-Drift BAW technology (for band 7);
- the 2.0mm x 1.6mm x 0.73mm TQQ0041E LTE Tx/Rx filter with LowDrift BAW technology (band 41);
- the 1.8mm x 1.4mm x 0.73mm TQQ0041T LTE Tx/Rx filter with LowDrift BAW technology (band 41);
- the 1.1 x 0.9 x 0.5mm 885075 LTE filter with LowDrift BAW technology (for band 40).

Three of the new filters (the 885067, TQQ0041E and 885075) are shipping in quantity, and the remaining two (the TQQ1007 and TQQ0041T) are expected to enter volume production in the March quarter.

Qorvo is presenting its expanding portfolio of high-performance RF solutions for smartphones, tablets, and other broadband mobile devices at the 2015 GSMA Mobile World Congress (MWC) in Barcelona, Spain (2-5 March).

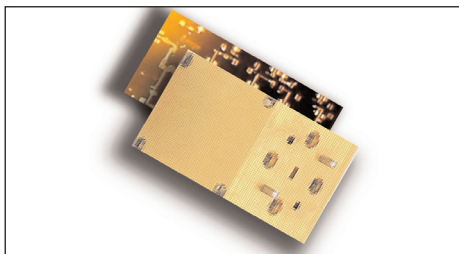
www.qorvo.com/mobile

www.triquint.com/products/lowdrift-nodrift-filters

Arralis launches GaAs pHEMT-based 100GHz MMIC for low-noise amplifiers and medium-power amplifiers

Arralis of Limerick, Ireland has launched the model TU-W1320302 4-stage monolithic microwave integrated circuit (MMIC) device, which is based on pseudomorphic high-electron-mobility transistors (pHEMTs) fabricated on gallium arsenide (GaAs) substrates. Operating over a frequency range of 98-102GHz, it provides better than 5dB noise figure with more than 20dB of stable small-signal gain.

As well as a low-noise amplifier (LNA), the device can also be used as a medium-power amplifier (MPA), supplied to deliver 16dBm of saturated output power. The robust design enables the device to



withstand more than 10dBm of input power without damage, negating the need, in most cases, for lossy input-stage protection.

Applications include narrow-bandwidth millimeter-wave imaging; high-resolution radar; sensing; point-to-point (P2P) communications; and short-haul/high-capacity/low-interference links. The firm reckons

that the device will be of interest for security applications where passive millimetre-wave imaging has returned to a strong growth cycle.

The 5mmx3mm MMIC die is currently in stock, and packaged versions with a WR10 waveguide interface are also available on a short lead time.

Arralis makes a full set of W-band millimetre-wave MMICs, enabling designers to realise complete receiver and transmitter front-ends. In December, the firm announced a contract with the European Space Agency (ESA) for its W-band chipset for a 94GHz radar system.

www.arralis.com

Skyworks' revenue grows 59% year-on-year

For fiscal first-quarter 2015 (to 2 January), Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) has reported record revenue of \$805.5m, up 12% on \$718.2m last quarter and 59% on \$505.2m a year ago (and exceeding guidance, given on 10 November, of rises of 7% and 52%, respectively, to \$770m).

"We saw healthy growth across all product categories, with the strongest being integrated mobile systems, which benefits from strong December-quarter seasonal patterns," says executive VP & chief financial officer Donald W. Palette. "This product category includes SkyOne, SkyLiTE, and our power amplifier duplexers as well as analog products like power management, WiFi and GPS," he adds.

As a proportion of total revenue, compared with last quarter, integrated mobile systems rose further from 39% to 48%. Consequently, power amplifiers fell further from 36% to 31% of total revenue and broad markets fell from 25% to 21%.

"Our broad markets product lines — serving the connected home, networking, media, automotive, and medical markets — grew 26% year-over-year, significantly outpacing the broader semiconductor industry," Palette adds.

Highlights of the quarter were:

- commencing volume production of SkyLiTE integrated systems supporting Mediatek's latest SoC (system-on-chip) reference designs across multiple smartphone platforms at several OEM customers;
- delivering diversity receive modules for LTE smartphones at several OEM customers including Samsung (a new product category for Skyworks, representing "a compelling growth avenue");
- delivering switching and connectivity modules for Xiaomi's smartphone Mi4 platform;
- capturing 10 new design wins in Cisco's latest home gateway supporting multiple cable operators;

- securing multiple analog devices in a leading telematics platform for GM vehicles;
- supporting Thales avionics platforms with hi-reliability analog IC switching products;
- introduced Zigbee connectivity modules for smart lighting products at LG and Philips;
- ramping local-area connectivity ICs for Fire TV and Echo streaming media devices at a major online retailer;
- capturing over \$10 of analog content supporting Technicolor's latest set-top box platform for DirecTV;
- expanding wearable designs with multiple devices in Timex's Ironman smartwatch;
- powering Linksys' 9-stream access points with 802.11ac front-end solutions.

"Our business results are being fueled by a global surge in connectivity across a wide-ranging set of applications and by the increase in analog-rich content that is required to power today's most innovative devices," says chairman & CEO David J. Aldrich. "Skyworks is at the forefront of this technology advancement — facilitating secure, high-speed, seamless connections through our integrated solutions," he adds. "As our results show, we are capitalizing on these trends."

On a non-GAAP basis, gross margin has risen further, from 44.5% a year ago and 45.9% last quarter to 46.7% (above the forecasted 46.5%). This is despite operating expenses rising further, from \$82.9m a year ago and \$93.9m last quarter to \$94.4m, driven by R&D expenses increasing from \$50.8m a year ago and \$58.2m last quarter to \$58.7m.

Operating income has risen further, from \$235.7m (operating margin of 32.8%) last quarter to \$282m (operating margin of 35%), almost double the \$141.8m a year ago (operating margin of 28.1%).

Likewise, net income has grown from \$127.7m (\$0.67 per diluted share) a year ago and \$216.1m

(\$1.12 of per diluted share) last quarter to \$244.8m (\$1.26 per diluted share, above the \$1.18 guidance, and surpassing \$5 in annualized EPS).

Cash flow generated from operations has risen from \$201m last quarter to a record \$383m (more than double the \$159m a year ago). Capital expenditure has increased further, from just \$16m a year ago and \$83m last quarter to \$87m. Depreciation was \$36m (up from \$30m last quarter and \$21m a year ago). During the quarter, cash and cash equivalents hence rose from \$806m to \$1.05bn (with no debt).

Skyworks' board of directors has subsequently declared a cash dividend of \$0.13 per share (payable on 3 March to stockholders of record at the close of business on 5 February).

"We have created a unique business model, combining the strong growth of connectivity and the Internet of Things with the financial returns of a diversified analog company," says executive VP & chief financial officer Donald W. Palette. "Our increasing market reach, expanding content opportunities and new product launches are enabling us to outperform normal March quarter seasonal trends."

For fiscal second-quarter 2015, Skyworks expects revenue of \$750m, up 56% year-on-year (significantly better than normal seasonality). Gross margin should be 46–46.5%, with operating expenses rising slightly to \$95.5m. Diluted earnings per share are expected to be \$1.12.

"While March is normally a seasonal slower quarter in the mobile industry, our broadening market footprint, our new product ramps, and an expanding solutions portfolio enable us to mitigate these seasonal patterns, a clear testament to our diversification," says Aldrich. "With the design momentum we have in place today, we're poised to continue our track record of above-market revenue growth, expanding profit margins, and earnings leverage."

www.skyworksin.com

GLOBALFOUNDRIES joins Imec to develop low-power RF for Internet of Things applications

CMOS technology platforms optimized to boost RF performance of ICs

GLOBALFOUNDRIES of Santa Clara, CA, USA (the second largest foundry in the world, with more than 160 customers and operations in Singapore, Germany and the USA) has partnered with nanoelectronics R&D center Imec of Leuven, Belgium for joint research on future radio architectures and designs for highly integrated mobile devices and Internet of Things (IoT) applications.

A key challenge for next-generation mobile devices is controlling the cost and footprint of the radio and antenna interface circuitry, which contain all of the components that process a cellular signal across the various supported frequency bands. Currently, a typical mobile device must support up to 28 bands for worldwide 2G, 3G, 4G and LTE network connectivity, and more complex carrier aggregation schemes and additional frequency bands are expected for future generations. These challenges are driving the need for an agile radio that integrates many of the separate components into one piece of silicon, including power amplifiers, antenna switches and tuners, and provides a solution that is both flexible and low cost.

GLOBALFOUNDRIES will closely collaborate with technical experts from Imec to investigate low-power and compact high-performance agile radio solutions that aim to enable a broad range of radio architecture designs, targeting improvements in area, performance and power consumption. They will also partner to develop ultra-low-power IC design solutions leveraging GLOBALFOUNDRIES' CMOS technology to address the demanding requirements of tomorrow's IoT devices. Ultimately, the partnership aims to build a technology and design infrastructure that will enable future RF architectures while minimizing critical interface requirements for radio power consumption and performance.

There are advanced chip technology challenges the industry needs to address to enable a higher level of integration and lower power consumption for future wireless communication

"This collaboration expands our relationship with Imec, and we're eager to leverage their R&D expertise in RF technology to accelerate time-to-volume of designs and deliver leading-edge RF technology," says Peter Rabbeni, director RF Segment Marketing at GLOBALFOUNDRIES. "This relationship further reflects our commitment to find RF design implementations that will efficiently extend the range of wireless communication applications without increasing the form factor or cost," he adds.

"There are advanced chip technology challenges the industry needs to address to enable a higher level of integration and lower power consumption for future wireless communication," says Harmke de Groot, senior director Perceptive Systems for the Internet of Things at Imec. "Leveraging Imec's advanced IC technology knowhow and system design experience, and GLOBALFOUNDRIES' CMOS technology, we will accelerate the investigation and develop new approaches."

www.globalfoundries.com
www.imec.be

Skyworks ramping products for over-the-top set-top boxes

Skyworks Solutions is ramping front-end modules, wireless connectivity switches, power amplifiers, low-noise amplifiers and power management solutions for streaming media and smart TV applications supporting OEMs such as Roku, Google, Amazon and Samsung.

Skyworks says that over-the-top (OTT) content provided through set-top boxes is one of the fastest-growing media segments as consumers migrate towards high-end streaming solutions across multiple devices. The firm's products

deliver WiFi media performance and support ultra-high-definition/4K resolution.

"Skyworks' analog and RF solutions are being leveraged across multiple next-generation platforms consumers are embracing to stream content throughout the home," says John O'Neill, VP of broad markets for Skyworks. "Our design-win momentum demonstrates how we are leveraging our expansive portfolio and deep product pipeline to capitalize on the demand for system-level solutions enabling wireless connectivity in

new markets and ecosystems," he adds.

According to Barbara Kraus, director of research at Parks Associates, nearly 50% of video content that US consumers watch on a television is on-demand or time-shifted. This is up from 38% in 2010, reflecting the rapidly changing market and move towards new digital media. A recent report from Pricewaterhouse Coopers states that OTT television streaming will grow to be a \$10.1bn segment in 2018, up from just \$3.3bn in 2013.

www.skyworksinc.com

Pasternack adds Active RF Components product manager

Pasternack Enterprises Inc of Irvine, CA, USA (which makes passive and active RF, microwave and millimeter-wave products) has appointed Tim Galla as product manager for Active RF Components.

Galla has more than 25 years of product development, applications engineering and business development expertise from many of the RF/microwave industry's most recognized names, says Pasternack, adding that he has a track record of developing and introducing market-differentiating products and creating new market opportunities. Galla will

focus on expanding Pasternack's rapidly growing lines of active components including RF amplifiers, limiters, mixers, oscillators, circulators, isolators and switches.

Prior to joining Pasternack, Galla held the position of business development manager and program manager of RF/microwave components at Mercury Systems. He has also worked for several other industry leaders including Watkins Johnson, Stellex Microwave Systems, Teledyne Microwave, Tyco Electronics and M/A-COM. Pasternack holds a degree in Electrical

Engineering from a leading California University, with an emphasis in advanced mathematics.

"With a long and diverse background in the RF/microwave components sector, Tim has garnered a broad perspective of this industry and the products that support it," comments Michael Rachlin, director of product management. "In this new role, we look forward to Tim assisting our customers' engineering and technical requirements with component and application expertise that spans the entire scope of the RF market."

Pasternack launches ultra-broadband and millimeter-wave low-noise amplifiers ranging from 30MHz to 40GHz

Pasternack has launched a line of ultra-broadband and millimeter-wave low-noise amplifiers that are in-stock and available to ship same-day. The new high-frequency LNAs offer very low noise figures, typically 2.5–3dB across the entire band, making them suitable for applications such as electronic warfare, instrumentation, fiber-optic communication systems, military communications, radar, SatCom, point-to-point radio links, telecom and R&D.

Featuring highly efficient GaAs pHEMT technology, Pasternack's newest release of RF amplifiers includes 17 models covering multi-octave bandwidths with flat gain response. The 50Ω hybrid

microwave integrated circuits (MICs) are enclosed in environmentally sealed metal packages with nickel or gold plating. The LNAs come with either stainless-steel SMA or 2.92mm connectors, and some packages are hermetically sealed with field-replaceable connectors, making them very durable and able to withstand harsh environmental conditions. The 2.92mm connectorized models operate to 40GHz.

The new ultra-broadband and millimeter-wave LNAs have IP3 levels as high as +42dBm and low VSWR (voltage standing wave ratio) and they are unconditionally stable. DC voltage supply ranges from +12 to +15V_{dc}, while bias current ranges from 80mA to 1300mA.

The voltage supply is internally regulated. The broadband low noise amplifiers contain internal circuits including DC blocking capacitors at the RF input/output ports and are guaranteed to operate over a temperature swing of –20°C to +70°C.

"We are continually expanding our lines of off-the-shelf RF amplifiers to meet the needs of our customers and current market trends," says Tim Galla, Active RF Components product manager. "This selection of ultra-broadband, low-noise amplifiers offers designers many options for highly linear gain and output power levels that cover a wide variety of applications for RF, microwave and millimeter-wave frequency bands."

www.pasternack.com

MACOM launches highest-linearity 4W Ka-band power amplifier

M/A-COM Technology Solutions Inc of Lowell, MA, USA has introduced a high-linearity 4W power amplifier, operating at 29–31GHz and suited to Ka-band high-data-density satellite communications.

Offered in both bare die format and a 5mm x 5mm 32-lead QFN package, the MAAP-011139 delivers 24dB of linear gain, 4W of saturated output power and 23% power-added efficiency. With gain of 24dB, the

device provides output power (P_{out}) of 36.5dBm (over 27dBm $P_{out}/tone$) while maintaining IM3 levels of 30dBc (twice the linear performance of competing alternatives, it is said). This two-times linearity performance allows the MAAP-011139 to replace two equivalent competing alternatives with a single device while operating in an overall more efficient mode, says MACOM. Furthermore, the device measures

3.1mm x 2.8mm x 0.05mm in bare die format, suiting real-estate-constrained users. Input and output return losses are 10dB.

"In combination with MACOM's comprehensive mm-wave Ka-band product portfolio, we can provide customers with a complete chip-set solution," says product manager Paul Beasley.

www.macom.com/products/product-detail/MAAP-011139-DIE



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www.rel-test.com

Peregrine extends RF SOI switch range to 40GHz

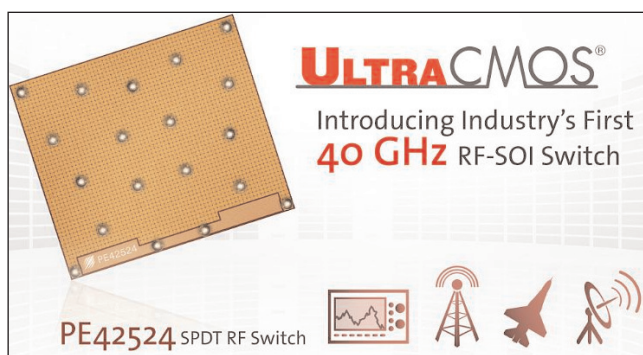
Latest SPDT RF switch adds to 13GHz, 18GHz and 26.5GHz products

Peregrine Semiconductor Corp of San Diego, CA, USA — a fabless provider of radio-frequency integrated circuits (RFICs) based on silicon-on-insulator (SOI) — has introduced the UltraCMOS PE42524, which is claimed to be the first RF SOI switch to operate up to 40GHz, significantly extending the firm's high-frequency portfolio into frequencies previously dominated by gallium arsenide (GaAs) technology.

Peregrine says that the PE42524 features high reliability and performance advantages in linearity, isolation, settling time and ESD protection, making the switch suitable for test & measurement, microwave backhaul, radar and military communications devices.

"UltraCMOS technology enables our high-frequency components, such as the PE42524, to reach performance levels previously considered unattainable in RF SOI," says senior marketing manager Kinana Hussain.

Peregrine's high-frequency switch portfolio, which includes 13GHz, 18GHz, 26.5GHz and now 40GHz products, is manufactured on the



firm's UltraCMOS technology, a patented variation of SOI technology on a sapphire substrate. The sapphire substrate offers several key benefits significant to high-frequency design, says Peregrine. Sapphire has a loss tangent that is 10 times better than bulk CMOS and three times better than GaAs, the firm reckons. As an ultra-high-resistivity substrate, sapphire provides high isolation and minimizes parasitic capacitances. The sapphire substrate eliminates many substrate-coupling effects, common in silicon-based substrates, offering RF system engineers exceptional levels of linearity and power handling performance.

The PE42524 is a single-pole

double-throw (SPDT) RF switch die that supports a wide frequency range from 10MHz to 40GHz, and delivers high port-to-port isolation (47dB), low insertion loss (2.2dB at 30GHz) and high linearity (50dBm IIP3 at 13.5GHz). It also

has a fast switching time of 225ns, a fast settling time of 840ns, and a high ESD rating of 2000V HBM on all pins. Unlike GaAs solutions, says Peregrine, no blocking capacitors are required if DC voltage is not present on the RF ports. The PE42524 is available as a flip-chip die with 500µm bump pitch, eliminating high-frequency performance variations due to bond wire length variances.

Samples, evaluation kits and volume-production parts are available. Offered as an RoHS-compliant, flip-chip die, the PE42524 is \$40 each for 1000-quantity orders and \$32.44 for 5000-quantity orders.

www.psemi.com/products/rf-switches/pe42524

Guerrilla RF completes \$500,000 funding round

Capital needed to launch mass production of first products and to develop further products

Guerrilla RF Inc of Greensboro, NC, USA, which provides monolithic microwave integrated circuits (MMICs) to wireless network infrastructure original equipment manufacturers, has closed on a \$500,000 funding round led by Charlotte Angel Fund and joined by Piedmont Angel Network as well as a growing list of individual angel investors.

Charlotte Angel Fund is a member-driven angel investment fund designed to make investments in early-stage high-growth companies, focusing on firms headquartered in North Carolina and South Carolina.

Founded in April 2013 by Ryan Pratt, Guerrilla RF has so far raised \$1.5m in funding and introduced more than 30 products. Using patented Guerrilla Armor technology that is claimed to enable greater coverage area and higher data rates for wireless networks, applications include enterprise/carrier-class WiFi access points, small cells, wireless backhaul, and cellular repeaters.

"The strong customer interest we have seen for our products has resulted in more than six design wins in the past several months,"

says founder & CEO Ryan Pratt, who adds that the firm is already in a position to require mass production of its first solutions. "This latest round of funding allows us to do just that and develop additional world-class products for the wireless network infrastructure market."

According to Research and Markets, the overall wireless network infrastructure market will increase at a compound annual growth rate (CAGR) of over 5%, accounting for over \$104bn in annual spending by the end of 2020.

<http://guerrilla-rf.com>

EC awards €4m for project iBROW to develop innovative broadband wireless communications

Resonant tunneling diode devices to target THz wireless data transfer

The project 'Innovative ultra-BROadband ubiquitous Wireless communications through terahertz transceivers' (iBROW), led by The University of Glasgow in Scotland, UK, has received €4m (£3.1m) in support from the European Commission's Horizon 2020 initiative (the largest-ever EU Research and Innovation program, which will allocate nearly €80bn of funding between 2014 and 2020).

iBROW brings together universities and private-sector firms from the UK, France, Germany and Portugal to explore the potential of resonant tunneling diode (RTD) technology to create ultra-broadband wireless communications.

Demand for broadband content and services has been growing at tremendous rates, and high-speed fibre-optic broadband is becoming increasingly common, but wireless technology is lagging behind the increasing capacity of broadband communications. Experts expect that by 2020 wireless data rates of tens of gigabits per second (Gbps)

will be required, which is not possible using the frequency spectrum of existing wireless systems. Without new forms of wireless data transfer operating at frequencies above 60GHz (and up to 1THz) there could be a significant bottleneck in the rates of delivery available to wireless devices, it is reckoned.

"We'll be working with our partners over the next three years to develop new forms of wireless communication which use resonant tunneling diodes (RTDs)," says Dr Edward Wasige, senior lecturer in Electronic and Nanoscale Engineering at the University of Glasgow. "RTDs are pure solid-state electronic devices operating at room temperature with reported working frequencies exceeding 1THz. They have the potential to create wireless broadband systems at frequencies where other electronic semiconductor devices cannot be used, and could allow wireless data transfer rates of up to 100Gbps in the long term," he adds.

"We'll be working to increase RTD

output power and optical detection efficiency with reduced energy consumption, through development of a low-cost and energy-efficient unified technology which can be integrated into wireless devices such as tablets and mobile phones as well as the base stations these devices communicate with."

In addition to the University of Glasgow's School of Engineering, the University of the Algarve and INESC Porto in Portugal and the Technische Universität Braunschweig in Germany will also contribute to the project.

Vivid Components Ltd will manage iBROW, Alcatel-Lucent Deutschland will be responsible for end-users and Opticap Ltd will manage packaging of the device. Also involved in the project are IQE Silicon Compounds, III-V Lab, Compound Semiconductor Technologies Global Ltd, and the Commissariat à l'Energie Atomique et aux Energies Alternatives.

www.gla.ac.uk/schools/engineering
<http://ec.europa.eu/programmes/horizon2020>

DelfMEMS demos first 12-throw RF MEMS ohmic switch

At the GSMA Mobile World Congress (MWC15) in Barcelona, Spain (2-5 March), DelfMEMS of Villeneuve d'Ascq, France, which develops RF MEMS (micro-electro-mechanical systems) switches for radio-frequency communications (targeting next-generation multi-standard, multi-mode, mobile telephony), is demonstrating what it believes to be the first 12-throw RF MEMS ohmic contact switch (SP12T).

"Until now, companies have tended towards the capacitive switch solution route," says CEO Cybele Rolland. "We chose the harder route of contact or Ohmic switching because of the superior performance and have succeeded in creating the world's

first, fully functional version," she adds. "This is a key milestone for the company and we have already signed several contracts, with more in the pipeline, and anticipate shipping in the second half of 2016.

RF MEMS switches have been known for many years as outstanding potential solutions for mobile handset RF performance, but have so far failed to see any reasonable level of success either due to cost or reliability concerns. We have solved these issues with our FreeFlex MEMS technology."

DelfMEMS says that the benefits of its RF-MEMS switching solution (made using FreeFlex MEMS technology) are being able to deliver

the performances required for the next generation of handsets, LTE-A and beyond, with ultra-low insertion loss, outstanding isolation and superior linearity to enable full uplink carrier aggregation.

The early samples of the SP12T switch (on show at MWC) have performance levels that are comparable to the current market-leading solutions, says DelfMEMS. However, for production devices the performance levels will be significantly higher, enabling the full potential of LTE-A and beyond data rates for both upload and download to be achieved, adds the firm.

www.delfmems.com
www.mobileworldcongress.com

German project to study use of high-frequency SiC power semiconductor switches in industrial applications

Under the project 'Modular Medium-frequency Process Power Supply with Silicon Carbide Power Semiconductor Switches' (MMPSiC), researchers in Germany at the Light Technology Institute (LTI) of Karlsruhe Institute of Technology (KIT), in cooperation with industrial partners TRUMPF Hüttinger GmbH of Freiburg (which makes process power supplies) and Lampertheim-based power semiconductor module maker IXYS Semiconductor GmbH, is studying the feasibility of using high-power silicon carbide switches in power supplies. The project aims to greatly enhance the efficiency of power supplies for industrial processes and to reduce energy consumption and CO₂ emission.

The three-year project (which began in 2014) has about €800,000 funding from the German Federal Ministry of Research (BMBF) under the programs 'Information and Communication Technology 2020'

(IKT 2020) and 'Power Electronics for Increasing Energy Efficiency' (LES 2). The LTI is receiving €439,000. Total project funding amounts to €1.3m.

In float-zone melting processes for producing highly pure crystalline materials such as silicon, the basic material is molten electrically within a very small zone. By moving the melting zone, the material crystallizes more purely. For example, this process is used to produce highly pure monocrystalline silicon for solar cells.

Up to now, the power supplies of float-zone systems have been tube-based amplifiers with a maximum electrical efficiency of 65%.

However, these could be replaced by power semiconductors made of SiC. Due to SiC's wider energy band-gap, much higher operating temperatures can be reached compared to conventional semiconductors. SiC-based power electronics is therefore characterized by an enhanced energy efficiency and compactness.

The efficiency of power supplies could be increased to well over 80%, it is reckoned, significantly reducing power consumption and greenhouse-gas emissions. For example, a single large-scale float-zone reactor, consisting of twenty 50kW process power supplies with an annual operating time of 4800 hours, would lead to a reduction of electrical energy by more than 200,000kWh and produce 109 tons of CO₂ less (Federal Environmental Agency Germany, July 2013).

"Power supply of energy-intensive industrial applications, such as a float-zone process, requires switching at high frequencies," says project manager Dr Rainer Kling of LTI. "SiC has not yet been tested at these high frequencies," he adds. Apart from long-term stability tests, the KIT researchers involved in the MMPSiC project are hence studying the control and layout of the circuitry.

www.kit.edu

Toyota to road test SiC power semiconductors

Using a Camry hybrid prototype and a fuel cell bus, Tokyo-based Toyota Motor Corporation aims this year to conduct tests on the streets of Japan that will evaluate the performance of silicon carbide (SiC) power semiconductors, which could lead to significant efficiency improvements in hybrids and other vehicles with electric powertrains.

Power semiconductors are found in power control units (PCUs) that are used to control motor drive power in hybrids and other vehicles with electric powertrains. PCUs play a crucial role in the use of electricity, supplying battery power to the motors during operation and recharging the battery using energy recovered during deceleration.

At present, power semiconductors account for about 20% of a vehicle's total electrical losses, so raising the efficiency of the power semicon-

ductors is a promising way to increase powertrain efficiency.

By comparison with existing silicon power semiconductors, SiC power semiconductors create less resistance when electricity flows through them. The technologies behind the SiC power semiconductors were developed jointly by Toyota, Denso Corp and Toyota Central R&D Labs Inc as part of the results of a broader R&D project in Japan (conducted by the R&D Partnership for Future Power Electronics Technology under consignment from the New Energy and Industrial Technology Development Organization).

In the Camry hybrid prototype, Toyota is installing SiC power semiconductors (transistors and diodes) in the PCU's internal voltage step-up converter and the inverter that controls the motor. Data gathered will include PCU voltage and current

as well as driving speeds, driving patterns, and conditions such as outside temperature. By comparing this information with data from silicon semiconductors currently in use, Toyota will assess the improvement to efficiency achieved by using SiC. Road testing of the Camry prototype will begin (primarily in Toyota City) in early February, and will continue for about one year.

Similarly, on 9 January, Toyota began collecting operating data from a fuel cell bus currently in regular commercial operation in Toyota City. The bus features SiC diodes in the fuel cell voltage step-up converter (used to control the voltage of electricity from the fuel cell stack).

Data from testing will be reflected in development, with the goal of putting the new SiC power devices into practical use as soon as possible.

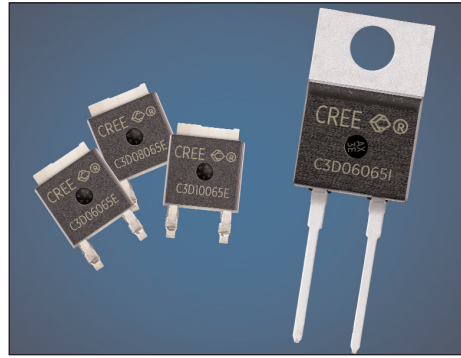
www.toyota-global.com

Cree adds four new 650V SiC Schottky diodes

Cree Inc of Durham, NC, USA has expanded its portfolio of silicon carbide (SiC) Schottky diodes with the addition of four new 650V diodes. Developed in response to the power supply industry's recent demand for components with a nominal voltage rating slightly higher than 600V, the new 650V Cree Z-Rec SiC Schottky diodes enable high-efficiency power systems with improved reliability, simplicity and total cost, the firm says.

Beneficial characteristics of the new diodes are said to include: zero reverse recovery current, high-frequency operation with low electromagnetic interference (EMI), temperature-independent switching behavior, reduced heat-sink requirements, and significantly higher surge and avalanche capabilities. The devices also have higher efficiency than comparable silicon diodes, with essentially no switching losses, while a positive temperature coefficient on VF enables parallel devices without thermal runaway.

Designed to satisfy power systems engineers' need for higher current in a more compact, surface-mount package, the new 6A C3D06065E, 8A C3D08065E and 10A C3D10065E Cree Z-Rec diodes are supplied in TO-252-2 (DPAK) packages with a smaller footprint than many of the



Cree's new 650V SiC Schottky diodes.

comparable diodes currently on the market, it is claimed. Exhibiting both zero recovery voltage and extremely fast switching, the new 650V devices enable right sizing of the diode, optimizing both cost and performance in applications including switch mode power supplies (SMPS), power factor correction (PFC) and motor drives. They may also negate the need for through-hole SiC Schottky diode assembly, as well as enabling smaller final assembly dimensions for new 650V designs.

Additionally, the three diodes are automotive qualified to AEC-Q101, and are suitable for use in the power factor correction and onboard power electronic conversion systems (e.g. chargers, dc/dc converters, inverters etc) of hybrid and electric vehicles (HEVs). Cree says that, unlike competitors, whose automotive-

qualified diodes are typically separate part numbers sold at higher costs, about 90% of Cree's C3D Schottky diode portfolio is, and always has been, automotive qualified at no extra cost. A complete list of Cree's automotive qualified diodes — available in five plastic package types, two voltage ratings (600V and 650V), and with current ratings spanning 2 to 20A — can be found on the Cree Power website.

The fourth new 650V diode — Cree's 6A, 650V C3D06065I internally isolated Z-Rec Schottky diode — is an alternative to full-pack diodes and a complement to the existing 8A C3D08065I and 10A C3D10065I. Featuring a TO-220 package with internal ceramic insulation (unique to Cree with regard to SiC Schottky diodes, it is claimed) that provides 2.5kV isolation, Cree's new 6A, 650V internally isolated diode also provides greater operating ranges and capabilities than comparable full-pack devices, including significantly higher maximum temperatures and greater power dissipation. Also, by eliminating the need to insert an external isolating sheet between diode and heat sink, it eases design, reduces cost and supports efficient manufacturing of HVAC, PFC and switch mode power supplies, Cree adds.

www.cree.com/Power

ST extends SiC portfolio with 215mΩ 1200V MOSFET

STMicroelectronics of Geneva, Switzerland has launched the SCT20N120 silicon carbide power MOSFET, which it says brings advanced efficiency and reliability to a broader range of energy-conscious applications such as inverters for electric/hybrid vehicles, solar or wind power generation, high-efficiency drives, power supplies, and smart-grid equipment.

The 1200V SCT20N120 extends the firm's family of SiC MOSFETs, with on-resistance ($R_{DS(ON)}$) better than 290mΩ all the way to the 200°C maximum operating

junction temperature (T_J). Typical $R_{DS(ON)}$ is 215mΩ. Switching performance is also consistent over temperature due to highly stable turn-off energy (E_{off}) and gate charge (Q_g). The resulting low conduction and switching losses, combined with ultra-low leakage current, simplify thermal management and maximize reliability, says the firm.

ST claims that, in addition to their lower energy losses, its SiC MOSFETs permit switching frequencies up to three times higher than similar-rated silicon IGBTs allow. This enables designers to specify smaller external

components and save size, weight and bill-of-materials costs, the firm adds. Also, the SCT20N120's high-temperature capability helps to simplify cooling-system design in applications such as power modules for electric vehicles.

As for the firm's existing 80mΩ SCT30N120 1200V SiC MOSFET, ST's proprietary HiP247 package with enhanced thermal efficiency allows reliable operation up to 200°C while maintaining compatibility with the industry-standard TO-247 power-package outline.

www.st.com/sicmos

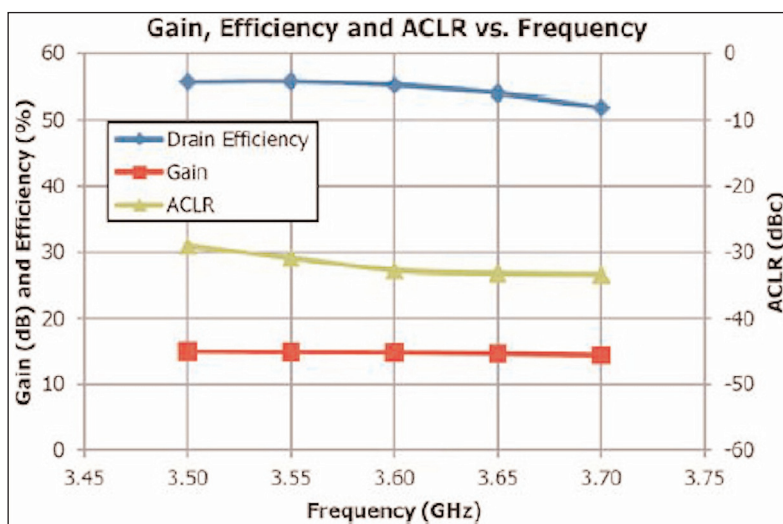
Cree releases Doherty power amplifier reference design for 3.5–3.7GHz small-cell wireless

To address the needs of small-cell designers, Cree Inc of Durham, NC, USA, which makes silicon carbide (SiC) and gallium nitride (GaN) wafers and devices, has introduced the CDPA35045 asymmetric Doherty power amplifier (PA) reference design for the 3.5–3.7GHz band.

This band is an additional spectrum space intended to complement small-cell technology by providing increased wireless system capacity for both licensed wireless carrier services and unlicensed public use, such as WiFi.

Providing 10W average output power and what is claimed to be excellent pre-distortion (DPD) correctability, the proven Doherty power amplifier design utilizes Cree's 30W CGHV27030S and 15W CGHV27015S GaN high-electron-mobility transistor (HEMT) devices, which can operate with either 50V or 28V drain supplies and enable enhanced design flexibility for telecoms, wideband tactical radio, and radar applications spanning low frequencies to 6GHz.

The CDPA35045 was evaluated by engineers at Xilinx in a 3.5GHz test



Performance for Cree's CDPA35045 asymmetric Doherty PA.

radio platform that implemented Xilinx CFR and DPD SmartCORE IP on a Xilinx ZC706 evaluation board featuring the firm's Zynq 7Z045 all-programmable system-on-chip (APSoC) as the processing engine. The evaluation proved that this combination of Xilinx's Zynq APSoC devices and Cree's GaN devices results in highly efficient, low-cost, and low-power products that enable full flexibility of control processing and the radio signal.

provides base-station designers with a proven design that supports the development of new small-cell wireless infrastructure equipment, greatly reducing design time and enabling faster product time to market.

See the white paper 'GaN PA Supports 3.5–3.7GHz Small Cell Applications Using Digital Predistortion' at <http://event.on24.com/r.htm?e=922056&s=1&k=FD8FD27383C6566C3F553BF1405C24BF> www.cree.com/rf

GaN Systems adds Ecomal Europe as distributor of GaN power switching transistors

GaN Systems Inc of Ottawa, Ontario, Canada has signed an agreement for Ecomal Europe to promote and distribute its gallium nitride (GaN)-based high-power switching transistors.

GaN Systems' gallium nitride power transistors are based on its proprietary Island Technology and offer what are claimed to be significant advantages over traditional silicon MOSFETs and IGBTs for smaller, lighter and more efficient power electronics. Ecomal Europe was selected for its expertise in power systems and complementary line-cards.

The partnership is seen as being synergistic. Many of GaN Systems' prospective customers in the region already have a relationship with Ecomal Europe, which has technical knowledge in applications particularly suited to GaN high-power switching devices, including inverters, UPS (uninterruptible power supplies), hybrid & electric vehicles (HEV/EV) and high-voltage DC–DC conversion.

GaN Systems claims to be the first firm to have developed and brought to the global market a comprehensive product range of devices with current ratings from 8A to 250A — its Island Technology die design,

combined with its low-inductance and thermally efficient GaNPX packaging and Drive Assist technology, means the its GaN transistors offer a 40-fold improvement in switching and conduction performance over traditional silicon MOSFETs and IGBTs, it is reckoned.

"Gallium nitride devices are recognised to be the future of power electronics and, as our product portfolio is now ready for commercialization, it's both key and timely for us to continue to build our worldwide distribution network," says president Girvan Patterson.

www.gansystems.com

Delta involved in \$3m DOE EERE grant to develop GaN-based on-board charger for plug-in electric vehicles

Energy efficiency of 95% and 30–50% volume & mass reduction targeted

Delta Products Corporation (DPC) of Fremont, CA, USA (part of Taiwan-based power and thermal management solutions provider Delta Group) says that it is participating in a US Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) \$3m award for the development of a high-efficiency, high-density, 6.6kW bi-directional on-board charger for plug-in electric vehicles (PEVs). The on-board charger will use novel designs based on gallium nitride (GaN) power switches that target energy efficiency better than 95% and reduce volume and mass by

30–50% compared with existing technology.

Under the EERE research program, Delta (as a tier-1 automotive supplier) is partnering with FCA US LLC (a member of the Fiat Chrysler Automobiles N.V. family of companies), Transphorm Inc of Goleta, near Santa Barbara, CA, USA (which designs and delivers GaN-based power conversion devices and modules) and Virginia Polytechnic Institute's Virginia Tech's Center for Power Electronics Systems.

"The development of a smaller, lighter, less expensive and more efficient bi-directional on-board

charger will be an enabling technology for affordable, fuelefficient plug-in electric vehicles and vehicle-to-grid applications," says Delta Products' president M.S. Huang.

Delta has developed an energy-efficient solution for PEV on-board chargers, DC-DC converters, fast charger modules, battery disconnect units, and off-board charging station and site management systems.

www.deltawww.com

www.transphormusa.com

www.ece.vt.edu

www1.eere.energy.gov/manufacturing/innovation/facilities/wbg.html

EPC launches monolithic GaN power transistor half-bridge enabling 97% system efficiency for 48V to 12V buck converter at 20A output

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA, which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications, has introduced the 60V EPC2102 and the 80V EPC2103 enhancement-mode monolithic GaN transistor half-bridges.

By integrating two eGaN power FETs into a single device, interconnect inductances and the interstitial space needed on the PCB are eliminated, resulting in a 50% reduction in board area occupied by the transistors. This increases both efficiency (especially at higher frequencies) and power density, while reducing assembly costs to the end-user's power conversion system. The half-bridges are suitable for high-frequency DC-DC conversion.

Using an EPC2103 in a typical buck converter, system efficiency is greater than 97% at 20A, when switching at 500kHz and converting from 48V to 12V. Also added to the



portfolio is the EPC2102 60V half-bridge, which achieves 98% system efficiency at 18A, when switching at 500kHz and converting from 42V to 14V. Both products come in a chip-scale package for improved switching speed and thermal performance and are only 6.05mm x 2.3mm for increased power density.

The EPC9038 and EPC9039 development boards are 2" x 2" (50.8mm x 50.8mm) and each contains one EPC2102 or EPC2103 integrated half-bridge component, respectively. Both boards use the

Texas Instruments LM5113 gate driver and have onboard supply and bypass capacitors. The boards have been laid out for

optimal switching performance and include various probe points to facilitate simple waveform measurement and efficiency calculation.

The EPC2102 and EPC2103 monolithic half-bridges are \$6.85 and \$7.58 each, respectively, in 1000-unit quantities. The EPC9038 and EPC9039 development boards are \$137.75 each. All are available for immediate delivery from Digi-Key.

www.digikey.com/Suppliers/us/Efficient-Power-Conversion
<http://epc-co.com/epc/Products/eGaNfets/EnhancementMode/MonolithicHalf-Bridge.aspx>

Fujitsu begins mass production of Transphorm's GaN power devices

CMOS-compatible 150mm fab targets increasing demand for GaN

Transphorm Inc, Transphorm Japan Inc, and Fujitsu Semiconductor Ltd have announced that Fujitsu Semiconductor group's CMOS-compatible, 150mm wafer fab in Aizu-Wakamatsu, Fukushima, Japan, has started mass production of gallium nitride (GaN) power devices for switching applications. The large-scale, automotive-qualified facility, which is providing exclusive GaN foundry services for Transphorm Inc of Goleta, near Santa Barbara, CA, USA, should allow dramatic expansion of Transphorm's GaN power device business. The increased production aims to satisfy the increasing demand for GaN devices for the next generation of compact, energy-efficient power conversion systems.

Transphorm has established what is claimed to be the industry's only qualified 600V GaN device platform, backed by its GaN power IP portfolio. The first photovoltaic power conditioner products using

the GaN module from Transphorm was launched in January. Other applications include ultra-small AC adapters, high-density power supplies for PCs, servers and telecom equipment, and highly efficient motion control systems.

In late 2013, Fujitsu Semiconductor and Transphorm announced the business integration of their GaN power device solutions. Since then, Transphorm's JEDEC-qualified process has been combined with Fujitsu Semiconductor's basic technology and ported to the CMOS-compatible, 150mm fab of Aizu Fujitsu Semiconductor Wafer Solution Ltd, involving key improvements for high-volume, silicon-compatible device manufacturing. Reckoning that a highly reliable manufacturing production line is an essential requirement for expanding business, the firms have finished the development in Aizu-Wakamatsu and now started mass production.

"The start of the mass production in a CMOS-compatible fab is a significant step forward toward achieving the widespread use of GaN power devices, as well as a demonstration of the successful integration of both companies' strengths," says Fujitsu Semiconductor's president Haruki Okada. "We will continue to enhance our high-quality manufacturing technology to support the stable supply of the products," he adds.

"Manufacturing Transphorm's GaN power devices at the Fujitsu Aizu-Wakamatsu facility will assure our customers a scalable, stable supply of products with the stamp of Fujitsu's proven, high-quality standard in mass manufacturing," says Transphorm's CEO Fumihide Esaka. "We will continue to expand our GaN power device portfolio with continued partnership with Fujitsu Semiconductor."

www.transphormusa.com

<http://jp.fujitsu.com/fsl/en>

Yaskawa Electric starts mass production of PV inverter

Transphorm Inc of Goleta, near Santa Barbara, CA, USA, which designs and provides gallium nitride (GaN)-based power conversion devices and modules, says that Japan's Yaskawa Electric Corp is launching mass production of what it claims is the smallest power conditioner in its class – and the first to use a GaN power module. Based on Transphorm's EZ-GaN IP-protected platform, Yaskawa's Enewell-SOL V1 series 4.5kW indoor PV inverter will be distributed in Japan, with a targeted annual production of 34,000 systems.

The new 98%+ peak efficiency GaN-based power conditioner operates at three times higher frequencies than silicon-based modules, it is reckoned. Due to its

smaller magnetics and heat-sinks, the unit is half the size of competing solutions, it is claimed. Also, its efficiency allows fan-free, low-noise operation. Powered by Transphorm, the Yaskawa PV inverter's TPD3215M module utilizes what is said to be the only qualified, high-voltage (600V) GaN-based solution on the market. Transphorm says that this level of mass production for the rapidly growing residential PV inverter segment is one more step toward establishing GaN as the new power conversion platform.

The firm adds that, over the last several years, GaN has emerged as a leading technology enabler for the next wave of compact, energy-efficient power conversion systems — ranging from ultra-

small adapters, high-power-density PCs, server and telecom power supplies, to highly efficient PV inverters and motion control systems.

Transphorm says that its efficient, compact and easy-to-embed solutions can simplify the design and manufacturing of electrical systems and devices, including power supplies and adapters, PV inverters for solar panels, and motor drives and power conversion for electric vehicles. The firm's access to high-scale foundry manufacturing, through its relationship with Fujitsu, enables it to meet growing demand from global customers needing GaN power conversion products.

www.yaskawa.co.jp/en

www.transphormusa.com

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Advantech receives over \$1m in orders for Extended Ku-Band GaN SSPAs for satellite news gathering

Advantech Wireless Inc of Montreal, Canada (which manufactures satellite, RF equipment and microwave systems) has received over \$1m of orders for its redundant/phase 250W/500W Extended Ku-Band SapphireBlu gallium nitride (GaN)-based solid-state power amplifier (SSPA) solution for the satellite news gathering (SNG) industry.

The Extended Ku-Band SapphireBlu GaN-based SSPA systems

include an L-band interface, provide very high frequency accuracy, allow high-order modulation schemes as per DVB-S2x standard, and require no field adjustment or tuning. Designed to operate as 1:1 redundant 250W, the system can be instantly switched to phase combined mode and deliver 500W of RF power when needed.

"The broadcasting industry has been rapidly adopting Advantech

Wireless' GaN technology for the new generation of SNG trucks and flyaways," says Cristi Damian, VP business development. "This revolutionary GaN based system meets the stringent requirements of critical TV broadcasting, where power availability is mandatory," he adds.

Advantech is exhibiting at the SATELLITE 2015 conference in Washington DC (16-19 March).

www.advantechwireless.com/

Advantech Wireless receives \$3m in orders to provide GaN-based SSPAs for satcom-on-the-move and flyaway terminals

Advantech Wireless has been awarded over \$3m in orders from defense organizations to provide its gallium nitride (GaN)-based solid-state power amplifier (SSPA) for satcom-on-the-move (SOTM) solutions and flyaway terminals. The units will be WGS certified in the Ka-band and X-band.

Advantech Wireless says that its GaN-based SSPAs and block up-converters (BUCs) — within the same footprint — deliver double the RF power, are 50% smaller, generate 30% less heat and reduce the energy consumption by up to 70%.

"We understand the challenges that government & military leaders

face, and our technologies empower them to communicate quickly, reliably and securely," says Cristi Damian, VP business development. "Defense organizations were among the first to adopt GaN technology, which in exchange allows higher power and higher traffic rates for mission critical operations."

Export approval of GaN AESA sensor for Patriot radar

The US government has given approval for Raytheon Company of Waltham, MA, USA to export a gallium nitride- (GaN)-based Active Electronically Scanned Array (AESA) Patriot sensor to Patriot Air and Missile Defense System partner nations.

"GaN-based AESA technology can bring customers of the combat-proven Patriot optimized 360° coverage while setting the stage for future capability improvements," says Ralph Acaba, vice president of Integrated Air and Missile Defense at Raytheon's Integrated Defense Systems business in Tewksbury, MA, USA. "GaN-based AESA technology improves Patriot's already high reliability rate and significantly reduces the radar's annual operation and maintenance costs beyond what has already been achieved with other recent

Patriot radar improvements."

The proven and mature GaN-based AESA technology that will be incorporated into Patriot is used in the design of the US Navy's new Air and Missile Defense Radar and a number of US Air Force systems. In February 2014, Raytheon demonstrated a GaN-based AESA prototype Patriot array using GaN manufactured in Raytheon's Department of Defense-certified Manufacturing Readiness Level 8 foundry. The firm's GaN foundry was the first to receive DoD MRL 8 certification, indicating that Raytheon's GaN is ready to enter production after having demonstrated proven manufacturing and quality processes.

Raytheon says that it has been developing GaN for 15 years and has invested more than \$150m to get this latest technology in the

hands of the warfighter faster and at lower cost and risk. The firm has demonstrated the maturity of the technology in a number of ways, including exceeding the reliability requirement for insertion into the production of military systems.

The Patriot air and missile defense system provides protection against a range of threats, including aircraft, tactical ballistic missiles, cruise missiles and unmanned aerial vehicles (UAVs). Continually upgraded and enhanced to reflect the latest technology, Patriot has been chosen by 13 nations around the globe. Raytheon is the provider of Patriot Air and Missile Defense Systems, both domestically and internationally, and system integrator for PAC-3 missiles.

www.raytheon.com/capabilities/products/patriot

EpiGaN appoints chief marketing officer

III-nitride epitaxial material supplier EpiGaN nv of Hasselt, near Antwerp, Belgium has appointed Markus Behet to the newly created role of chief marketing officer (CMO) for its GaN/Si and GaN/SiC epitaxy wafer product lines serving applications in the power switching and RF markets. Behet will lead the firm's global commercial and marketing programs, reporting directly to CEO Dr Marianne Germain.

Incorporated in 2010, EpiGaN was founded by Germain, together with chief technology officer Dr Joff Derluyn and chief operating officer Dr Stefan Degroote as a spin-off of nanoelectronics research center Imec of Leuven, Belgium. The founders jointly developed gallium nitride-on-silicon (GaN-on-Si) technology on 6" and 8" wafers at Imec, part of which has been licensed to EpiGaN. In 2011, EpiGaN was joined by a consortium of



Markus Behet.

start-up investment firms, consisting of Robert Bosch Venture Capital, Capricorn CleanTech Fund and LRM enabling the installation of a wafer production facility. In mid-2012, EpiGaN

closed its first capital round of €4m, to allow it to start volume production of GaN-on-Si epitaxial material.

EpiGaN says the appointment of a CMO signals a major strategic step in the continuing expansion of its global marketing and sales activities in rapidly proliferating GaN technology, which is being driven towards technology and process maturity.

Behet joins EpiGaN from Dow Corning, where he held global market segment positions for their SiC and

GaN/Si wafer business. Previously he worked for Triquint Semiconductor, Infineon Technologies and Siemens, where he was in charge of key marketing, business development and sales positions for GaAs-based RF power and foundry business lines. Earlier, Behet was R&D manager at imec. He holds a PhD in semiconductor physics and electrical engineering from Aachen Technical University, Germany.

"Markus' track record in global marketing and his deep III-V industry knowledge make him exceptionally well qualified for this newly created position," states Germain.

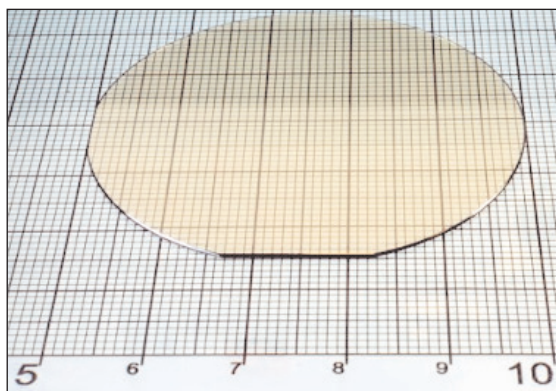
"EpiGaN's GaN/Si and GaN/SiC wafer technologies will enable the power electronic industry to take the next step of innovation towards more efficient, higher-performance and lower-cost power devices and system solutions," says Behet.

www.epigan.com

Ammono begins fabrication of 2-inch semi-insulating GaN substrates for space application

Ammono S.A. in Warsaw, Poland, which produces bulk gallium nitride (GaN) using ammonothermal technology, has developed a new type of highly resistive 2-inch Ammono-GaN semiconductor crystal with high structural quality — as confirmed by narrow x-ray diffraction (XRD) rocking curves (20 arcsec) — and large curvature radius (reaching a few hundred of meters). The resistivity, estimated by capacitive and microwave methods, is at least $10^{10}\Omega\text{cm}$, proving the extremely isolating properties of the new material, says the firm.

The crystals have been used for the production of 2" highly resistive substrates. The work was performed in the framework of the European Space Agency PECS program 'Low Dislocation GaN for Space Applications' under contract number 4000108320/13/NL/KML, supervised by ESA's Dr Andrew Barnes.



Ammono's 2" semi-insulating GaN substrate.

The new type of Ammono highly resistive material has been developed in response to specific demands for future semiconductor materials used in space technology. "Our new semi-insulating Ammono-GaN substrates enable efficient epitaxy and processing of GaN-based high-electron-mobility transistors (HEMTs)," says Dr Marcin Zajac, senior scientist & project coordinator

at Ammono. "High substrate resistivity prevents parasitic current leakage in lateral transistors, which is necessary for proper operation of the final device," he adds. "Moreover, it is expected, that the offered very low dislocation density of the Ammono-GaN substrate and epitaxial device structure is a key issue in device reliability, which is

essential for application of the developed material in space electronics — transistors for RF communication, radars, DC-DC power converters, high-efficiency solar panels and many others".

The detailed parameters and measurement results were presented by Zajac last September at the ESA 7th Wide Band Gap Semiconductor and Components Workshop (ESA-ESRIN 2014) in Frascati, Italy.

www.ammono.com

Element Six accelerates synthetic diamond development

Luxembourg-registered synthetic diamond materials firm Element Six (a member of the De Beers Family of Companies) says its Technologies Group experienced more than 20% growth in 2014 (its third consecutive year of high growth).

In 2015 Element Six aims to extend its R&D to use synthetic diamond to enhance the power levels of extreme ultraviolet (EUV) optics, to help to create environmentally friendly and cost-effective methods to treat industrial wastewater, and to create novel thermal management solutions for semiconductor devices.

"Not only has Element Six championed the use of synthetic diamond in the fields of semiconductors and optics, it also served as a collaborative partner to esteemed academic and private organizations interested in taking advantage of diamond's unique properties," says Technologies Group head Adrian Wilson. "As technology advances, across all industries, we see more challenges — often requiring smaller and more powerful devices that can withstand greater abuse," he adds. "Our R&D teams already have projects underway to accelerate synthetic diamond solutions for various emerging markets."

Growth in Technologies Group

In 2014, Raytheon Company proved that Element Six's gallium nitride (GaN)-on-diamond wafers greatly

outperform industry-standard gallium nitride-on-silicon carbide (GaN-on-SiC) in RF devices. In HEMT devices, Raytheon achieved a three times improvement in GaN-on-diamond's RF areal power density, compared with GaN-on-SiC devices. The study asserted that GaN-on diamond substrates, fabricated by Element Six, exhibit a clear advantage over other substrate materials — partly because synthetic diamond dissipates heat up to five times more effectively than silicon or silicon carbide.

Last September, Element Six was chosen by the European Commission's Seventh Framework Program for Research and Technological Development to help build a new ultrafast pulse disk laser. As part of the three-year project, Element Six will further develop its low-loss, high-purity single-crystal chemical vapor deposition (CVD) diamond material to help create a new ultrafast pulse disk laser to increase productivity for precision micro-machining. Element Six also partnered with academic institutions including the University of Strathclyde and University of Warwick in the UK and Harvard University in the USA to spur innovation in high-power lasers and nano-scale sensing. Furthermore, working with academics in Delft University in The Netherlands,

Element Six established that diamond spin qubits were a prime candidate for the realization of quantum networks.

Product innovation in 2015

Element Six says that, in the year ahead, it is focused on continued development of its synthetic diamond products to address growing demands across the semiconductor, optics, water treatment, detectors, industrial and electronics industries.

In particular, in semiconductors, GaN RF devices have seen steady growth, particularly in the military radar and commercial cellular base-station markets. According to Yole Développement, such devices could reach more than 18% of the overall RF device market by 2020. Element Six predicts that use of GaN substrate technology for high-power RF power amplifiers, for both commercial and defense applications, will take a significant share of the market in 2015 due to the higher power levels and efficiencies that GaN enables. In preparation for the demand for high-power GaN RF power amplifiers, and to unlock their intrinsic performance capability, Element Six is further developing GaN-on-diamond substrate technology that provides thermal management of GaN devices and can be cost-effectively scaled to high volume.

www.e6.com/GaN

Presto becomes approved Keysight solutions partner

Turn-key back-end production services firm Presto Engineering Inc of San Jose, CA, USA, which provides semiconductor product engineering & test services to integrated device manufacturer (IDM), fabless and electronics companies, says that it is now an approved solutions partner of Keysight Technologies Inc of Santa Rosa, CA, which provides electronic measurement instruments and systems and related software used in the design, development, manufacture, installation, deployment and operation of electronic equipment.

"We strive to incorporate the best and most up-to-date equipment in the solutions we provide to our customers, and Keysight's products and services are essential components in many of our most advanced solutions for semiconductor RF and high-speed communication (HSC) markets," says CEO Michel Villemain. "Our engineers have extensive RF and HSC test and qualification expertise, including on-wafer probing which is becoming more prevalent, especially for the optical communication supply chain," he adds. "This

experience, together with the advanced Keysight products and services, will help us to further enhance our ability to develop custom test solutions for RF and HSC."

Presto also offers ESD, reliability, qualification and failure analysis capabilities as part of its turn-key solution. This combined expertise helps RF and HSC device developers to optimize the performance of their products and accelerate time-to-market, claims the firm.

www.presto-eng.com

www.keysight.com

Soitec launches second generation of eSI RF-SOI substrates

Soitec of Bernin, France has introduced its eSI90 substrate, the newest high-end wafer in its radio-frequency silicon-on-insulator (RF-SOI) product family. The eSI90 is designed to improve the RF performance of mobile communication components such as high-linearity switches and antenna tuners that are integrated in high-end smart phones for LTE Advanced networks using carrier aggregation (which enables multiple LTE carriers to be used together, providing higher data rates).

The new wafers comprise Soitec's second generation of eSI substrates, based on engineered high-resistivity (HR) substrates. The firm says that eSI substrates have been widely adopted by leading RF semiconductor companies to address device cost and performance needs for the 3G and 4G/LTE mobile wireless markets. Based on Soitec's Smart Cut technology, eSI products are claimed to be the first 'trap-rich' type of mat-

erials in full production (incorporating a trap-rich layer between the high-resistivity handle wafer and the buried oxide, which significantly improves the performance of the finished ICs). The new eSI90 wafer exhibits higher effective resistivity than first-generation eSI wafers, enabling a 10dB improvement in linearity performance in RF front-end modules to address the stringent new requirements of LTE Advanced smart phones.

"Soitec continues to be the innovation frontrunner in RF-SOI substrates for the mobile industry with the introduction of eSI90, enabling high-performance RF devices for LTE Advanced and next-generation smart phones," says Dr Bernard Aspar, senior VP & general manager of Soitec's Communication & Power business unit. "We estimate that more than 1 billion RF devices are produced each quarter using our eSI wafers."

Soitec says that it developed a new metrology standard, the harmonic quality factor (HQF), to predict the expected RF linearity of finished ICs. HQF correlates with the second harmonic distortion value of a coplanar waveguide deposited on the substrate. The new eSI90 wafers' HQF maximum value is set to -90dBm compared with -80dBm for first-generation eSI substrates. This lower limit enables chip makers to take advantage of design and process improvements to increase the RF performance of their semiconductor designs and to meet MIMO (multi-input multi-output) and carrier aggregation LTE Advanced requirements, providing faster data connections, claims Soitec.

The firm says that the new eSI90 substrates are already under evaluation at multiple leading chip-makers and foundries. Production-ready samples are now available.

www.soitec.com

Sumitomo Chemical buys Hitachi Metals' compound semiconductor materials business

GaAs epi and GaN epi and substrate business to be expanded

Sumitomo Chemical Co Ltd of Tokyo, Japan has agreed to acquire the compound semiconductor materials business of Tokyo-based Hitachi Cable Ltd, effective from 1 April. The business includes compound semiconductor materials such as gallium arsenide (GaAs) epiwafers as well as gallium nitride (GaN) substrates and epiwafers (in which Hitachi Metals is considered to be a forerunner).

Sumitomo Chemical says that the acquisition will allow it to expand its GaN substrate and epiwafer business for use in electronic and optical components, for which the market is taking off, while at the same time devoting effort to early commercialization of the products for use in power devices. In addition, it is reckoned that the fusion of Hitachi Metals' resources and

mass-production technology with Sumitomo Chemical's technical expertise will accelerate commercialization of firm's next generation of GaN epiwafers that are currently under development.

Regarding GaAs epiwafers, which Sumitomo Chemical has already commercialized, the firm aims to further strengthen its business foundation by making the best use of each company's resources.

Compared with an elemental semiconductor such as silicon, compound semiconductors have excellent properties, such as higher electron mobility, higher-speed/higher-frequency operation, and higher light-receiving or light-emitting efficiency. Compound semiconductors are widely used in various fields of industry, including electronic components such as

materials for smartphones and optical components like LEDs. Next-generation power devices, for which compound semiconductors can be used, are capable of improving power efficiency and will contribute to realizing energy-saving society. As such, demand for compound semiconductors for such use is expected to grow substantially in the future.

Sumitomo Chemical says that it is positioning the compound semiconductor materials business for next-generation power devices as a promising area in its long-term business portfolio for the IT-related Chemicals Sector. The business acquisition is intended to further reinforce relevant operations of the firm.

www.hitachi-cable.com

www.sumitomo-chem.co.jp/english

Riber's revenue falls 29% in 2014 to €16.6m

Research-driven upturn in orders promises improved 2015

For fourth-quarter 2014, Riber S.A. of Bezons, France, which makes molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells, has reported revenue of €7.4m, up on €4.3m last quarter but down 44% on €13.2m a year ago. Full-year revenue was €16.6m, down 29% on 2013 due to a significant deterioration in the market. Of total revenue, 55% came from Europe, 34% from Asia and 11% from the Americas. Full-year earnings will be released on 2 April, but Riber expects a net loss of over €3m (compared with net income of €0.2m in 2013).

MBE Systems revenue fell in 2014, by 45% from €116.9m in 2013 to €19.3m (falling from 17 systems to just 11 R&D machines), due mainly to contraction in available research budgets in first-half 2014, faced with persistently slow industrial markets.

Riber has hence focused on research laboratories, which represent the most resilient market segment. Specifically, the commercial development of new ranges of MBE systems and increasing sales of services & accessories have helped to further strengthen Riber's positions alongside its R&D clients. Riber has also continued to move forward

with its organic light-emitting diode (OLED) development plan, with pilot materials sold in Korea in second-half 2014.

Revenue for Services & Accessories (€6.1m) and Cells & Sources (€1.1m) are hence up 10% overall on 2013. This growth has been driven by the increase in sales to research labs, particularly with the development of a business line to refurbish systems that have become obsolete.

Riber says that, regarding the market for OLED flat screens, it further strengthened its close technical links with the market's leading operators in 2014 in order to support the development of its new range of linear cells, for which an order was recorded during second-half 2014 to equip a pilot line.

Various on-site qualification tests are planned for first-half 2015.

Considering the rise in commercial activity over second-half 2014, an upturn is expected in 2015, with orders gradually picking up again. In particular, fourth-quarter 2014 confirmed the improvement in Riber's order levels, with five MBE research systems ordered in China, Japan, New Zealand, Romania and Russia (the latter delivered at the end of 2014). Meanwhile, orders for

services and components also picked up during second-half 2014. At the end of December 2014, including orders for six systems and €1.9m of orders for services, cells and accessories, the order book totaled €6m (although this is still down 15% year-on-year and 31% at end-June 2014).

Due to the upturn in orders during second-half 2014, as well as the deliveries made and the effective cash management approach implemented, Riber's consolidated net cash position at the end of 2014 was positive, coming in at nearly €2m, an improvement on €1.7m at the end of 2013 and the low of -€0.9m at the end of June 2014, despite the difficult environment.

"Thanks to the significant progress made over the past year in terms of diversifying products, developing services, ensuring effective control over costs and delivery times, against a backdrop of expected growth in semiconductor research programs, Riber is confident that its performance levels will pick up again in 2015 and it will be able to achieve its strategic objectives for profitable growth over the medium term," says chairman Frédérick Goutard.

www.riber.com

AXT's margins grow despite inventory-driven revenue dip

For fourth-quarter 2014, AXT Inc of Fremont, CA, USA, which makes gallium arsenide, indium phosphide and germanium substrate and raw materials, has reported revenue of \$19.6m, up 5.4% on \$18.6m a year ago but down 15% on \$23.1m last quarter (and below its guidance of \$20.5-21.5m). The shortfall is due mainly to customers working down substrate inventory levels at year end. Full-year revenue was \$83.5m, down 2% on 2013's \$85.3m.

"While the fourth quarter demand weakness contributed to a modest decline in our annual revenue from

the prior year, meaningful improvements in our cost structure early in the year — coupled with ongoing discipline in our spending throughout the year — and a positive shift in our revenue mix resulted in a significant improvement year-over-year to our bottom line," says CEO Morris Young.

Gross margin has risen further, from 15.1% a year ago and 23% last quarter to 25.4% in Q4/2014. Full-year margin has improved from 13.9% in 2013 to 20.6% in 2014.

Full-year operating expenses rose from \$19.5m in 2013 to \$20m. In particular, quarterly operating

expenses have risen from \$4.4m a year ago and \$4.7m last quarter to \$5.6m, due largely to professional fees from an internal investigation (initiated in Q4) of certain potential related-party transactions.

Compared with net income of \$644,000 last quarter, the higher expenses have contributed to a net loss of \$311,000 in Q4 (still less than the loss of \$1.2m a year ago). Full-year net loss has also improved from 2013's \$8m to \$1.4m in 2014. During the year, cash and investments grew by \$1.3m to \$48.9m.

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Veeco's Q4 MOCVD revenue up 55% year-on-year while orders almost triple

Margin greater than expected as firm returns to EBITDA profitability

Epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA has reported revenue for full-year 2014 of \$392.9m, up 18% on \$331.7m in 2013.

Fourth-quarter 2014 revenue was \$113.6m, up 22% on \$93.3m last quarter and 55% on \$73.2m a year ago (near the top end of the \$100–115m guidance range, and the first quarter above \$100m in two years). Growth has been driven by metal-organic chemical vapor deposition (MOCVD) and Data Storage products.

Data Storage revenue was \$23m (20% of total revenue), up 44% on \$16m both last quarter and a year ago.

MOCVD revenue was \$78m, up 9.9% on \$71m last quarter and up 56% on \$50m a year ago. However, molecular beam epitaxy (MBE) revenue was \$5m, down 17% on \$6m both last quarter and a year ago (although Veeco reckons that its GENxplor system gained market share).

Q4 also included 3 weeks of revenue (\$8m) from Solid State Equipment Holdings LLC (SSEC) of Horsham, PA, USA (now called Veeco Precision Surface Processing, or PSP, after being acquired in early December for \$150m), which manufactures single-wafer wet etch, clean and surface preparation equipment targeting high-growth segments in advanced packaging, micro-electro-mechanical systems (MEMS) and compound semiconductors.

On a non-GAAP basis, gross margin has risen further, from just 22% a year ago and 35.5% last quarter to 38.5%, due to the increased volume in MOCVD and Data Storage products as well as the addition of PSP to the portfolio. Full-year gross margin has risen from 31.5% to 36.3% (above the forecasted 34–36%).

Despite adding expenses from PSP, operating expenditure (OpEx) has risen only slightly, from \$37.8m last quarter to \$38.1m, and fallen as a proportion of revenue from 40.5% to

33.6% (as well as being down from \$48m a year ago).

"We developed differentiated new products, lowered operating expenses and improved gross margins," notes chairman & CEO John R. Peeler. "Veeco achieved significant milestones during 2014 as part of the transition back to growth and profitability," he adds.

Net income was \$5.1m (\$0.13 per share), compared with a loss of \$0.76m (\$0.02 per share) last quarter and \$16.4m (\$0.42 per share) a year ago. Full-year net loss was cut from \$28.1m (\$0.72 per share) in 2013 to \$4.1m (\$0.10 per share) in 2014.

Compared with losses of \$23.3m a year ago and \$1.8m last quarter, in fourth-quarter 2014 Veeco returned to profitability in adjusted earnings before interest, taxes, depreciation and amortization (EBITDA), at \$8.3m (exceeding the guidance of \$1.7–6.7m, aided by the addition of PSP). Full-year adjusted EBITDA has also turned positive, at \$2.6m, compared with a loss of \$36.7m in 2013.

Despite generating \$49m in cash flow from operations during the quarter, cash & short-term investments fell from \$487m to \$391.4m.

\$M	Q4 13	Q1 14	Q2 14	Q3 14	Q4 14
MOCVD	50	64	67	71	78
MBE	6	7	10	6	5
PSP	NA	NA	NA	NA	8
ALD	0	0	0	0	0
Data Storage	16	20	18	16	23
Total	73	91	95	93	114

Veeco's quarterly revenues by business sector.

However, this was largely due to \$145m of cash being used in early December to complete the acquisition of Solid State Equipment LLC. What is now Veeco PSP should "improve access to high-growth markets through complementary technology that will drive increased sales and profitability," says Peeler.

Full-year order bookings have risen by 53.8%, from \$331.6m to \$510m. In Q4/2014, bookings totaled \$196m, up 80% on \$107m last quarter and 130% on \$85m a year ago (and the highest quarterly level since 2011). In particular, Data Storage bookings were \$45m, more than tripling from \$14m last quarter and doubling from \$21.6m a year ago (also the highest since 2011), as customers invested in both capacity and technology. MBE bookings were \$5m, down on \$9m last quarter and \$11m a year ago. However, MOCVD bookings were \$142m, up 75% on \$81m last quarter and almost tripling from \$52m a year ago, due primarily to orders for the next-generation EPIK700 MOCVD system (mostly Sanan's order for 25 two-reactor EPIK systems). PSP's bookings were \$3m. Order backlog at the end of Q4/2014 was \$287m

► (including nearly \$200m for MOCVD, plus \$28m added from PSP).

During Q4/2014, Veeco successfully demonstrated its FAST-ALD (atomic layer deposition) technology for flexible organic light-emitting diode (OLED) encapsulation at a key customer. However, at the same time, the incumbent deposition technology has progressed to satisfy the current market requirements, and Veeco has not received any sizable orders for OLED encapsulation tools. While this opportunity "may not be permanently off the table", the firm has hence lowered the near-term revenue forecasts for its ALD technology and taken a non-cash asset impairment charge (goodwill, intangibles and property, plant and equipment) of \$55m in Q4. Veeco has also decided to lower its spending rate in ALD, refocus R&D efforts on semiconductor and other applications, and continue to monitor the flexible OLED market opportunity.

Veeco has begun shipping its new EPIK700 MOCVD system (including two systems that received beta signoff during Q4). The new system is said to improve LED customers' productivity and yield and to lower their total cost of ownership. The firm expects to ship, bill and invoice over \$25m of EPIK700 systems in first-quarter 2015. However, as is standard practice with new product introductions (as required by accounting rules), Veeco will wait until initial production shipments

are installed and final-accepted by customers before the systems are largely recognized as deferred revenue on the balance sheet.

As a result, for first-quarter 2015

Veeco expects revenue to dip to \$92–100m. Gross margin should fall slightly to 36–38%. Operating expenditure should be steady at \$37–39m. Adjusted EBITDA is expected to remain positive, at \$0–2m. Loss per share should be \$0.13–0.07. Chief financial officer Sam Maheshwari notes that, if Veeco had been able to take revenue on EPIK700 systems upon shipment, its Q1 revenue guidance would show growth to \$120–130m, and the firm would be solidly profitable on an adjusted EBITDA basis.

Following the dip in Q1/2015, revenue is expected to be much higher in Q2 and Q3. For full-year 2015, Veeco is targeting gross margin of more than 40% (aided by about \$65m in revenue from PSP, which should be accretive to both gross and operating margins). The firm

\$M	Q4 13	Q1 14	Q2 14	Q3 14	Q4 14
MOCVD	52	83	75	81	142
MBE	11	4	6	9	5
PSP	NA	NA	NA	NA	3
ALD	0	0	0	3	0
Data Storage	22	15	23	14	45
Total	85	103	104	107	196

Veeco's quarterly order bookings by business sector.

expects EBITDA profitability in each quarter, with profitability increasing through the year.

Veeco plans to reduce spending in ALD by \$4m on an annualized basis (incurring a restructuring charge of about \$1m). Despite this, due to revenue growth, quarterly OpEx should rise after Q1 to \$40–42m.

"I am highly confident that 2015 will be another year of improved performance for Veeco [targeting over 30% growth, or about 20% excluding PSP], fueled by great new products targeted at growth opportunities in LED, power electronics and mobile devices," says Peeler. "We have a strong team focused on keeping our organization streamlined and improving both gross margin and bottom-line performance."

www.veeco.com

Fraunhofer IAF buys K465i MOCVD system for nitride-based R&D

Veeco says that the Fraunhofer Institute for Applied Solid State Physics IAF of Freiburg, Germany has bought a TurboDisc K465i gallium nitride (GaN) metal-organic chemical vapor deposition (MOCVD) system.

Fraunhofer develops electronic and optoelectronic devices based on III-V micro- and nanostructures for applications such as security, energy, communication, health and mobility.

"After more than a decade of research in the field of nitride epitaxy on sapphire, silicon and silicon carbide (SiC) substrates, we have decided to upgrade our operation to include Veeco's MOCVD technology," says Fraunhofer IAF deputy director Dr Martin Walther, head of the Epitaxy Department. "The K465i offers a clean process and exceptional run-to-run repeatability that will enable us to achieve new levels of development

in high-growth markets," he adds.

Veeco says that K465i MOCVD systems feature excellent film quality, low defects and high productivity (key for effective GaN processing). The system also incorporates the firm's Uniform FlowFlange technology for superior uniformity and run-to-run repeatability. Since its launch in 2010, the K465i has been the world's top selling MOCVD system, says Veeco.

www.iaf.fraunhofer.de/en.html

Aixtron's revenue rebounds by 27% in Q4, driving 6% growth in full-year 2014

Gross margin recovers from low of 14% last quarter to 20%; positive EBITDA expected in second-half 2015

Deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany has reported full-year revenue growth of 6% from €182.9m in 2013 to €193.8m in 2014. Results are "in line with our stated expectations, but continue to be unsatisfactory," comments president & CEO Martin Goetzeler. "This was mainly due to the low top-line level reflecting the challenges that specifically the MOCVD [metal-organic chemical vapor deposition] industry faces." However, fourth-quarter 2014 revenue was €58m, up 27% on €45.6m last quarter and 14% on €51.1m a year ago.

Although still down on 34% a year ago, quarterly gross margin has rebounded from the low of 14%

last quarter to 20%. Full-year gross margin has improved from -4% in 2013 to 21% for 2014.

Reflecting efficiency gains from the firm's 5-Point-Program to return to sustainable profitability (initiated in May 2013), operating expenses have risen less than expected, from €88.4m for 2013 to €99.8m for 2014 (staying below the targeted €100m), including rising from €24.4m in Q3 to €30.5m in Q4. This is despite full-year R&D spending being increased from €57.2m for 2013 to €66.7m for 2014, in preparation for the launch of the firm's next-generation Showerhead MOCVD tools.

Full-year EBITDA (earnings before interest, tax, depreciation and

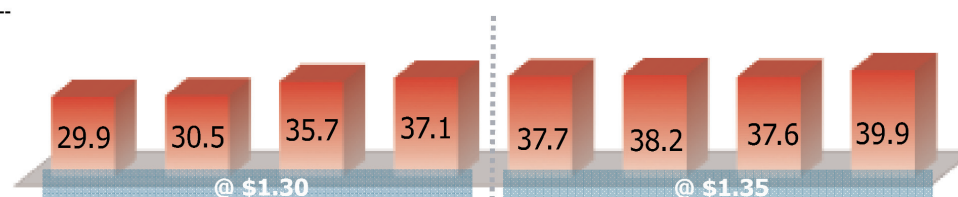
amortization) improved from -€67.9m for 2013 to -€41.3m for 2014. Compared with +€3.7m a year ago, Q4/2014 EBITDA was -€13.9m, but this was a slight improvement on -€14.1m last quarter, despite restructuring costs for the firm's reorganization being recorded mainly in Q4.

Full-year free cash flow has plummeted from -€1.1m in 2013 to -€47m in 2014, driven mainly by substantial expenses for future technologies (with the planned increase in inventories related to the launch of the next-generation MOCVD tools financed through advance payments from customers). However, after slumping from -€0.2m in Q4/2013 to -€21.7m in

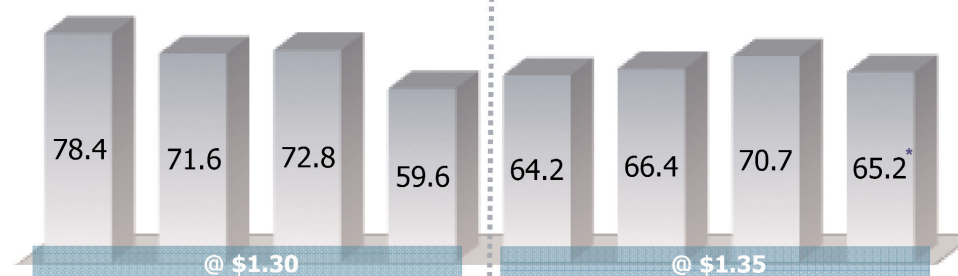
24 - Month Business

(€ million)

Equipment (only)
Order Intake

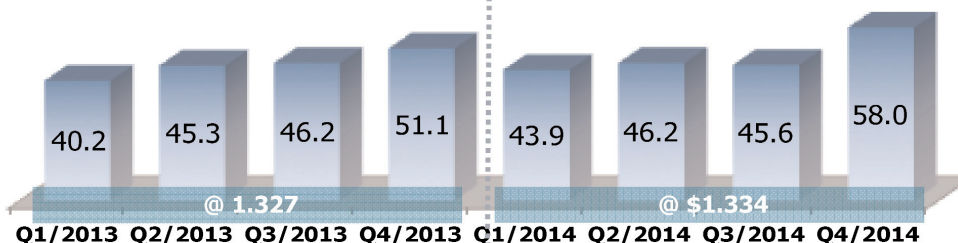


Equipment (only)
Order Backlog



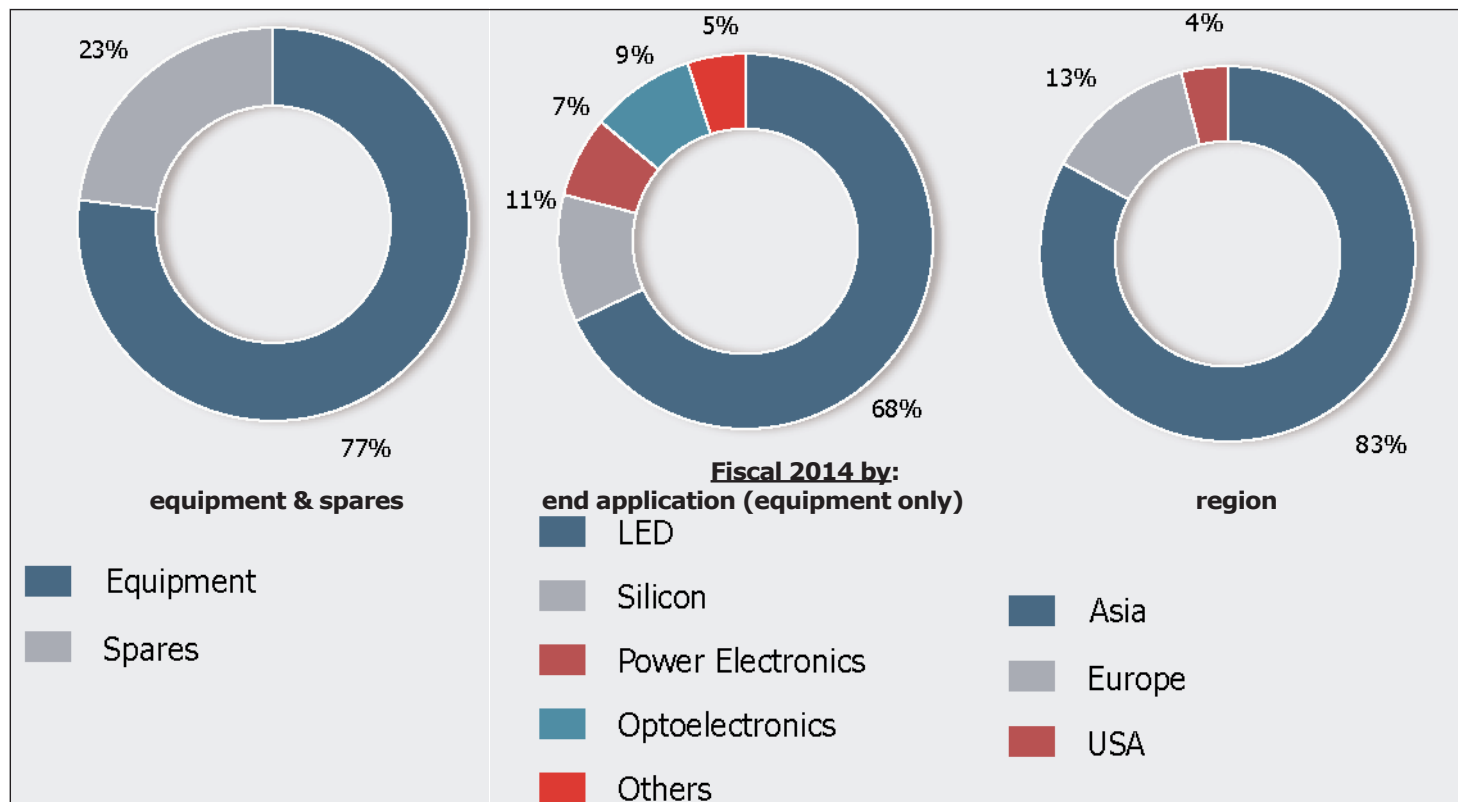
*) revalued on Jan.1, 2015 to €69.0m at \$1.25/€

Total Revenues
(incl. equipment,
service, spare parts)



USD order intake and backlog were recorded at the prevailing budget rate (2014: \$1.35/€)

USD revenues were converted at the actual period average FX rate (2014: \$1.334/€)



Q3/2014, quarterly free cash flow rebounded to positive €5.9m in Q4.

During 2014, cash and cash equivalents has fallen by €38.2m from €306.3m at the end of 2013 to €268.1m at the end of 2014, due mainly to the currency difference of the US\$-based cash and cash equivalents. However, this represents a slight rebound from €260.5m at the end of Q3.

Full-year equipment order intake has risen by 15% from 2013's €133.2m to €153.4m for 2014. In particular, Q4 order intake was €39.9m, up 6% on €37.6m last quarter and up 8% on €37.1m a year ago. The growth reflects the improved market demand throughout the reporting period, says Aixtron. Total equipment order backlog of €65.2m at the end of 2014 was 9% higher than the €59.6m at the end of 2013 and 12% higher than the January 2014 opening backlog of €58.1m. In addition, due to internal booking principles, Q4 does not include a large order from a Chinese LED maker for 50 AIX R6 Showerhead MOCVD tools received in September, as this will be recognized as order intake and revenue mostly in the course of 2015.

"In fiscal year 2014 order intake

and revenues developed positively," comments president & CEO Martin Goetzeler. "The global trend towards LED lighting continues. This development, as well as the availability of new MOCVD tool generations, will have a positive impact on investment demand," he adds. "Even if this is not yet reflected in the figures, we have achieved an important milestone with the market launch of the AIX R6 and a resultant major order," Goetzeler notes.

"We as management strongly believe that it is important continuing to invest in R&D, thereby reducing our dependency on one product while creating new business opportunities," states Goetzeler. "Our future-oriented technologies have already started to perform well, despite the fact that market introduction of these new products still requires preparatory efforts," he adds. "Due to our focus

Considering the ongoing ramp-up costs for the new AIX R6 system as well as costs for some crucial R&D projects, Aixtron expects a return to positive EBITDA in second-half 2015

on active cash management, we continue to be in a solid financial situation."

Aixtron says that, in the course of its 5-Point-Program, it is further adapting its organizational structure in line with customer and market requirements. Alongside cost-cutting measures, Aixtron is pursuing new market opportunities, e.g. with its new AIX R6 product generation and in promising future business fields such as power and logic semiconductors as well as organic light-emitting diodes (OLED).

For 2015, Aixtron expects growth across all technology areas (and thus improved demand for the corresponding production systems), driving a sequential increase in results in both halves of 2015 compared with the previous six-month periods and growth in full-year revenue to €220–250m. Also, considering the ongoing ramp-up costs for the new AIX R6 system as well as costs for some crucial R&D projects, Aixtron expects a return to positive EBITDA in second-half 2015, as the firm presses ahead with implementing its roadmaps, productivity and efficiency programs across all areas.

www.aixtron.com

IQE second-half 2014 revenue up 11.7% on first-half 2014

In an unaudited update for 2014, epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK says it expects full-year revenue to be about £112m (down 11.7% on £126.8m in 2013). Second-half revenue was about £60m (up 15% on £52m in first-half 2014).

The Wireless business (IQE's largest division, with an estimated global market share of over 50%) enjoyed double-digit sequential growth in second-half 2014 over first-half 2014, driven by the proliferation of increasingly complex wireless communication devices and systems such as LTE/4G, dual-band WiFi, and GPS location devices (which require increasingly complex compound semiconductor solutions).

Further, just after the end of 2014, IQE secured a major contract renewal with a key tier-1 customer (worth over \$50m) that should also lead to some expansion in IQE's market share. "The outlook for this business unit remains robust, driven by increasing adoption of 4G and LTE globally," says IQE.

For the Photonics business, revenue grew by over 20% year-on-year. "We further strengthened our relationships with major tier-1 photonic companies with additional long-term

supply agreements, and made excellent progress on our range of VCSEL [vertical-cavity surface-emitting laser] products, both technically and commercially, with several important world firsts in energy efficiency and speed records for data-center applications, and initial design wins across several other application areas," the firm adds.

The Infrared business won some significant orders in 2014, including one in October for \$1.1m and this January for \$3.25m. The technology is also starting to see initial adoption for potential uses in consumer related markets, adds the firm.

IQE says its solar concentrated photovoltaic (CPV) technology has also made good progress, but the market has taken much longer to develop than initially expected. However, the firm has now moved from a development phase into pilot production, with initial orders received in fourth-quarter 2014, and wafers now being shipped. IQE is now pressing ahead with plans to increase production during 2015/16.

Finally, IQE says that it has made progress in its gallium nitride (GaN) technology platforms, particularly for base-station and power-switching

applications (announcing a major supply relationship with M/A-COM Technology Solutions of Lowell, MA).

EBITDA (earnings before interest, taxes, depreciation and amortization) is projected to be up by 8% year-on-year to about £27m, including second-half EBITDA of about £16m (up on £11.1m in first-half 2014). Adjusted, fully diluted earnings per share (EPS) is expected to be up 20%, from 2p in 2013 to about 2.4p.

Net debt at end-2014 is £31m, down from £34.4m at end-2013 and £35.5m at the end of first-half 2014. This is after about £5m of cash restructuring costs (now complete) and after £8m of contingent deferred consideration (payments of which will end in 2016). IQE expects to make further progress on reducing net debt through 2015.

IQE says that its board is confident that it is set to achieve market expectations for 2015. The Wireless business is enjoying an improved outlook, the Photonics business is continuing to show strong double-digit growth, and new technologies — including the development of GaN — are progressing well, it notes.

IQE will report full results in March. www.iqep.com

Wireless business unit renews long-term contract with tier-1 customer

IQE has concluded the renegotiation of a long-term supply contract with an existing tier-1 customer for the supply of wafer products used in wireless applications.

The new supply contract guarantees IQE at least 75% of the customer's demand for epiwafers produced using its metal-organic chemical vapor deposition (MOCVD) platform. It will also see expansion in terms of additional products from its molecular beam epitaxy (MBE) platforms. IQE says the contract renewal underlines the strength of the long-term customer relationship that it has developed.

Supply against the new contract

will be fulfilled by IQE's Wireless business unit from its North American facilities in Massachusetts and Pennsylvania, as well as its manufacturing site in Taiwan.

Worth an estimated \$50m plus, the contract covers epiwafer products for radio frequency (RF) applications including power amplifiers (PAs), low noise amplifiers (LNAs) and switches used in smartphones, tablets, PCs and other connected devices.

"Wireless products continue to represent a key part of IQE's core business," says IQE's CEO & president Dr Drew Nelson. "The renewal of our long-term supply

contract with this important key tier-1 customer demonstrates a strong commitment to IQE," he adds.

"This contract renewal, with additional market share, is a testament to the quality, and cost effectiveness of IQE's wafer products, and to the best-in-class levels of service we are able to deliver," comments Russ Wagner, head of IQE's Wireless business unit. "The size of the contract is also clearly indicative of the continuing robust demand for compound semiconductor solutions in the wireless industry, being further driven by the adoption of 4G/LTE and WiFi on a global scale."

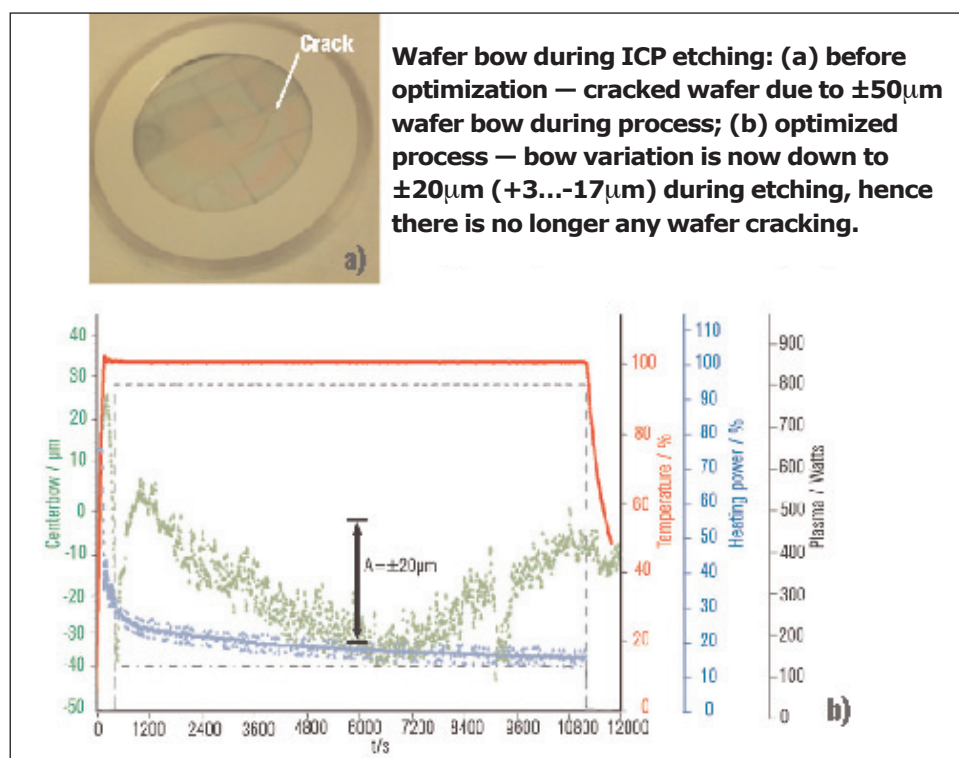
FBH uses LayTec's EpiCurve in-situ metrology to eliminate SiC/GaN wafer cracking in ICP etching

In-situ metrology system maker LayTec AG of Berlin, Germany says that researchers at Berlin-based Ferdinand-Braun-Institut für Höchstfrequenztechnik (FBH) have applied EpiCurve in-situ metrology for optimizing etching recipes in a Sentech SI 500 inductively coupled plasma reactive-ion etch (ICP-RIE) tool.

With standard etching recipes the SiC/GaN wafer (pasted to a glass or sapphire carrier) frequently cracks because it suffers from a $\pm 50\mu\text{m}$ wafer bow due to vertical temperature gradients and differences in the thermal expansion coefficients of carrier, substrate and GaN.

By using EpiCurve in-situ strain engineering, the wafer bow was reduced to $\pm 20\mu\text{m}$ (see Figure) and wafer cracking can be completely avoided, says the firm.

A presentation of the research can be found at the following link:



www.laytec.de/epicurve

www.fbh-berlin.com

www.laytec.de

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ClassOne acquires Microprocess Technologies' Spin Rinse Dryer and Spray Solvent Tool product lines

ClassOne Technology of Kalispell, MT, USA, which manufactures wet-chemical processing equipment (especially for cost-conscious emerging markets and users of smaller substrates), has acquired two complete product lines from Microprocess Technologies (a division of Fabrication Concepts) of Palm, PA, USA, which makes processing systems and parts.

Included in the acquisition are the Microprocess Spin Rinse Dryer (SRD) and Spray Solvent Tool (SST) families, which have become ClassOne's Trident SRD and SST lines.

"This acquisition is a natural fit for us," says ClassOne's president Byron Exarcos. "ClassOne's fundamental mission is to provide higher-performance wet processing equipment at lower cost to the user, just as we've done with our Solstice electroplating tools — and that's exactly what the new Trident SRDs and SSTs deliver," he adds.

"ClassOne will continue development and enhancement of the products, and they also will be able to make the tools available to a broader worldwide market," comments Microprocess Technologies' president Charles Brown.

"This acquisition is the culmination of a relationship that's been in progress for some time with Microprocess Technologies," says ClassOne's chief financial officer Richard Dotson. "Months ago we began with an exclusive sales agreement for the SRD and SST products, and now ClassOne has secured full ownership of both lines. The manufacturing will be moving to our Kalispell facility, where ClassOne's wet processing experience and ongoing product engineering will make these outstanding products even more advanced in the future," he adds.

"ClassOne has been actively seeking opportunities to expand its

offerings in high-growth segments of the industry," states Exarcos.

"Some of the emerging technologies such as MEMS, LEDs, power devices and RF are estimated to be growing at double-digit annual rates."

In many of those fabs the Spray Solvent Tool is becoming an essential process-of-record tool for metal lift-off, resist strip and more, he adds.

"In those scenarios, Trident tools are being seen as attractive solutions, because they're able to handle a range of advanced processes at a cost substantially lower than competitive systems," he claims.

Exarcos says that many of the Trident performance advantages are the result of design features such as wrap-around heating to enhance drying, a Deluge spray manifold to improve rinsing and reduce particles, and ClassOne's new Solaris system controller.

www.classone.com/products
www.microprocesstech.com

Ichor's European head office opened by Scottish Minister Relocation expands capacity, after license to sell Lam legacy products

Ichor Systems Inc of Tualatin, OR, USA (which designs and makes process tools, gas delivery modules and chemical delivery modules for original equipment manufacturers) has had its new 36,600ft² European head office in Hamilton International Park, Blantyre (near Glasgow), opened by Fergus Ewing MSP, the Scottish Government Minister for Business, Energy and Tourism.

In April 2012, Ichor acquired semiconductor firm Semi Scenic (founded in 2003, and based in a 12,000ft² plant in the Scottish Enterprise Technology Park, East Kilbride, since 2005). Ichor's European operation (which has 85 staff, 36 of them in Scotland) will now be managed from Blantyre.

"With this move from East Kilbride to Blantyre we have increased our production capacity by a factor of



From left to right – director Mark Firth, managing director Don Nicolson and president & CFO Maurice Carson of Ichor Systems, with Fergus Ewing MSP (Scottish Government Minister for Business, Energy and Tourism).

five and have set ourselves up for substantial further growth," says Ichor Systems' managing director Don Nicolson.

Last year the company secured a global product licence from Lam Research, enabling it to sell specific Single Chamber Etch (SCE) licensed legacy products directly to wafer manufacturers throughout the world. This has in turn bolstered Ichor's operations in Scotland.

Ichor has spent £0.5m on refurbishing and enhancing the Blantyre plant, which it holds on a ten-year lease. "I would like to thank the Government for making available £175,000 in Regional Selective Assistance (RSA) towards the costs of refurbishment," says Nicolson.

"I would also like to thank Alan Simpson & his team at TSquared for delivering the high-specification cleanroom facility ahead of schedule."

www.ichorsystems.com/legacyservices.html
www.lamresearch.com

Eulitha delivers PhableR 100 lithography system to China production company

Eulitha AG of Würenlingen, Switzerland (a spin-off of the Paul Scherrer Institute in Villigen, Switzerland that develops nano-lithographic technologies for optoelectronics, photonics, biotechnology and data storage applications) says that its PHABLE photolithography technology for low-cost printing of photonic patterns is continuing to attract interest from the industry and research fields. The latest example is a China-based manufacturer of specialty optical components. After evaluating the alternatives (including nanoimprint lithography), the firm chose Eulitha's unique PhableR 100 system due to its significant process and cost advantages.

With the PhableR 100 system, many different types of gratings

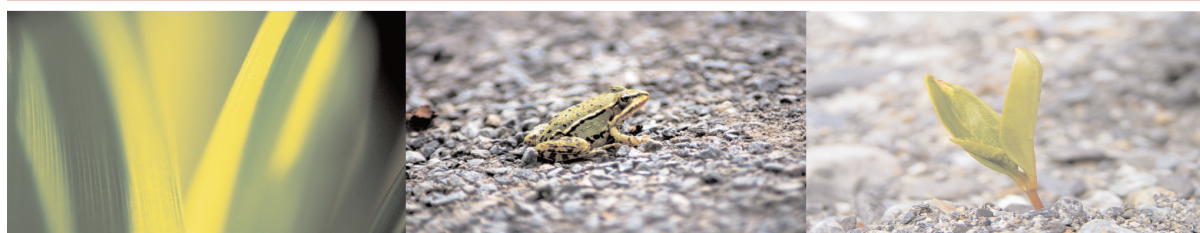


Eulitha's PhableR 100 system.

and photonic crystal type patterns can be realized with a robust photolithographic exposure. The system was delivered and qualified in the final days of 2014. Eulitha will continue to support the customer's production with specialty photomasks and process support.

The PhableR 100 system is capable of exposing periodic patterns down to feature sizes below 150nm, which rivals high-end i-line steppers. The focus-free image formed by the system enables uniform printing on non-flat samples often found in photonic and optoelectronic sectors. "We are very happy with the market reaction to the unique value offered by our breakthrough technology in manufacturing and research environments," says sales director Rene Wilde. "Production of patterned sapphire substrates (PSS) and light extraction structures on LEDs remains to be our main focus but this adoption by an optical manufacturer demonstrates the wide ranging application field for our novel technology."

www.eulitha.com



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JEOL and UC Irvine partner to develop electron microscopy and materials research center

The University of California's Irvine Materials Research Institute (IMRI) has entered into a strategic partnership with JEOL USA Inc of Peabody, MA (a subsidiary of Japan's JEOL Ltd that supplies electron optical equipment and instrumentation for scientific and industrial R&D) to create an electron microscopy and materials science research facility. IMRI will serve as an interdisciplinary hub for the study and development of new materials, targeting advances in solar cell, battery, semiconductor, biological science, and medical technologies.

The IMRI is headed by Dr Xiaoqing Pan, a researcher in the physics of materials who has joined the UC Irvine faculty this year to lead the \$20m initiative.

The new 'JEOL Center for Nanoscale Solutions' electron microscopy cluster will house JEOL's highest-performing transmission electron microscopes (TEM) for characterizing and analyzing materials to determine their potential for advanced applications.

The facility will be the first research lab in the Americas to install the new JEOL Grand ARM,



GRAND ARM JEM-ARM300F TEM with 63pm resolution

which is reckoned to exceed atomic resolution boundaries for any existing commercially available TEM. The Grand ARM offers 63pm resolution at 300keV for atom-by-atom characterization and chemical mapping. It features JEOL-proprietary spherical aberration correctors integrated in the image-forming system and illumination system, and an ultra-stable cold-cathode

field emission electron gun.

The center will also house the high-throughput, nano-analysis JEM-2800 TEM/STEM, which features dual large-area Silicon Drift Detectors with what is claimed to be unprecedented sensitivity for high-throughput EDS analysis.

"The electron microscopy initiative and the IMRI at UC Irvine will provide new tools and great opportunities for potential collaborations with the many researchers on campus and in southern California," says Pan. In his work he has pioneered the development of advanced functional materials and the characterization of their structure-property relationships at the atomic scale, ranging from ceramics and semiconductors to biological materials and nanomaterials.

"With the installation of our flagship atomic-resolution TEM, the JEOL Center for Nanoscale Solutions will be the most advanced electron microscopy cluster available for probing the atomic structure and properties of materials," reckons JEOL USA president Peter Genovese.

www.jeolusa.com

EXpressLO releases FIB specimen preparation module

EXpressLO LLC of Lehigh Acres, FL USA, which provides specimen preparation solutions for focused ion beam (FIB), has launched the Aspirato lift-out module for the EXpressLO ex-situ lift-out station.

To be featured at the 8th Annual FIB SEM Workshop at Johns Hopkins Applied Physics Laboratory in Laurel, MD USA (25 February), the Aspirato module enables faster processing of FIB specimens by improving lift-out speed and specimen placement, allowing users to maximize the advantages of the EXpressLO grids and lift-out method.

"Researchers are always challenged to find ways to achieve higher

throughput. Aspirato improves speed, specimen manipulation accuracy, and positioning reliability for lift out to our patented EXpressLO grids, which are uniquely designed to allow specimens to return to the FIB for further processing," says founder & president Dr Lucille Giannuzzi. "More control over specimen positioning to our grids enables users to quickly place the area of interest in the optimal position for either FIB post-processing or for S/TEM [scanning/transmission electron microscope] imaging," she adds. "In addition, because Aspirato is a module, it can be implemented on

all EXpressLO units, eliminating concerns over obsolescence of older systems."

Aspirato complements the EXpressLO portfolio of intellectual property, reinforcing the firm's expertise in creating solutions that improve FIB specimen preparation. The firm says that Aspirato and the EXpressLO solutions benefit FIB users in industry and at universities, in both the life sciences and physical sciences. ExpressLO adds that its solutions provide a fast and cost-effective alternative to executing lift outs inside an expensive FIB instrument.

www.EXpressLO.com

k-Space supplying thin-film metrology tools for solar PV

k-Space Associates Inc of Dexter, MI, USA (which supplies instrumentation and software for surface science and thin-film technology applications) says that it is supplying thin-film metrology tools to the photovoltaic industry in an effort to improve the efficiency and reliability of solar panel technologies.

Building on its presence in the crystalline III-V multi-junction solar cell market, k-Space now has over 100 tools in operation in commercial in-line photovoltaics production facilities around the world. These in-line tools are monitoring both process and material quality parameters and providing real-time feedback for process control.

k-Space says its PV metrology tools are tailored to measure the unique material properties and production processes of thin-film solar technologies, such as cadmium telluride (CdTe) and copper indium gallium diselenide (CIGS). Absorp-



tion edge, film thickness, panel temperature, surface roughness, and absolute spectral reflectance during solar panel production are some of the parameters monitored.

"There is a need for improved in-line, real-time metrology during solar panel production," says CEO Darryl Barlett. "Starting in 2011, we adapted our semiconductor wafer-based metrology tools to thin-film solar panel manufacturing, as semiconductor materials are used in both processes. By measuring

and storing data for each panel during production, our customers are not only able to make real-time adjustments to their process, but they also have access to data that can enable further product and process development," he adds.

Recognizing the need for metrology tools in photovoltaics production, k-Space

has staff with extensive experience in photovoltaics research and manufacturing. "My experience in photovoltaic production over the past 20 years has shown that inserting in-line metrology and diagnostics tools has been the most effective means of improving efficiency and yield," comments product development engineer Greg DeMaggio. "Optimization of processes requires fast, reliable feedback," he concludes.

www.k-space.com

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SETi doubles efficiency and ships samples of 20mA, 2.5mW UVC LEDs

General production availability expected in April

Sensor Electronic Technology Inc (SETi) has started shipping samples of its UVC LEDs with 2.5mW of optical power at 265–280nm. First launched in August 2013, the 3.5mm x 3.5mm ceramic SMD LEDs have evolved from 0.8mW of power at 20mA to 1.3mW in 2014 and now 2.5mW, still at 20mA. The product is targeted at cost-sensitive, high-volume markets such as disinfection.

The latest increase in performance is part of SETi's performance roadmap that builds on develop-

ments made through the US Defense Advanced Research Projects Agency (DARPA) Compact Mid-Ultraviolet Technology (CMUVT) program. The performance represents a doubling of wall-plug efficiency (P_{out}/P_{in}) of 2.3% (while external quantum efficiency, or EQE, has been measured at 2.9%). SETi also continues to develop new epitaxial and chip fabrication processes along with novel packaging techniques.

The 2.5mW UVC LEDs were showcased at the SPIE Photonics West

2015 exhibition in San Francisco (10–12 February) and were presented in the LEDs1 Session 12.

The latest LEDs have been shipped to strategic customers for evaluation, and SETi anticipates production availability for the broader market in April.

"SETi will continue to focus on internal epi, chip and packaging as well as leverage device developments from DARPA and other programs," says president & CEO Emmanuel Lakios.

www.s-et.com

SETi appoints president & chief executive officer

Sensor Electronic Technology Inc (SETi) of Columbia, SC, USA, which develops and manufactures deep-ultraviolet (DUV) LED devices and modules, says that Emmanuel Lakios has joined it as president & CEO, coordinating all company activities.

Lakios has 30 years of technology and business management experience in the semiconductor and equipment industries. Prior to

joining SETi, he held positions as president and chief operating officer of Imago Scientific Instruments. Also, during 20 years at Veeco Instruments Inc, he held various senior management positions including president & general manager of Process Equipment and president of Field Operations.

SETi says that Lakios brings a strong track record in technology management, strategic market

development, and operational performance.

"SETi has a great opportunity for growth with its leading-edge DUV LED technology," comments Lakios. "New applications for this class of LEDs emerge daily," he adds. "Our mission is to maintain our technical leadership and product position, addressing the requirements of the market places we serve."

Luminus appoints vice president of marketing

Luminus Devices Inc of Woburn, MA and Sunnyvale, CA, USA, which makes LEDs and solid-state light sources, has appointed Mark Pugh as VP of marketing. His solid-state lighting (SSL) experience adds new depth and market knowledge to the executive management team, says the firm.

Before joining Luminus, Pugh co-founded Xicato in July 2007 and was instrumental in creating the 'LED Module' category for the SSL industry, Luminus says. Over the last 7 years, he developed the product and business strategy establishing Xicato's dominant posi-

tion in the critical lighting designer and specification market.

Prior to Xicato, Pugh was a founding member of the Lumileds joint venture (JV) between Hewlett Packard and Philips. Based in The Netherlands, he was responsible for manufacturing and marketing, and established and cultivated global partnerships, channels and developed new markets. Pugh later became the VP of business development and strategic marketing as the JV expanded in 1999, starting new businesses for Lumileds such as LED backlighting for televisions and displays.

"Luminus offers the market a never-before-seen portfolio of solutions aimed at multiple market segments, from high-volume consumer and commercial applications like retrofit lamps and general illumination fixtures to high-value specialty lighting applications in medical, entertainment and projection displays," says Pugh.

Pugh attended the Strategies in Light event in Las Vegas, NV, USA (24–26 February), where Luminus was exhibiting.

www.luminus.com/products
www.strategiesinlight.com

Crystal IS introduces global partner distribution channel offering Optan UVC LEDs as instrumentation light source

Crystal IS Inc of Green Island, NY, USA, an Asahi Kasei company that makes proprietary ultraviolet light-emitting diodes (UVC LEDs) grown pseudomorphically (strained) on aluminum nitride (AlN) substrates, has introduced the Optan distribution channel. The first five distribution partners will carry select bins of Optan UVC LEDs for specific geographic locales. These partners and corresponding geographic regions are: Asahi Kasei Microdevices (AKM) and Opto Science in Asia Pacific (APAC); Epigap Optronic GmbH and Pacer International for Europe; and Thorlabs for North America.

Crystal IS says that Optan allows developers to fully exploit the power of UV-based technology to improve

productivity, increase accuracy and create greater flexibility in product designs. The light output and spectral quality — enabled by the unique, low-defect AlN substrate — delivers what is claimed to be best-in-class reliability, and longer lifetimes, for life sciences and analytical instrumentation (including environmental monitoring).

"In addition to delivery, we wanted to be sure Crystal IS distributors offered a full complement of services to customers needing to select a light source for their instrumentation needs," says CEO Larry Felton. "To that end, our partner selection process carefully reviewed capabilities in consultation and services in optical systems."

Distribution partners will offer Optan to those looking for light sources for different instrumentation applications including:

- HPLC (high-performance liquid chromatography) for purification of proteins and pharmaceutical manufacturing;
- real-time monitoring applications for water quality in drinking water and industrial wastewater; and
- ozone monitoring for detection of harmful pollutants.

Optan LEDs are available in peak wavelengths from 250nm to 280nm and power bins from 0.5mW to 2mW, suitable for spectroscopic applications because of their high spectral quality and reliability, says Crystal IS.

www.cisuv.com/products/optan

Nikkiso starts shipping 30mW deep-UV LEDs

Nikkiso America Inc of San Diego, CA, USA (the US arm of Tokyo-based Nikkiso Co Ltd, which is developing and commercializing deep ultraviolet LEDs) has initiated shipments of what is claimed to be the world's highest-power deep-UV LEDs, featuring three times more optical power output than is commercially available from other sources in the UV-C and UV-B range.

Nikkiso's UV-LED business introduced the new high-power deep UV-LED product line for the first time in North America at the SPIE Photonics West 2015 exhibition in San Francisco (10–12 February). The UV-LEDs are designed for applications in biomedical instrumentation and treatment, germicidal purification and sterilization, and industrial curing and printing.

Developed by 2014 Nobel Prize winning professors Akasaki and Amano, the new Nikkiso UV-LED products include single-chip LEDs and multi-chip LED modules. The single-emitter products feature what is claimed to be industry-



tional illumination, low voltage and direct current drive. Great demand is therefore expected for deep-UV LEDs in fields such as

leading power of 30mW at UV-C and UV-B wavelengths. Utilizing these devices, Nikkiso's new multi-watt module products feature intensities in excess of 100mW/cm². The devices can be used in stand-alone light sources, or integrated as OEM components into end-customers' final product solutions.

Using proprietary aluminium gallium nitride (AlGaIn) technology, Nikkiso notes that its UV-LEDs offer advantages over UV lamps including mercury-free operation, direct on-off modulation and instantaneous analog power control, compact and lightweight form factor, flexible emission wavelength, direc-

biomedical instrumentation and dermatology, curing of industrial resins and inks, and air purification and water sterilization.

Nikkiso says that its UV-LED factory in Japan's Ishikawa Prefecture has production technology that enables mass manufacturing on a commercial basis, including new epitaxial equipment, wafer fabrication, and cleanroom facilities. The production facility represents a \$22m investment into Nikkiso's UV-LED business, targeted at ensuring a stable supply of deep-UV LED products to the firm's partners (accelerating the development of deep-UV LED applications).

www.NikkisoUVLED.com

SemiLEDs' quarterly revenue grows 29%

Further growth expected following completion of facility consolidation plus new design wins

For fiscal first-quarter 2015 (to end-November 2014), LED chip and component maker SemiLEDs Corp of Hsinchu, Taiwan has reported revenue of \$2.9m, down 15% on \$3.4m a year ago but up 29% on \$2.3m last quarter, due to both design wins in target end-markets and the completion of previously announced facility consolidation activities.

Revenue from LED chips grew by 40% sequentially (comprising 24% of total revenue). Revenue from LED components grew 50% (comprising 55% of total revenue). However, this was offset by revenue from lighting products falling 15% (comprising 13% of revenue).

Gross margin has improved from last quarter's negative 134% to negative 53% (also better than the minus 75% a year ago).

While R&D expenses have been cut further by \$81,000 from \$0.83m to \$0.75m, selling, general & administrative (SG&A) expenses have risen by \$300,000 from \$1.85m last quarter to \$2.15m. So, total operating expenses have risen slightly from \$2.67m to \$2.9m

(though still less than \$3.5m a year ago). Despite this, operating margin has improved from last quarter's negative 251% to negative 152% (better than the negative 159% a year ago).

On a non-GAAP basis, net loss was \$3.9m, cut from \$5m last quarter and \$5.9m a year ago.

Although better than \$4.2m a year ago, cash used in

While relocation efforts were largely complete by the end of the fourth quarter, we continued to experience lingering effects of these activities in the first fiscal quarter as we completed the hook-up and start-up of this equipment. With our facility consolidation now concluded and new design wins in our target markets, we look forward to realizing further benefits from these efforts in fiscal Q2/2015

operations has risen from \$1.9m last quarter to \$2.7m. So, despite capital expenditure being cut from \$0.93m a year ago and \$0.77m last quarter to \$0.6m, free cash outflow has hence worsened from \$2.7m last quarter to \$3.3m (though still better than \$5.1m a year ago). Consequently, during the quarter, cash and cash equivalents fell from \$12.6m to \$8.7m.

"As discussed last quarter, while relocation efforts were largely complete by the end of the fourth quarter, we continued to experience lingering effects of these activities in the first fiscal quarter as we completed the hook-up and start-up of this equipment," chairman, president & CEO Trung Doan. "With our facility consolidation now concluded and new design wins in our target markets, we look forward to realizing further benefits from these efforts in the second fiscal quarter."

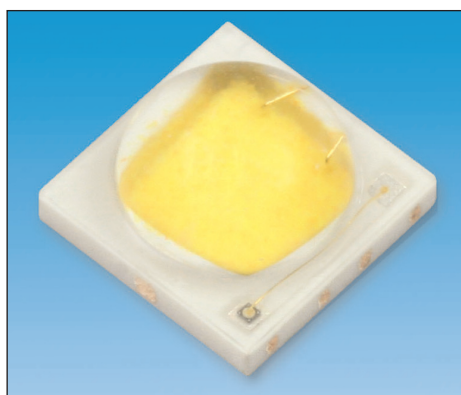
Consequently, for fiscal Q2/2015 (to end-February), SemiLEDs expects revenue to grow further, to \$3.4–3.7m.

www.semileds.com

Toshiba boosts high-power white LEDs to 160 lumens

Tokyo-based Toshiba Corp's Semiconductor & Storage Products business has begun mass production of a new series of high-luminous-efficiency power white LEDs with what is claimed to be industry-leading luminous flux of 160–170lm for room-temperature operation.

Using gallium nitride on silicon (GaN-on-Si) technology developed for LED lighting, the 3.5mm x 3.5mm lens-package TL1L4 series achieves high luminous efficacy of typically 160lm/W, with a correlated color temperature (CCT) of 5000K and $R_a = 70$ at a forward current (I_F) of 350mA operating at room temperature ($T_a = 25^\circ\text{C}$). At an ambient



Toshiba's high-luminous-efficiency TL1L4 Series power white LED.

temperature of $T_a = 85^\circ\text{C}$, operating current can be driven to 1A (a junction temperature T_j of $<150^\circ\text{C}$), and

the luminous flux is improved by more than 60% over Toshiba's existing TL1L3 series, contributing to improvements in luminous efficacy and lower power consumption for LED lighting.

The absolute maximum forward current is 1.5A at $T_a < 55^\circ\text{C}$ ($T_j < 150^\circ\text{C}$). Color options spans nine color temperatures, from 2700K to 6500K. Hot binning tests for electrical and optical characteristics at $I_F = 350\text{mA}$ and $T_j = 85^\circ\text{C}$ simulate real-life operating conditions.

Applications include LED light bulbs, base lights, down lights, street lights and floodlights.

www.toshiba-components.com/LEDs

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FerroTec

Soraa launches small-form-factor LED light engines delivering high CBCP and full-visible-spectrum light

Soraa Inc of Fremont, CA, USA, which develops solid-state lighting technology built on 'GaN on GaN' (gallium nitride on gallium nitride) substrates, has launched a small, low-profile series of light engines that provide fixture manufacturers access to the firm's full-visible-spectrum GaN-on-GaN LED technology.

From narrow spot to flood, Soraa's Optical Light Engines produce high CBCP, and the optical design provides what is claimed to be flawless beam definition and smooth beam edges, as well as being customizable with the firm's SNAP System. Designed for seamless fixture integration, the Optical Light Engines are compatible with a wide variety of industry-standard LED drivers and suit use in enclosed, non-ventilated indoor and outdoor fixtures.

Soraa says that its Point Source Optics technology produces high-intensity, uniform beams within a very slim form factor. Narrow-spot options at 10° or narrower are offered with a low profile of just 16mm for 500 lumens and 28mm for 1000 lumens. The optics technology also enables the firm to



Soraa's Optical Light Engines.

offer a unique 4° ultra-narrow-spot version that is as low as 28mm.

Soraa's Violet-Emission 3-Phosphor (VP₃) LED technology allows for rendering of colors and whiteness. Utilizing every color, especially deep red emission, VP₃ Vivid Color renders warm tones accurately, and achieves a color-rendering index (CRI) of 95 and deep red (R9) rendering of 95. Also, unlike blue-based white LEDs without any violet emission, the VP₃ Natural White is achieved by engineering the violet emission to properly excite fluorescing brightening agents including natural objects like human eyes and teeth, as well as manufactured white materials such as clothing, paper and cosmetics.

Soraa's new Optical Light Engines

are available in three sizes 11, 16, 30 (diameters of 1.5" or 37mm, 2" or 50mm, and 4" or 100mm); lumen outputs of 500 or 1000lm; beam angles of 4°, 10°, 25° and 36°; color temperatures of 2700K, 3000K, 4000K and 5000K; and with an optional heat-sink.

Additionally, Soraa's narrow-spot-beam light engines work with the firm's magnetic accessory SNAP System. With a simple magnetic accessory attachment, beam shapes can be altered and color temperature can be modified, allowing flexibility in design and display.

Soraa exhibited at the Strategies in Light event in Las Vegas, NV (24–28 February) and is exhibiting at LEDucation in New York (5–6 March).

www.soraa.com

Flip Chip Opto launches 300W, 600W and 960W chip-on-board lighting modules

LED lighting technology firm Flip Chip Opto Inc of Fremont, CA, USA has announced its P-Series of high-power LED flip-chip/chip-on-board (COB) products.

The high-performance lighting modules consist of patented 3-Pad LED flip chips with a Pillar Metal Core printed circuit board (P-MCPCB) to reduce module thermal resistance, resulting in lower junction temperature, lower thermal decay and the feasibility of smaller light-emitting surface (LES). The firm says that this enables designers to enhance 'lumen-per-dollar'

performance by either driving the modules at higher currents for more light output, or shrinking the heat-sinks and optics dimensions, or reducing LED chip counts.

The high-power P-Series COBs feature 45mil x45mil 3-Pad LED flip chips and high flux density in a small LES. The models P110-12S8P (96 chips), P110-15S12P (180 chips) and P110-15S19P (285 chips) support 'boost' power at 300W, 600W and 960W with LES of 45mm, 60mm and 85mm, respectively. Their high lumen-per-dollar value and extremely low thermal

resistances (0.01°C/W, 0.008°C/W and 0.007°C/W) make the COB solutions suitable for replacing high-intensity discharge (HID) luminaires in stadium, sport complex, wharf, storage, airport, golf course, farmland and architectural display applications.

All three models are available for sample purchase. OEM quantities are subject to delivery with standard lead times of 4 weeks.

Flip Chip Opto demonstrated its products at the Strategies in Light event in Las Vegas (24–26 February).

www.fcopto.com

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Cree launches XLamp MHD family, delivering chip-on-board performance in surface-mount LED

Building on its XLamp MH family of LEDs, Cree Inc of Durham, NC, USA has introduced the XLamp MHD-E and MHD-G high-power LEDs, which combine the high lumen density and reliability of a ceramic chip-on-board LED with the design and manufacturing advantages of a surface-mount package.

Utilizing elements of the Cree SC5 Technology Platform, the ceramic XLamp MHD LEDs simplify development, increase design flexibility and improve manufacturing efficiency compared to mid-power LEDs, the firm says. The MH family enables new designs and significantly lower system costs, Cree claims.

"The high lumen output and high reliability of Cree's new MHD-G LED

allows us to develop a new downlight that outperforms other downlights in the market," comments Baly Luo, general manager of Aeon Lighting Technology. "ALT's compact size 4" downlight that is built with the MHD-G LED generates over 1800 lumens at 3000K while other downlights can only produce 800 to 1000 lumens," he adds.

Featuring Cree EasyWhite technology in a 7mm x 7mm package, XLamp MH LEDs enable a smaller board size, tighter beam angle and a more traditional appearance than mid-power LEDs, Cree says. Delivering more than 1800 lumens at 14W and 2500 lumens at 19W respectively, the MHD-E and MHD-G LEDs are suitable for semi-directional, high-lumen applications

such as downlight, high-bay and outdoor area applications.

"With the MHD LEDs, we're offering chip-on-board performance to lighting manufacturers that prefer surface-mount technology, making it easier for them to achieve lower system cost than with the same commoditized mid-power LEDs that everyone is using," says Paul Thieken, Cree's director of marketing, LED Components.

The MHD-E and MHD-G LEDs are available in 2700–6500K color temperatures with high-CRI (color rendering index) and multiple voltage options. Product samples are available now, and production quantities are available with standard lead times.

www.cree.com/xlamp/mh

Cree adds field-adjustable color temperature to SmartCast-enabled CR Series LED troffers

Cree has introduced field-adjustable color temperature for SmartCast Technology-enabled CR Series LED troffers, delivering dynamic and customizable lighting for building managers and occupants.

As the first of Cree's luminaires to feature instantly adjustable color temperatures, the firm's SmartCast Technology combined with its TrueWhite Technology allow superior color quality and consistency while providing greater flexibility to control illumination at no additional cost, it is claimed.

"The new field-adjustable CCT feature demonstrates the next-generation of controllable lighting by being more flexible to individual needs and preferences, while delivering exceptional efficacy and value," says Norbert Hiller, Cree executive VP, lighting.

In combination with SmartCast Technology, Cree luminaires featuring field-adjustable color temperature enhance commercial building design by eliminating the need to decide on color temperature at the onset of installation, says the firm. With the ability to

choose from 3000K to 5000K in 500K increments, SmartCast Technology-enabled CR Series LED troffers enable the use of only one troffer type in any space, regardless of lighting preference. The result is simplified specification, ordering and installation with a lighting-control system that reduces energy consumption by more than 70% (compared to traditional fluorescent luminaires without SmartCast Technology), it is reckoned, allowing customers to realize the full promise of LED lighting controls.

www.cree.com/smartcast

ITC investigates infringement of LED lighting patents

Following Cree's complaint filed on 12 January, the US International Trade Commission (ITC) has agreed to open an investigation into unfair trade practices by Feit Electric Company Inc and its Asian supplier Unity Opto Technology Co Ltd.

The investigation ('Certain Light-Emitting Diode Products and Com-

ponents Thereof') includes Cree's allegations of infringement of eight of its US patents related to LED lighting and Feit's false and misleading advertising claims, including that certain of its products meet ENERGY STAR specifications.

Cree requests that ITC issues limited exclusion and cease and desist orders.

"Feit and Unity Opto are enjoying an unfair advantage in the market and discouraging the development of new products that benefit consumers," says Cree's chairman & CEO Chuck Swoboda.

www.usitc.gov/secretary/fed_reg_notices/337/337_947_notice02122015sogl.pdf

Zhaga Consortium starts work on new specification for chip-on-board LED arrays

The Zhaga Consortium, which develops specifications for interchangeable LED light sources, is now working on a new Book that will include chip-on-board (COB) LED arrays.

In response to feedback from a broad range of stakeholders, the new Zhaga Book will specify a family of six rectangular or square LED modules with different dimensions.

COB arrays are already in widespread use throughout the LED lighting industry, but different manufacturers offer a wide range of alternative sizes. This creates problems for luminaire makers and other stakeholders such as COB holder suppliers, and limits their options to use alternative products from different suppliers without changing their luminaire or holder designs.

"We consulted many luminaire makers, and received broad support for our plans to standardize

this type of LED light source," says Musa Unmehopa, secretary general of the Zhaga Consortium. "These companies asked us to standardize properties such as the mechanical dimensions of the module, the position of electrodes, and the diameter of the light-emitting surface."

Zhaga standardization removes arbitrary variations in a small number of parameters, in order to enable interchangeability of LED light sources. For customers, this simplifies the comparison and selection of products. For COB-array makers, it allows a focus on areas where they can offer value-added differentiation to customers, such as thermal properties, quality of light or luminous efficacy.

The new Zhaga Book will define LED light engines comprising rectangular and square LED modules with a circular light-emitting surface (LES) and a separate LED driver.

The Book will define a family of modules with different dimensions.

In most cases, modules compliant with the new Book will employ COB technology for the light-emitting section. However, the Zhaga specification will not prevent the use of alternative technology approaches.

To lay the groundwork for the new Book, Zhaga analysed the main COB-array products on the market and checked luminaire makers' requirements. It was hence decided to specify a family of six rectangular or square modules, with the following PCB dimensions: 12 x 15mm, 16mm x 19mm, 19mm x 19mm, 20mm x 24mm, 24mm x 24mm, and 28mm x 28mm.

The circular LES sizes defined in the new Book will correspond to the LES categories specified in several current Zhaga Books that cover spotlight modules (Books 3, 5, 10 and 11).

www.zhagastandard.org

Everlight adds chip-on-board LED series

Taiwan's Everlight Electronics has launched two chip-on-board (COB) LED families: the XUAN series of high-power COBs and Color Choice (Color on Demand) COB series CHI.

The 36V XUAN series offers both high efficiency and easy assembly. Covering a wide wattage range at customers' preference from 2–50W, the MCPCB device can achieve a luminous efficiency of >130lm/W. Designed with a high-thermal-conductivity Mirror-Aluminium substrate, it can be attached to the heat-sink by holder or screws. Also, its wide driving operation range ensures high efficacy in the typical driving state. In an over-driven state, however, it can still deliver high lumen output and, with an appropriate heat-sink, also remains stable to enable an economic lighting design. Seven different designs on the XUAN LED are currently available in 1313 and 1919 dimen-

sions with correlated color temperature (CCT) options from warm to cool (2700–6500K) and color rendering index (CRI) ratings of 82 (>80), 92 (>90) and > 97 Ra. The XUAN LEDs are best suited to LED single-light-source applications such as spotlights and downlights.

For color on demand, the Color Choice Series CHI COBs (9–29W) are designed on a ceramic PCB package and is based on the two color temperatures 2700K and 5700K which, when thoroughly mixed, can take on every ANSI color temperature in this CCT range. All mixture points achieve >110lm/W and a CRI>80 (R9>0). The Color Choice Series directly targets indoor retail, hospitality and residential lighting applications. Offered with wattages of 9W, 19W and 29W, CHI LEDs can supplement direct luminaires and spotlights with dynamic color temperature

variability and allow the seamless setting of any desired color temperature between 2700K and 5700K. The Color Choice Series' color temperature tunability is achieved by subdividing the COB into two electrically insulated segments for warm-white 2700K and cool-white 5700K color temperatures, which can be controlled/driven independently from each other. Each circuit requires a separate power supply unit or a co-channel power supply.

Everlight says that this makes the Color Choice Series suitable for elegant and simple mood lighting, adjustment to changing daylight and decorative lighting aspects in private homes, stores, hotels and bars. The CHI COBs are suited to large spotlights in retail applications or smaller directional lamps such as MR16, PAR20, PAR30 and PAR38 lamps for general lighting use.

www.everlight.com

Cree's quarterly revenue flat year-on-year as 33% growth in LED lighting offsets drop in LED demand from China

Lighting products rise to 56% of revenue as LEDs fall to 37%

For fiscal second-quarter 2015 (ended 28 December 2014), Cree Inc of Durham, NC, USA has reported revenue of \$413.2m, down 3.4% on \$427.7m last quarter but similar to \$415.1m a year ago and in the upper half of the target range of \$400-420m due to strong growth in LED lighting.

Power & RF product revenue was \$31m, level with last quarter but up 18% on \$26.4m a year ago (remaining about 7% of total revenue).

Lighting product revenue was \$230m, up 33% on \$173.7m a year ago and up 3% on \$223.1m last quarter (rising from 42% of total revenue through 52% to 56% of total revenue). Double-digit growth in LED fixtures more than offset the expected lower LED bulb sales).

LED product revenue (LED components, LED chips, and silicon carbide materials) was \$152m, down 29% on \$215m a year ago and 13% on \$173.6m last quarter (falling from 52% of total revenue through 41% to 37% of total revenue). The drop was due to lower LED demand (primarily from China).

"Growth in lighting and power & RF has been offset in the first half of fiscal 2015 by the decline in sales of LED products," notes chairman & CEO Chuck Swoboda.

Although still down on 38.2% a year ago, on a non-GAAP basis, gross margin has rebounded from 32.4% last quarter to 33.9% (above the targeted 33.5%). This is due primarily to the lower mix of LED sales being more than offset by Lighting product gross margin rising from 24.9% to 28.1% (driven by improved lighting execution and a more favorable mix). LED product gross margin rose only slightly from 39% last quarter to 39.1% (due to strong factory cost management being offset by much lower factory utilization). Power & RF product gross margin fell from 57.6% to 55.5% (due to product mix).

Operating income was \$34m (operating margin of 8.2%, down on 14% a year ago but level with last quarter and 50 basis points higher than targeted). This was despite operating expenses rising from \$103.5m last quarter to \$106m. This "reflects the improvement in our lighting business and ability to offset the slowdown in LEDs," says Swoboda.

Net income was \$37.9m (\$0.33 per diluted share), down on \$56.8m (\$0.46 per diluted share) a year ago but up on \$29.6m (\$0.24 per diluted share) last quarter. However, without an \$0.08 per share tax benefit (related to the retroactive reinstatement of the US federal R&D tax credit at the end of December), net income would have been \$29m (\$0.25 per diluted share, still above last quarter, and above the targeted \$0.20-0.24).

Cash generated from operations was \$14.8m (down from \$98.8m a year ago but up from \$13.3m last quarter). Capital expenditure was \$55m, comprising the regular patent spending of about \$5m plus property, plant & equipment spending of \$50m (roughly level with \$49.8m a year ago but down from \$63.4m last quarter, and in line with the lower spending planned for fiscal 2015). Free cash flow was hence minus \$40m.

Cree also spent \$266m

to buy back 8.1 million shares of its common stock, plus \$80.5m in December to purchase a 13% stake in Taiwan-based LED epitaxy, chip and packaging firm Lextar Electronics Corp.

Altogether during the quarter, after also drawing \$105m on its line of credit, Cree's total cash and investments fell by \$274.9m to \$829.9m.

Based on the view that Cree is well-positioned to continue to grow the company and increase profits over the next several years, in October the board of directors authorized an increase in the stock repurchase program to \$550m in fiscal 2015 (in the fiscal year to date, Cree has spent \$320m to repurchase 9.3 million shares). Subsequently, in January, Cree closed on a \$500m working capital line of credit facility (having repaid the original \$150m facility). Its purpose is to fund share repurchases, capital expenditures and other general business needs, as well as providing short-term flexibility to optimize returns on the firm's cash and investment portfolio.

Free cash flow was negative \$40m due primarily to a \$59m working capital build resulting mainly from a \$43m decrease in accounts payable (related to higher purchases earlier in the quarter versus last quarter) and a \$21.8m increase in inventory to \$332.5m (rising from 96 days to 108 days) as LED inventory reductions were offset by an increase in lighting inventory.

The lighting inventory build was higher than forecast due to a combination of increased in-transit inventory (to account for recent increases in shipping times from Asia) and a short-term increase as Cree qualifies and ramps up two new subcontractors. Excluding these two items, overall inventory was similar to last quarter. For fiscal Q3, Cree targets lower inventory

Gross margin is expected to fall slightly to 33.5%, with Lighting product gross margin improving due to factory productivity improvements and cost reductions, while LED and Power & RF product margins fall slightly due to lower factory loading

levels as new subcontractors come online (which should bring inventory back down to the 90-day target) as well as lower capital expenditure, which should support positive free cash flow.

"The market for LED lighting is still in the early stages, our new product pipeline is strong, sales momentum is building and our brand is growing in the market," says Swoboda. "As evidenced by our significant share repurchases in Q2, we believe we are on the right track to continue to grow the company and increase profits over the next several years," he adds.

Business highlights during the quarter include the following:

- introducing the SC5 Technology Platform for lighting-class high-power LEDs (which doubles light output, enabling system costs to be cut by up to 40% in most lighting applications), leading to the launch of the XLamp XHP50 and XHP70 LEDs (the first Extreme High Power LEDs based on the SC5 Technology

Platform);

- launching the third-generation ('GEN3') Cree LED Bulb (which looks more like an incandescent light bulb due to the new 4Flow filament design);

- acting to protect Cree's intellectual property by filing lawsuits at the US International Trade Commission (ITC) and the US District Court for the Western District of Wisconsin against Feit Electric Company Inc and its Asian supplier Unity Opto Technology Co Ltd.

For fiscal third-quarter 2015 (ending 29 March), Cree targets revenue of \$395–415m, consisting of lighting sales flat to slightly higher sequentially (as higher indoor LED fixture sales offset seasonally lower outdoor sales), LED sales down by single digits (due to normal seasonality and the Chinese New Year holiday), and Power & RF sales similar to fiscal Q2. "We should start to see the impact of the GEN3 bulb on our Q3 sales as it gains more shelf space and rebates become available in

more markets," says Swoboda. Gross margin is expected to fall slightly to 33.5%, with Lighting product gross margin improving due to factory productivity improvements and cost reductions, while LED and Power & RF product margins fall slightly due to lower factory loading. Operating expenses should be similar to fiscal Q2, as increased spending to fund Cree's IP enforcement strategy is offset by reductions in other areas. Net income is expected to be \$23–28m (\$0.21–0.25 per diluted share).

"The LED business seems to have stabilized in the current revenue range, and we target overall company revenue growth in our fiscal Q4," says Swoboda. "We are optimistic about the long-term growth prospects for LEDs based on initial customer feedback and our new SC5 based products and overall increased LED lighting adoption, but it will take time to work through the design cycles and current market conditions," he adds.

Cree launches CXA2 LED arrays, boosting efficacy by 33% and cutting system cost by 60%

LED chip, lamp and lighting fixture maker Cree Inc of Durham, NC, USA has supplemented its XLamp CXA LED array family with CXA2 arrays, which deliver up to 33% higher efficacy in the same form factors.

Utilizing elements of the firm's SC5 Technology Platform, the improvement in lumen density enables better performance and greatly reduces system size and cost. The new chip-on-board (COB) LEDs allow lighting manufacturers to rapidly deliver more innovative solutions for applications such as track, downlight and outdoor lighting, claims Cree.

"We are working together with Cree to evaluate their latest COB technology," says Massimo Paravicini, R&D director of Italy-based lighting manufacturer Reggiani Illuminazione. "The new

CXA2 LED arrays, which deliver excellent performance in such small LES [light emitting surface], would be a great solution for the new generation of indoor luminaires we are currently developing," he believes.

With the new CXA2 LED arrays, lighting manufacturers can achieve the same or better performance with a smaller LES compared with earlier products. For example, a 3800 lumen output from a larger 19mm LES LED can be replaced with a smaller 12mm LES LED, resulting in up to 60% system cost savings from lower LED, mechanical and optic material costs, it is reckoned.

CXA2 LED arrays share the same physical design as earlier arrays, allowing lighting manufacturers to leverage the existing optical, mechanical and electrical design elements to accelerate time to mar-

ket without additional cost. LM-80 data is available for all CXA2 LED arrays for lighting manufacturers seeking ENERGY STAR qualification. The arrays are also UL-recognized components and feature a level 4 rating.

Through improvements in the light conversion process, Cree has reduced LED-to-LED color variations and, among other options, offers CXA2 LED arrays in 2- and 3-step EasyWhite bins. To address a wide variety of applications, the arrays are available with color temperatures of 2700–6500K, a color-rendering index (CRI) of 70, 80 or 90 and with multiple voltage options and LES range of 6–30mm with a lumen range of 250–19,000lm. Product samples are available now, and production quantities are available with standard lead times.

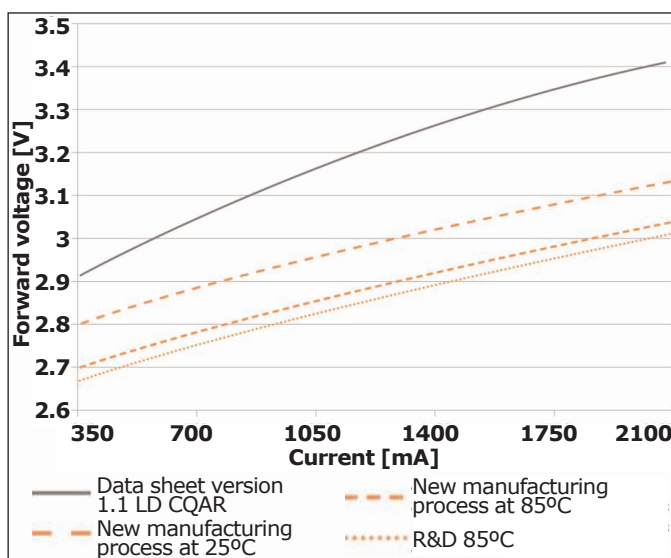
www.cree.com/cxa2

Osram boosts efficiency of blue LED chips by 8%

Osram Opto Semiconductors GmbH of Regensburg, Germany claims that it has achieved one of the best values in the world in terms of forward voltage for blue high-current chips, leading to an increase in efficiency of up to 8%.

Optimized indium gallium nitride (InGaN) chips featuring Osram's UX:3 chip technology are the basis for blue or white LEDs, and are already used in production. The firm also sees considerable potential for reducing forward voltage by a further 20–30mV by the summer, offering a further boost in efficiency.

The blue Osram Oslon Square (LD CQAR), for example, now has a typical forward voltage of only 2.87V instead of the 3.05V specified so far in the data sheet – the lowest typical values in this component class worldwide, it is reckoned. At 85°C a voltage of 2.78V can be achieved. Depending on the operating point, this translates into an increase in efficiency of these LEDs of 6–8%, which can be trans-



Forward voltage versus current for Osram's optimized LED, compared with the data sheet for the previous Oslon Square (LD CQAR) LED.

ferred to the entire UX:3 chip family, which can be found in all blue and white LEDs. The LEDs are used in a wide range of applications – the Oslon Square, for example, in street lighting and industrial lighting.

"The reduction in forward voltage

was achieved thanks to a new process in the epitaxy," says project manager Dr Marcus Eichfelder. Production of the first optimized chips started last August.

"In the laboratory we have already succeeded in further reducing the forward voltage by as much as 30mV," says Dr Joachim Hertkorn, Epitaxy expert at Osram Opto. This would improve efficiency of the LED chips by a further percentage point.

"In view of the speed with which this first step has been implemented, we are confident that the improved process can be transferred to production by the summer," he adds. "Any further reductions in forward voltage will then only be marginal owing to the laws of physics."

Far-red Oslon SSL LED added to optimize horticultural lighting

Osram Opto Semiconductors is expanding its product range for horticultural lighting with a new type of its Oslon SSL LED.

In addition to the existing hyper red (660nm) and deep blue (450nm) versions, firm has developed a far-red Oslon SSL LED with a wavelength of 730nm. For certain plants such as tomatoes, pepper or roses, it is exactly this wavelength that leads to better growth. Customers now have better coverage of the color spectrum for their horticulture applications, says Osram. The new far-red Oslon SSL has been available since January.

The new ultra-compact Oslon SSL (3mm x 3mm x 2.35mm) is available in two product versions with a narrow beam angle of 80° and 150°. The LEDs can hence be arranged close to each other and

offer a uniform light impression. All Oslon SSL versions can be combined easily, says Osram, because they have the same size of footprint and solder pad as well as the same technical characteristics. This offers high design flexibility for ambitious horticultural lighting applications, where each greenhouse lighting system needs a tailored-made solution, adds the firm.

LED lighting can stimulate plant growth by up to 40%. Different wavelengths address different plant properties: blue light supports flowers to open up and red light helps stems to grow better. Thus, a combination of the three existing versions of the Oslon SSL LED family — far red (730nm), hyper red (660nm) and deep blue (450nm) — provides better coverage of the color spectrum and an

optimal growth pattern, says Osram. With this range of three colors, a large variety of plants can be addressed.

There are several general benefits of LEDs for use in horticultural lighting, notes the firm. Because of the single LEDs, the lighting can easily be steered and controlled in the greenhouses. LEDs have a longer lifetime than other lighting technologies, and they are very energy-efficient and thus drastically reduce energy consumption over time. They also emit no heat in the lighting direction, so the plants will not be damaged. Furthermore, LEDs are available in different wavelengths, so lighting solutions can be adjusted exactly to the value that the respective plant needs.

www.osram-os.com

Osram launches high-brilliance, high-power 976nm laser bar for fiber-laser pumping

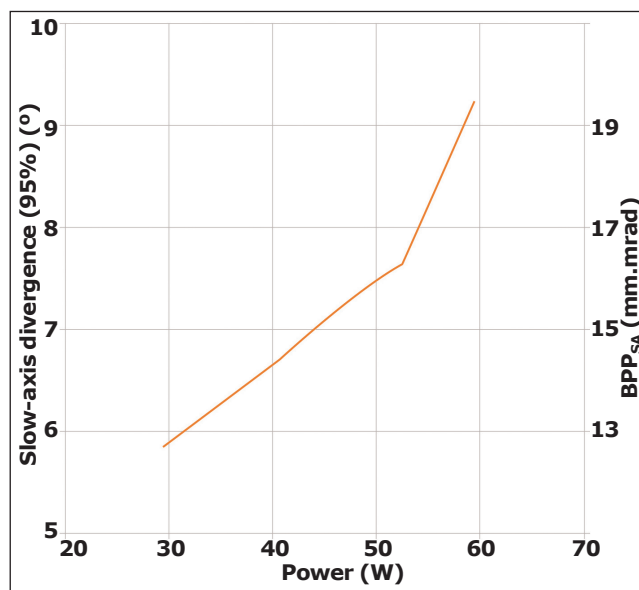
Osram Opto Semiconductors GmbH of Regensburg, Germany says that its new 5mm-wide SPL BF98-40-5 laser bar (consisting of five emitters, each 100 μ m wide with a cavity length of 4mm, spaced 1mm apart) has an optimized chip design in terms of beam quality, allowing 976nm-wavelength emission with a high brilliance of 3W per millimeter and 1mrad divergence angle (i.e. 3W/mm \cdot mrad) at an optical output of 44W.

Osram Opto says that, due to its high brilliance, the laser diode considerably reduces the complexity of coupling light into fibers, and diode- or fiber-laser systems for material processing can be made simpler and more cost-effective. Even at its maximum output of more than 60W, the component has a long life, the firm adds.

Brilliant laser sources generate a narrow beam of light with extremely small beam divergence and high power density. The lateral divergence of the beam emitted by the SPL BF98-40-5 (calculated for the portion of the beam containing 95% of the optical output power) is between 6° at 30W and about 9.5° at 60W.

Simple injection into fibers

The beam quality of a laser is a crucial factor for coupling laser light into optical fibers. The lower the



Beam quality and life-time for optical output up to 60W. Picture: DILAS Diodenlaser GmbH.

brilliance, the less light is coupled into the fiber. This, in turn, makes the systems more inefficient and more expensive. Conversely, a brilliant light source greatly simplifies the design of the optical system. "Our new laser bar can significantly reduce the system costs for fiber-coupled diode lasers," claims Sevugan Nagappan, product marketing manager for IR at Osram Opto Semiconductors.

Fiber-coupled diode laser systems are used predominantly in the automobile industry for vehicle chassis welding, soldering and

coating. Laser diodes emitting at 976nm are also ideal for pumping ytterbium-doped fiber lasers which, due to their excellent beam quality, can be used for cutting metal. Osram has specifically matched the wavelength of the SPL BF98-40-5 to this pumping application.

Long operating life

The new laser bar offers electro-optical efficiency of 65% at 44W. This reduces the level of cooling needed for the laser diode and improves the efficiency of the entire system,

says Osram Opto. The temperature rise at the chip is therefore not as great, so the laser exhibits good aging stability. Tests show a drop in output of less than 1% after 4000 hours of operation at an optical output of 65W and a cooling water temperature of 25°C.

Osram Opto notes that it defined the fundamental principles for developing the high-power high-brilliance laser bar within the HEMILAS project sponsored by the German Ministry for Education and Research (BMBF).

www.osram-os.com

DILAS launches 240W, 915nm fiber-laser pump module

Diode laser maker DILAS of Mainz, Germany has expanded the wavelength range of its tailored bar-based, scalable concept with its new high-brightness fiber-laser pump module delivering up to 240W optical output power at 915nm.

Based on DILAS' tailored bar architecture, the platform combines optimized chip structures with high-brightness beam-shaping technologies, all assembled with automated production processes.

The tailored bar is a monolithic multi-emitter source, allowing the handling of multiple emitters during each manufacturing step, to lower complexity and ease manufacturing. The result is enhanced reproducibility, beam quality and fiber-coupling efficiency, claims the firm.

The 240W of scalable output power is delivered out of a 200 μ m, 0.22 NA (numerical aperture), mode-strip cladding power free,

non-detachable, pig-tailed fiber. In addition, single-wavelength scalability of output power will be available soon by combining several of these modules by spatial and polarization multiplexing techniques into larger assemblies.

The new tailored bar-based, fiber-coupled modules target a wide range of high-power fiber-laser pumping applications in industry, R&D and direct-diode applications.

www.dilas.com

First group-IV lasers grown on silicon by FZ Jülich and the Paul Scherrer Institute

Germanium-tin lasers emitting at 3µm target bio & medical applications

In cooperation with international partners, Germany's Forschungszentrum Jülich and the Paul Scherrer Institute (PSI) in Villigen, Switzerland have presented what is claimed to be the first semiconductor laser consisting solely of main group IV elements ('Lasing in direct bandgap GeSn alloy grown on Si', Wirths et al, Nature Photonics; DOI: 10.1038/nphoton.2014.321). The germanium-tin (GeSn) laser can be applied directly onto silicon, hence facilitating optical data transmission on computer chips (faster than possible via copper wires and requiring only a fraction of the energy).

"Signal transmission via copper wires limits the development of larger and faster computers due to the thermal load and the limited bandwidth of copper wires," says professor Detlev Grützmacher, director at Jülich's Peter Grünberg Institute, Semiconductor Nanoelectronics (PGI-9). "The clock signal alone synchronizing the circuits uses up to 30% of the energy – energy which can be saved through optical transmission," he adds. "The integration of optical components is already well advanced in many areas," continues Grützmacher PGI's head of Semiconductor Nanoelectronics (PGI-9). "However, in spite of intensive research, a laser source that is compatible with the manufacturing of chips is not yet achievable."

Suitable material for chip production

Compared with group IV silicon, typical telecom lasers made of group III-V elements, such as gallium arsenide (GaAs) for example, are costly and, due to their different crystal properties, cannot be grown directly on silicon (needing instead to be produced separately and then bonded to a silicon wafer). Also, device lifetime is greatly reduced due

to the thermal expansion coefficients of these elements being significantly different from that of silicon.

In contrast, group IV semiconductors such as silicon and germanium can be integrated into the manufacturing process without any major difficulties. However, neither element is very efficient as a light source, due to having an indirect energy bandgap. In contrast to direct-bandgap semiconductors, they emit mostly heat and just a small amount of light when excited. Many research groups are hence trying to manipulate the material properties of germanium so that it can amplify optical signals, making it a usable laser source.

Compound with a high tin content

Jülich's Peter Grünberg Institute says that it has now created the first 'real' direct-bandgap group IV semiconductor laser by combining germanium and tin (which is also a group IV element). "The high tin content is decisive for the optical properties," comments PhD student Stephan Wirths. "For the first time, we were able to introduce more than 10% tin into the crystal lattice without it losing its optical quality," he adds. "The functioning of the laser is so far limited to low temperatures of up to -183°C, however," notes co-author Dr Dan Buca. "This is mainly due to the fact that we worked with a test system that was not further optimized."

In cooperation with colleagues in professor Siegfried Mantl's group at PGI-9, Wirths applied the laser directly onto a silicon wafer whose properties were subsequently measured at the Paul Scherrer Institute, where PhD student Richard Geiger fabricated the laser structures.

"That way, we were able to demonstrate that the germanium-tin compound can amplify optical signals, as well as generate laser light," says Dr Hans Sigg of PSI's Laboratory

for Micro and Nanotechnology.

For the demonstration, the laser was excited optically. Currently, Buca's group at Jülich is working on linking optics and electronics even more closely. The next big step will be generating laser light with electricity instead, and without the need for cooling if possible. The aim is to create an electrically pumped laser that functions at room temperature.

New wavelength for new applications

GeSn absorbs and emits light in a wavelength range of about 3µm. Many carbon compounds, such as in greenhouse gases or biomolecules, also display strong absorption lines at this boundary between near- and mid-wavelength infrared. Hence, sensors made of GeSn promise a new possibility for detecting these compounds.

Along with computer chips, completely new applications that have not been pursued so far for financial reasons may thus benefit from the new laser material. Examples include gas sensors or implantable chips for medical applications that can gather information about blood sugar levels or other parameters via spectroscopic analysis. In the future, cost-effective, portable sensor technology – which may be integrated into a smart phone – could supply real-time data on the distribution of substances in the air or ground, contributing to better understanding of weather and climate development.

The research was funded partly by the Swiss National Science Foundation (SNF). Funding for CVD growth came from the European Community's Seventh Framework Program (grant no. 619509; project E2SWITCH) and the BMBF project UltraLowPow (16ES0060 K).

www.fz-juelich.de/pgi/pgi-9

www.psi.ch/lmn/lmn

University of New Mexico researcher receives NSF CAREER award to study blue and green VCSEL arrays using non-polar and semi-polar GaN

Daniel Feezell, an assistant professor in the University of New Mexico's Department of Electrical and Computer Engineering, has received a \$500,000 US National Science Foundation (NSF) Faculty Early Career Development (CAREER) award, running from 1 March through February 2020, for the project 'Short-Wavelength Vertical-Cavity Surface-Emitting Laser Arrays Using Nonpolar and Semipolar GaN'.

The project's basic thrust is to develop arrays of blue and green vertical-cavity surface-emitting lasers (VCSELs) with stable polarization of the light emission by using novel orientations of gallium nitride.

Applications of the technology could include improved high-density optical data storage and high-resolution printing, improved mobile displays and projectors, and advancements in chemical/biological sensing and atomic clocks.

An example of a possible practical application would be the addition of projection capabilities on smartphones. Such a projector could be included on the back of the phone, right next to the camera. "This would allow your phone to become a display projector, so you could view movies, pictures, or Power-Point slides on the wall or on a screen instead of directly on your phone," Feezell says.

The vertical geometry of VCSELs has several advantages over conventional edge-emitting lasers, including high beam quality, small form factor, the ability to form densely packed arrays, and lower power consumption, says Feezell. His work will focus on adding stable polarization and increasing the output power using arrays.

Feezell will also be researching how to create a green VCSEL, which has not yet been developed. Since red and blue VCSELs have already been developed, adding a



UNM assistant professor Daniel Feezell.

green VCSEL would complete the RGB (red, green, blue) spectrum, allowing the creation of white light, which makes possible technologies such as display screens or LED light bulbs for room lighting and other applications.

Much of the work on the project will be done at UNM's Center for High-Technology Materials, and some will be done

Feezell will also be researching how to create a green VCSEL, which has not yet been developed. Since red and blue VCSELs have already been developed, adding a green VCSEL would complete the RGB spectrum, allowing the creation of white light, which makes possible technologies such as display screens or LED light bulbs

in collaboration with the Center for Integrated Nanotechnologies at Sandia National Laboratories.

The project will fund one graduate student, and will also include an outreach effort with Southwestern Indian Polytechnic Institute (SIPI), an Albuquerque national Indian community college and land-grant institution serving American Indian and Alaskan Native students. Outreach activities will include assessing the potential of installing energy-efficient, solid-state lighting in rural Native American communities, mentoring local teachers, and developing courses at UNM.

Feezell believes that GaN-based VCSELs hold untapped potential: "It's still an immature field, and many of the applications are still not developed or known."

"Getting this grant will allow me to continue my research in this area, which I've been working on for the last five or six years," says Feezell, who came to UNM about three years ago from the University of California, Santa Barbara (UCSB). "Very few groups are working in this area, and the hope is that this grant will enable UNM and my research group to become leaders in the development and application of GaN-based VCSELs."

The NSF CAREER program is geared toward helping early-career faculty get strong starts on their academic careers. The award is NSF's most prestigious award in support of junior faculty who exemplify the role of teacher-scholars through outstanding research, excellent education, and the integration of education and research within the community. Such activities are intended to build a firm foundation for a lifetime of leadership in integrating education and research.

www.feezellgroup.com

www.ece.unm.edu/faculty_Staff/Feezell.html

ProPhotonix launches compact green laser diode module

ProPhotonix Ltd of Salem, NH, USA, a designer and manufacturer of diode-based laser modules and LED systems for OEMs and medical equipment companies (as well as a distributor of laser diodes for Panasonic, Ushio, Osram, QSI, and Sony), has launched the Compact Green Laser Diode Module, an extension of its Compact Laser Diode Module Series.

At 8mm in diameter, the Compact Green Module is designed for appli-

cations where space is a key consideration. As well as their compact size, they have high reliability and constant power output, says the firm. The low current requirements of the modules mean they can be battery operated, making them suitable for a wide variety of applications including alignment, positioning and light scattering.

The Compact Green Series of 520nm lasers are available in a range of output powers and with

elliptical spot, collimating and diffractive options.

"With the launch of Compact Green series we have taken advantage of our position as a leading laser diode distributor to access the latest in laser diode technology, delivering a truly compact, complete solution," says Jeremy Lane, managing director of Laser Operations.

ProPhotonix exhibited at the SPIE Photonics West 2015 event in San Francisco (10–12 February).

New 405nm laser module with external photodiode for output control

ProPhotonix has announced the development of a new 405nm laser module with an external photodiode, which is claimed to provide excellent output power control over an extended product life-time.

The firm says that 405nm laser diodes are not typically packaged with an internal monitor photo-

diode, because the photodiode typically degrades over time. The new design includes an external photodiode designed to deliver excellent output control in the 1–150mW range. The durable photodiode has high sensitivity to 405nm radiation for more precise control of laser output.

"This new 405nm laser module demonstrates ProPhotonix's ability to overcome design challenges and deliver custom laser diode modules tailored to customer's application needs," says Jeremy Lane, managing director of Laser Operations at ProPhotonix.

www.prophotonix.com

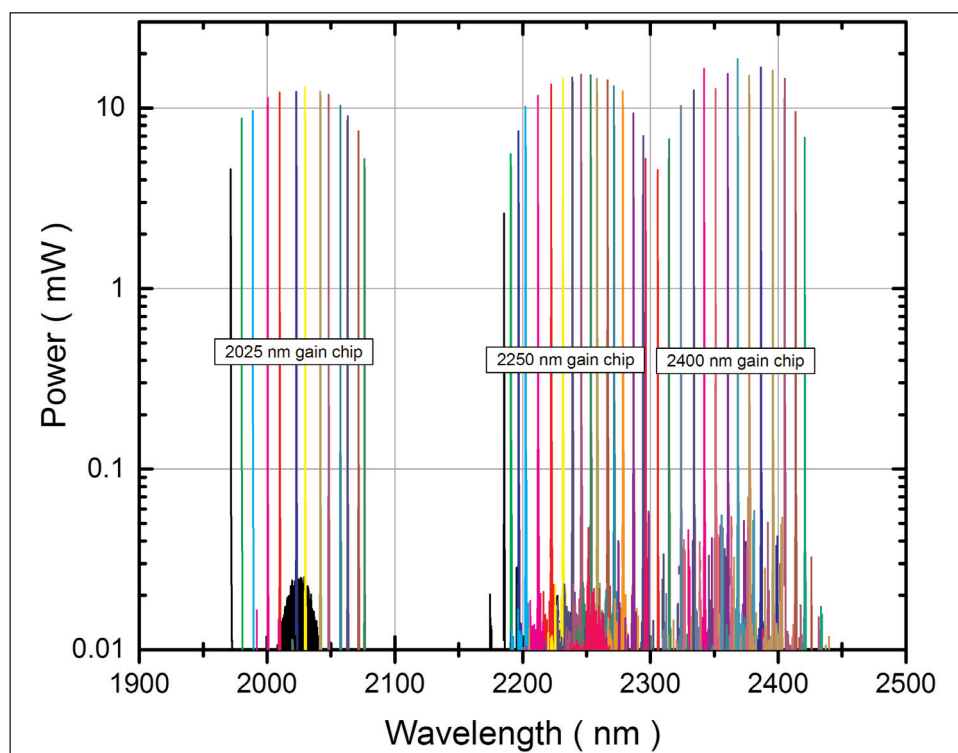
Brolis launches mid-infrared gain chips for tunable spectroscopy at 1900–2500nm

Brolis Semiconductors Ltd of Vilnius, Lithuania has introduced ultra-broad gain and high-output-power single-angled-facet (SAF) chips for demanding tunable spectroscopy applications at 1900–2500nm.

Established by brothers Augustinas Vizbaras, Kristijonas Vizbaras and Dominykas Vizbaras in 2011, Brolis specializes in mid-infrared type-I gallium antimonide (GaSb) laser diodes and molecular beam epitaxy (MBE). Based on the proprietary technology, the new chips deliver >100nm/chip tunable single-mode emission with side-mode suppression ratio (SMSR) of more than 25dB and CW output power of 5–20m. The output beam is strictly TE₀₀ mode.

The new products are supplied in TO5 or C-mount packages. The output beam direction is normal to the package output plane.

www.brolis-semicon.com



CW output vs wavelength of three different gain chips in Littrow configuration.

ProPhotonix adds new visible laser diodes from Ushio

ProPhotonix Ltd of Salem, NH, USA, a designer and manufacturer of laser diode modules and LED illumination systems for OEMs and medical equipment companies (as well as a distributor of laser diodes for Panasonic, Ushio, Osram, QSI, and Sony), has added two new visible laser diodes from Ushio Opto Semiconductors Inc to its product catalog.

The HL40033G offers high optical output power (100mW) at a wavelength of 405nm and is suited to use in direct imaging for PCBs, industrial applications, display and biomedical applications.

The HL63253MG (a 450mW, 638nm laser diode) is also now available, offering a solution for laser projectors, show lasers as

well as laser modules.

"The launch of these new laser diodes from Ushio broadens the range of solutions ProPhotonix offers its customers, providing greater choices for their product requirements," says Jeremy Lane, managing director of Laser operations.

www.prophotonix.com

ProPhotonix extends laser diode module range with 488nm blue Photon module

ProPhotonix Ltd of Salem, NH, USA, a designer and manufacturer of laser diode modules and LED illumination systems for OEMs and medical equipment companies (as well as a distributor of laser diodes for Panasonic, Ushio, Osram, QSI, and Sony), has extended its Photon laser module series to include the new 488nm Photon module.

Designed as a complete solution for OEM use, the compact and self-contained design of the Photon laser diode module range offers high reliability and is available with CW or TTL modulation, says ProPhotonix. The 488nm Photon laser module is available with output powers of 5mW, 10mW and 20mW. Elliptical spot and line options are also available. Applications include alignment, fluorescence, spectroscopy and particle measurement in industrial, medical & bio-medical sectors.

"The extension of the Photon range, to incorporate the 488nm, demonstrates our commitment to integrating the latest in laser diode technology into our modules for our OEM customers," says Jeremy Lane, managing director of Laser Operations at ProPhotonix.

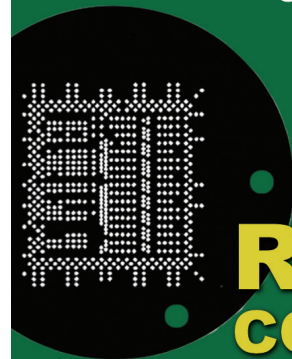
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Marktech opens its first photodetector production facility in California

Emitter and LED maker expands to Si and InGaAs detectors

Marktech Optoelectronics of Latham, NY, USA, whose capabilities span wafer growth through finished packaging and custom solutions, has officially opened its first detector manufacturing facility in Semi Valley, California.

The new plant will feature a class 1000 cleanroom and will focus on standard and custom photodetectors using both silicon and indium gallium arsenide (InGaAs). Standard packages include TO-5, TO-18, TO-39 and TO-46 with a variety of lens



New business unit manager Barry Jones.

detection area since we have focused on both IR and visible

options. Custom-designed products include chip-on-board (CoB) types, modules and hybrids with built-in electronics.

"This is a major step for us, moving into the

emitters and LEDs," says Marktech's president William Moore.

Heading up the new venture is Barry Jones, who has more than 34 years of experience in the design and manufacturing of optoelectronic detection and RF microelectronic devices. Prior to joining Marktech, Jones served in various positions including CEO and general manager of Pacific Silicon Sensor Inc and operations manager at Centro Vision Inc in California.

www.marktechopto.com

Marktech launches photodetector range

Marktech Optoelectronics launched its new line of photodetectors at Photonics West (7-12 February).

Made in Marktech's new California facility, the photodetectors include a wide array of products ranging from 250nm to 2.6µm including specialty photodetectors (GaP Schottky), standard photovoltaic silicon photodiodes, silicon phototransistors, silicon avalanche photodiodes (APDs), InGaAs PIN photo-



diodes and InP PIN photodiodes.

"For 30 years we have been focused on the emission side of

sensors," notes CEO Mark Campito. "Our new California facility allows us to offer our customers a large selection of both standard and custom detectors for complete solutions from one source."

These photodetectors join Marktech's wide range of emitter sensors ranging from deep UV 280nm to 1720nm short-wave infrared and InGaAs/InP epitaxial wafers from 1.0µm to 2.6µm.

SUWTECH launches high-power fiber-laser pump module

At the SPIE Photonics West 2015 event in San Francisco, CA, USA (7-12 February), II-VI SUWTECH of Shanghai, China (part of II-VI Inc of Saxonburg, PA, USA, which provides amplification solutions for next-generation optical networks) introduced a high-power fiber-coupled diode pump module platform that will offer scalability for different power levels up to 300W with different emitter and fiber configurations (105µm and 200µm fiber core). With more emitters integrated, the single-emitter-based platform offers increased brightness.

The high-brightness pump enables fiber-laser manufacturers

to generate higher pump power levels using fewer modules, allowing them to increase pump block efficiency, design more compact pump configurations, and simplify their packaging, says the firm. A novel optical scheme delivers light into the fiber with high coupling efficiency, and a controlled under-filled numerical aperture (NA) - along with a cladding mode stripping feature - allows increased reliability and reduced losses at the combiner. A compact housing aids thermal management. Integrated design and fewer components enable high volume with high manufacturing efficiency with high consistency in module-to-module

performance, claims the firm.

II-VI also offers unique 300W per port Nx1 high-power combiners with the modules together that can handle 300W per input port. High-power Nx1 multimode combiners enable high-efficiency combining of multiple high-power pump sources into a single output fiber. Up to 31 input ports are available, corresponding to multi-kilowatt power handling capability. All II-VI Photonics combiners conform to stringent environmental and mechanical standards to give high reliability and long lifetime for all field applications, the firm adds.

www.phototech.com/main/products_jg/Laser.php

Northwestern demonstrates MWIR imaging at high temperature

InAs/GaSb type-II superlattice targets compact, less costly and more portable detectors for surveillance and disease detection

Researchers at Northwestern University's Center for Quantum Devices (CQD) have developed an indium arsenide/gallium antimonide (InAs/GaSb) type II superlattice that demonstrates high-resolution mid-wavelength infrared (MWIR) imaging while operating at high temperatures (Chen et al, *Optics Letters*, vol. 40, issue 1, p45-47 (2015)).

MWIR radiation (with a wavelength of 3–5 μ m) has a wide range of applications, from aerial surveillance to cancer detection. As the uses for high-sensitivity, high-resolution imaging continue to expand, MWIR sources are becoming more attractive.

However, currently, commercial technologies for MWIR detection, such as indium antimonide (InSb)

and mercury cadmium telluride (MCT), can only operate at cryogenic temperatures in order to reduce thermal and electrical noise.

"A higher operating temperature eliminates the need for liquid nitrogen," says Manijeh Razeghi, the Walter P. Murphy Professor of Electrical Engineering and Computer Science and director of the CQD. "That makes detectors more compact, less expensive, and more portable," she adds.

In Northwestern's device, a 320 \times 256-pixel unipolar focal plane array (FPA) using pMp architecture exhibited what was reckoned to be excellent infrared imaging from 81K to 150K as well as about 98% operability, illustrating the possibility for high-temperature operation. At 150K and –50mV operation bias,

the 27 μ m pixels exhibited dark current density of 1.2 $\times 10^{-5}$ A/cm², with 50% cutoff wavelength of 4.9 μ m, quantum efficiency of 67% at peak responsivity (4.6 μ m), and specific detectivity of 1.2 $\times 10^{12}$ Jones.

With MWIR cameras being capable of passive infrared imaging, Northwestern says that its new technique was particularly successful at obtaining infrared images of the human body, which has potential for vascular imaging and disease detection.

The research was supported by US Defense Advanced Research Projects Agency (DARPA), the Army Research Laboratory, Air Force Research Laboratory, and NASA.

www.opticsinfobase.org/ol/abstract.cfm?uri=ol-40-1-45
<http://cq.d.eecs.northwestern.edu>

Princeton Optronics' VCSEL arrays help Google's project Tango to make mobile displays 3D

Princeton Optronics Inc of Mercerville, NJ, USA, which manufactures high-power single- and multi-mode vertical-cavity surface-emitting lasers (VCSELs) and VCSEL arrays, says it is working with Google's Advanced Technology and Projects group (ATAP) on the development and deployment of compact mobile imaging systems that will enable users to interact with their environments in three dimensions.

"Mobile devices today assume that the physical world ends at the boundaries of the screen," comments Google ATAP's Johnny Lee (who is leading Project Tango) in a recent YouTube video. "Our goal is to give mobile devices a human-scale understanding of space and motion," he adds.

A key component in the Tango system is an illumination source

which serves to enhance and expand the 3D space that the system can see. The highest power conversion efficiency in the industry and low speckle make Princeton Optronics' VCSEL arrays suitable illumination devices for 3D applications, claims the firm. Additionally, the ability to be surface mounted and manufactured in high volume using conventional semiconductor processing means that VCSEL arrays are well suited to high-volume consumer electronics applications.

Princeton Optronics recently received approval for two patents (US Patent numbers 8,675,706B2 and 8,783,893B1) for surface-mounted VCSELs for illumination applications that uniquely positions them for this market, the firm reckons.

The arrays can be packaged in a variety of configurations for high-volume applications, very similar to LEDs. They can be operated reliably up to 80°C and do not require a hermetically sealed housing, reducing packaging costs. Chip sizes range from 0.1mm² to 25mm² and output powers range from several milliwatts to hundreds of watts. Also, optics can be added to the package, creating greater options for beam handling in the customer's illumination system.

Sample devices are immediately available at 850/860nm and other selected wavelengths in the 650–1100nm region. Other wavelengths can be fabricated according to custom request.

www.princetonoptronics.com
www.google.com/atap/projecttango/#project

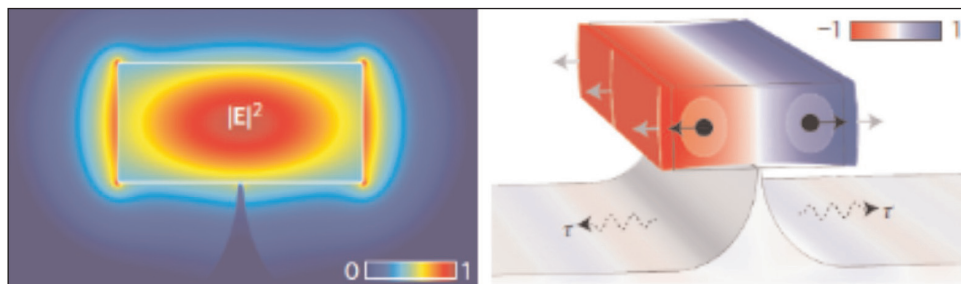
Ghent University and Imec demonstrate interaction between light and sound in nanoscale waveguide

Silicon photonics enables light–matter interaction via stimulated Brillouin scattering

Researchers at Ghent University and nanoelectronics R&D center Imec of Leuven, Belgium have demonstrated interaction between light and sound in a nanoscale area using a silicon photonic nanowire (R. Van Laer, B. Kuyken, D. Van Thourhout and R. Baets. 'Interaction between light and highly confined hypersound in a silicon photonic nanowire', *Nature Photonics* (2015) <http://dx.doi.org/10.1038/nphoton.2015.11>). Their findings are said to elucidate the physics of light-matter coupling at these scales, and pave the way for enhanced signal processing on mass-producible silicon photonic chips.

In the last decade, silicon photonics has gained increasing attention as a key driver of lab-on-a-chip biosensors and of faster-than-electronics communication between computer chips. The technology builds on silicon photonic nanowires carrying optical signals from one point to another at the speed of light. They are fabricated with the same toolset as microelectronic circuits.

Fundamentally, the wires work only because light moves more slowly in the silicon core than in the surrounding air and glass, trapping light inside the wire by total internal reflection. But manipulating the



Both light (left) and sound (right) are trapped in a nanoscale silicon core.

light is not easy, because one light beam cannot easily change the properties of another. However, light–matter interaction can allow photons to control other photons.

Researchers from the Photonics Research Group of Ghent University and Imec have reported a type of light-matter interaction where they managed to confine not only light but also sound to the silicon nanowires. Oscillating 10 billion times per second, the sound cannot be trapped in the wire by total internal reflection. Unlike light, sound moves faster in the silicon core than in the surrounding air and glass. So, the researchers sculpted the environment of the core to make sure that any vibrational wave trying to escape it would actually bounce back. They hence confined both light and sound to the same nanoscale

waveguide core, which is claimed to be a world's first observation.

Trapped in that small area, the light and vibrations strongly influence each other: light generates sound and sound shifts the color of light, via the process of stimulated Brillouin scattering. The researchers exploited this interaction to amplify specific colors of light. They anticipate that this demonstration will open up new ways to manipulate optical information. For example, light pulses could be converted into sonic pulses and back into light, implementing much-needed delay lines. The researchers also expect that similar techniques could be applied to even smaller entities such as viruses and DNA, which have unique acoustic vibrations that may be used to probe their global structure.

www.imec.be

Alfalight receives \$1.9m Raytheon contract to deliver laser subsystems for aerospace application

Alfalight Inc of Madison, WI, USA, which designs and makes infrared and visible laser and electro-optical systems for defense and security applications, has received a contract to deliver laser modules for an aerospace system built by Raytheon Space and Airborne Systems (SAS). The 18-month contract has a value of \$1.9m, with an option to increase the total to \$3.1m later in 2015.

Alfalight has received the Supplier Excellence Award from Raytheon for "exceptional" quality and delivery of its high-performance, ruggedized laser diode subsystems. Alfalight first qualified to provide the lasers to Raytheon for this application in 2007.

"This contract is evidence of the value of Alfalight's technology and our long-term success as a supplier

of lasers to the defense market," says president & CEO Mohan Warrior. "This new business and our strong relationship [with Raytheon Space and Airborne Systems] underscore many years of dedication to designing and manufacturing rugged, integrated laser systems for the most demanding and critical applications," he adds.

www.alfalight.com

Advanced Photonix to merge with Luna Innovations

Combined annual revenues total nearly \$50m

Advanced Photonix Inc (API) of Ann Arbor, MI, USA (which designs and makes APD, PIN, and FILTRODE photodetectors, HSOR high-speed optical receivers, and T-Ray terahertz instrumentation) and Luna Innovations Inc of Roanoke, VA, USA (which manufactures fiber-optic sensing and test & measurement products for the telecoms, aerospace, automotive, energy and defense markets) have agreed to merge.

API stockholders will receive shares of Luna common stock at a ratio of 0.31782 for each share of API common stock owned by them. After mailing existing stockholders with a joint proxy statement/prospectus — filed in a Registration Statement on Form S-4 with the US Securities and Exchange Commission (SEC) — API and Luna will each hold stockholder meetings for approval of the merger and issuance of Luna stock, respectively.

It is reckoned that the combined firm will provide greater capability across a broader market base, with a strong balance sheet and potential operating synergies. The merged company will have pro forma combined revenue for the 12 months to end-September 2014 of \$49.9m (\$29.9m for API; \$20m for Luna). The cost savings resulting from a single public company infrastructure should better position it for improved profitability, it is added. The combined firm will also have significant intellectual property protection for the technologies in its product portfolio, with over 200 patents and patent applications.

The combined company will have a foundation from API's High Speed Optical Receiver (HSOR) and Optosolutions product lines and Luna's core test & measurement products, enabling continued investment in the growth of areas such as Luna's strain & temperature sensing business and API's next generation of receivers and detectors. Additionally, the plan is

to continue developing a pipeline of technologies for future commercialization in Luna's Technology Development Division and API's Terahertz operations. "The combined product lines will strengthen the merged company's position in the marketplace by offering more for each customer," says API's president & CEO Richard Kurtz.

"This merger will enable us to provide even greater capability across a broadened market base, providing improved opportunity for growth," says Luna's president & CEO My Chung. "Joining forces with a company like API will help us accelerate our path to profitability," he adds.

"We're creating a significantly stronger company through the combination of Luna's proven technology with API's components and subsystems," comments Luna's chairman Richard Roedel.

The merged firm will be have optical technol-

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ogy based products serving the telecom markets and the non-destructive testing (NDT) market. "With this strong balance sheet combined with significant savings that will be realized from the elimination of public company costs, it will enable continued investment in our combined organic growth platforms of HSOR, Terahertz and Luna's temperature- and strain-sensing instrumentation products," says chief operating officer Robin Risse.

The combined company will keep the Luna name and be headquartered in Roanoke, with My Chung remaining as CEO and a member of the board of directors. The board will be expanded to seven members: the CEO plus six independent directors consisting of three from Luna (Richard W. Roedel as chairman, John B. Williamson III and Michael W. Wise) and three designated by API's board (API's non-executive chairman Donald Pastor plus Gary J. Spiegel and Ed J. Coringrato Jr). Spiegel and Coringrato (who have no prior association with API) formerly served as senior VP of Newport Corp and CEO of CyOptics Inc, respectively. All existing API directors other than Don Pastor will not be involved in the combined entity as directors.

Operationally, API's Steve Williamson and Robin Risse will continue in their current capacities as chief technology officer and chief operating officer, respectively. One CEO and CFO are expected to be eliminated and the aggregate board cost substantially reduced. The Luna suite of officers will continue in their respective positions but API's CEO and CFO will not be part of the merged company once closed. The merger promises to achieve significant savings in the aggregate compensation cost incurred by the two companies.

www.advancedphotonix.com
www.lunainc.com

Oclaro's core communications revenue grows 4% quarter-to-quarter

100G grows almost 60%, rising from 24% of sales to 40%

For its fiscal second-quarter 2015 (ended 27 December 2014), Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications) has reported revenue of \$86.8m, down 15.6% on \$102.9m a year ago and 2.7% on \$89.2m last quarter but at the high end of the \$80–88m guidance range.

By end-market (as a proportion of total revenue), Telecoms business comprised 52%, Datacoms 46% and Industrial & Consumer 2% (compared with 8% last quarter).

The Industrial & Consumer (I&C) business in Komoro, Japan (sold on 27 October 2014 to Japan's Ushio Opto Semiconductors Inc) contributed \$1.8m of revenue in fiscal Q2 and \$7.5m in fiscal Q1. However, excluding I&C, core communications revenue was \$85m, up 4% on \$81.7m last quarter.

Revenue growth was driven largely by 100G, which increased by almost 60% quarter-on-quarter (rising from 24% of total sales to almost 40%). "The expansion of our 100G business is the cornerstone of our growth plan. Therefore, we have decided to start breaking out 100G separately from 40G," says CEO Greg Dougherty. As expected, there were continued declines in revenue for both 40G (from 25% of total sales to 22%) and 10G-and-below (from 43% to 37%). "Our recent results validate that our strategy focused on 100G for packet optical transport is indeed working."

Specifically, revenue growth was primarily due to 100G client-side pluggable transceivers, lithium niobate modulators, and narrow-linewidth micro-iTLA lasers. "We saw our 100G client-side business achieved record revenue levels, driven by two factors. One, the market in China bounce backed, as we predicated on our last call. Two, we saw an increase in the

adoption of 100G client interfaces in high-end router platforms," says Dougherty. "We continue to see steady progress in growth from our 100G lithium niobate and our micro-iTLA product lines. Both of these businesses are ramping nicely and we expect to see continued growth."

By region, China rose from 23% to 29% of total revenue, while the Americas fell from 32% to 30%, South-east Asia fell from 20% to 18%, and Japan fell further, from 4% to 2%. Europe was level with last quarter, at 21%. There were three greater-than-10% customers: Coriant (dropping from 26% last quarter to 20% as its 40G business fell), Huawei (rising from 11% to 15%) and Alcatel-Lucent (returning as a 10% customer, representing 12.5%), while Cisco fell below 10%.

On a non-GAAP basis, gross margin was 16.5%, down from 16.9% a year ago but level with last quarter and at the high end of the 13–17% guidance range, as a richer mix of 100G products offset the loss of the I&C business' positive contribution.

Operating expenses were \$24.2m, down 15% on \$28.4m last quarter (due equally

to a reduction in I&C-related cost, the absence of year-end audit fees and favorable foreign exchange rates) and down 30% on \$34.2m a year ago (as a result of restructuring programs that have significantly reduced R&D spending from \$16m to \$11.3m and selling, general & administrative spending from \$18.2m to \$12.9m).

With depreciation of \$4.3m, adjusted EBITDA (earnings before interest, taxes, depreciation and amortization) was negative \$5.5m, cut from \$8.9m last quarter and \$10.7m a year ago, and better than the guidance range of negative \$10m to negative \$6m. Also, excluding the positive adjusted EBITDA contribution from I&C of \$1.9m in fiscal Q1, continuing operations requirements improved by 50% quarter-to-quarter, attributed to the continued improvement in cost structure and good execution on the firm's 100G strategy.

In addition to the adjusted EBITDA of –\$5.5m, cash reserves were impacted by the timing of a net \$10m accounts payable payment carried over from fiscal Q1, an increase in accounts receivable of \$8m, and capital expenditure (CapEx) of \$4.5m (compared with \$4.7m last quarter). All this was offset by a net \$14m received from the sale of the I&C business. Total cash, cash equivalents, restricted cash and short-term investments hence fell during the quarter from \$94m to \$79m.

"Market demand for 100G in both telecom and datacom continues to build and we expect to leverage our products and technology to drive future revenue growth," says Dougherty. "We expect 40G to continue to ramp down over the next 12–18 months," he adds. "While our overall 10G revenue came down [in fiscal Q2], we are seeing strong demand for our tunable 10G transceiver business."

The expansion of our 100G business is the cornerstone of our growth plan. As expected, there were continued declines in revenue for both 40G (from 25% of total sales to 22%) and 10G-and-below (from 43% to 37%). Our recent results validate that our strategy focused on 100G for packet optical transport is indeed working"

► For fiscal third-quarter 2015 (ending 28 March), Oclaro expects revenue to fall seasonally to \$78–85m (including the majority of the impact of the expected 10–15% annual price reductions negotiated in the December quarter). Gross margin should be 13–17%. Adjusted EBITDA is expected to be between –\$9m and –\$5m.

“Our recent results demonstrate that we are steadily making progress in achieving our financial and business objectives [towards adjusted EBITDA breakeven and then positive operating income],” says Dougherty. “Over the last year, we’ve reduced the level of [quarterly] revenues needed in our adjusted EBITDA breakeven model from \$110m to \$100m through a combination of cost reduction and improved operating performance,” he adds. “Given our revenue growth, mix of products and our continued vigilance on cost cutting, we now believe that adjusted

EBITDA breakeven is achievable at revenue of \$90–95m. We expect to hit these targets while still continuing to invest heavily in R&D. We also believe that this updated revenue target is obtainable in the current calendar year.” Oclaro expects CapEx to rise to \$5–8m per quarter to support growth.

“Our improved financial results reinforce the effectiveness of our turnaround plan,” says Dougherty. “We plan to continue to drive improvement in our cost structure throughout the quarters ahead to build a successful and sustainable company,” he adds. “As we begin calendar year 2015, we turn our attention to our growth strategy. We are focused on realizing our ambition to be the market leader in 100G optics again for long-haul, metro, enterprise and data-center networks.”

“We completed our alpha builds in Q2 of CFP2 coherent products and are very encouraged by the initial

performance that our customers are experiencing... The modules are working well with seven different DSPs,” notes Dougherty. “Now entering the beta phase, the CFP2 coherent products are not expected to contribute meaningful revenue until late in calendar year 2015. We believe that the availability of plug-gable coherent modules will be quickly embraced to long-haul and metropolitan applications,” he adds.

“Additionally, we are seeing demand growth of these modules for data-center interconnects, representing a new and potentially significant market opportunity,” Dougherty says. “We continue to have much stronger demand than we concurrently satisfy as we go through the typical ramp start-up process for our pilot-production line. We are very focused on successfully ramping the coherent CFP2 into production as it is a key requirement for achieving our growth objectives.”

Oclaro completes placement of \$65m of 6% convertible notes

Oclaro has completed its private placement of \$65m of 6% convertible senior notes due 2020. This includes the purchase of \$10m of notes by the initial purchaser exercising its over-allotment option. The notes were offered and sold to qualified institutional buyers by the initial purchaser.

The notes mature on 15 February 2020 and will bear interest at a fixed rate of 6% per year, payable on 15 February and 15 August of each year, from 15 August 2015.

The notes will be general senior, unsecured obligations of Oclaro. They will not be redeemable at Oclaro’s option prior to 15 February 2018. On or after that date, the notes will be redeemable at Oclaro’s option if the last reported sale price of the firm’s common stock for at least 20 trading days (which need not be consecutive) in any 30 trading day period exceeds 130% of the conversion price for the notes. The redemption price will equal

100% of the principal amount of the notes being redeemed, plus accrued and unpaid interest, including additional interest (if any) up to, but excluding, the redemption date plus the sum of the present values of each of the remaining scheduled payments of interest that would have been made on the notes being redeemed had they remained outstanding from the redemption date to the maturity date.

In addition, upon the occurrence of a fundamental change, holders of the notes will have the right, at their option, to require Oclaro to repurchase their notes in cash at a price equal to 100% of the principal amount of the notes to be repurchased, plus accrued and unpaid interest up to (but excluding) the fundamental change repurchase date.

The notes will be convertible, at the option of the holders, into consideration consisting of shares of Oclaro’s common stock (and cash

in lieu of fractional shares) at any time prior to the close of business on the day immediately preceding the maturity date on 15 February 2020.

The initial conversion rate is 512.8205 shares of Oclaro’s common stock per \$1000 of notes (equivalent to about \$1.95 per share). The conversion rate will be subject to adjustment upon the occurrence of certain events. In addition, Oclaro may be obligated to increase the conversion rate for any conversion that occurs in connection with a make-whole fundamental change and with Oclaro’s delivery of a notice of redemption for the notes.

The net proceeds to Oclaro from the private placement were about \$61.1m, after deducting the initial purchaser’s discounts and commissions and estimated offering expenses. Oclaro intends to use the net proceeds for general corporate purposes, including working capital.

www.oclaro.com

JDSU reports quarterly 40G/100G transmission optical component revenue growth of 30% year-on-year

Investment spending in 100G metro expected to begin this year

For its fiscal second-quarter 2015 (ended 27 December 2014), JDSU of Milpitas, CA, USA has reported revenue of \$437.1m, up 0.8% on \$433.6m last quarter but down 2.3% on \$447.6m a year ago (and at the lower end of the \$433–457m guidance range). However, excluding about \$25m of 3D sensing and OSP last-time-buy revenues a year ago, core network laser and anti-counterfeiting businesses' combined revenue grew 3.5% year-on-year.

The Americas (\$189.5m), Asia-Pacific (\$149.9m) and EMEA (\$97.7m) represented 43.3%, 34.3% and 22.4%, respectively, of total revenue, compared with 44.7%, 31.1% and 24.2% last quarter and 47.8%, 28.8% and 23.4% a year ago.

By application sector, revenue for Network Enablement (NE) was \$133.7m (30.6% of total revenue), up 0.7% on \$132.8m last quarter but down 14.2% on \$155.8m a year ago (and below the \$135–145m guidance), reflecting weak US carrier spending, partially offset by growth in mobility. Revenue for Service Enablement (SE) was \$45.7m (10.5% of total revenue), up 16.6% on \$39.2m a year ago but down 5.2% on \$48.2m last quarter (and below the \$47.5–52.5m guidance range).

Revenue for Optical Security and Performance Products (OSP) was \$50.6m (11.6% of total revenue), up 16.9% on \$43.3m last quarter (reflecting growth in anti-counterfeiting business and a slight increase in government business) and just above the mid-point of the \$49–51m guidance range, but down 7.3% on \$54.6m a year ago (reflecting the exit from lower-margin business, which contributed about \$6m a year ago).

Revenue for Communications and Commercial Optical Products (CCOP) was \$207.1m (47.3% of

total revenue), down 1.1% on \$209.3m last quarter but up 4.6% on \$198m a year ago (and above the mid-point of the \$200–210m guidance range).

Of this, CCOP's Commercial Laser revenue was \$40m, marking a third consecutive quarter at or over \$40m, up 70.2% on \$23.5m a year ago. In particular, fiber-laser revenue rose by 20.1% from \$12.4m last quarter to a record \$14.9m, driven by strength in Gen2 kilowatt fiber lasers for industrial cutting applications.

CCOP's Optical Communications revenue was \$167.1m, level with last quarter but down 4.2% on \$174.5m a year ago, reflecting lower 3D sensing revenue (down from \$22m last quarter to \$14m) partially offset by higher Telecom revenue and record Datacom revenue (up 17.2% on last quarter). In particular, revenue for higher-speed transmission (40G and 100G) is up 30.3% year-on-year (growing from 43% of overall transmission revenue a year ago and 48% last quarter to 49%).

Sales mix was 73% Telecom, 21% Datacom and 6% Consumer & other (compared with 69%, 17% and 14% a year ago, respectively). The shifts reflect revenue growth in datacoms of 16.4% year-on-year, driven by new products and design wins, notably in the 100G, CFP2 and CFP4 product lines and the substantial reduction in 3D sensing revenue.

The quarter-on-quarter decline in the average selling price (ASP) for Optical Communications components was 3.1% (in line with the expected 10–14% year-on-year for full-year fiscal 2015).

On a non-GAAP basis, gross margin has grown further, from 48.5% a year ago and 49% last quarter to 49.1%, with gains in each business segment reflecting continued operational discipline, favorable

product mix from SE, strength in Commercial Lasers, and OSP's last-time-buy product exits last year.

In particular, CCOP gross margin has grown from 32.3% a year ago and 32.5% last quarter to 33.4%. This was due mainly to higher product mix of Commercial Lasers (for which gross margin rose from 49.4% a year ago and last quarter's record of 50.7% to a new record of 51.8%). In contrast, Optical Communications gross margin was 29%, down from 30% a year ago (reflecting primarily a product mix shift from the decline in 3D sensing revenue) although it has begun to bounce back from a low of 27.9% last quarter.

Aided by strong cost controls (cutting operating expenses sequentially from \$173m to \$171.6m), adjusted operating margin was 9.9% (above last quarter's 9.1% and exceeding the mid-point of the 8.5–10.5% guidance range, but below 11% a year ago due mainly to higher R&D investments). However, CCOP operating margin in particular has grown from 12.1% a year ago to 12.8% (exceeding the 10.5–12.5% guidance range).

"We continue to experience the benefits of diversification and product differentiation, which drove strength in both gross margin and operating margin at the higher end of the guidance range even as US carrier spend impacted revenue," says president & CEO Tom Waechter.

Net income was \$35.4m (\$0.15 per share), up from \$33.8m (\$0.14 per share) last quarter but down from \$45.3m (\$0.19 per share) a year ago due to lower revenue, higher operating expenses and higher income tax.

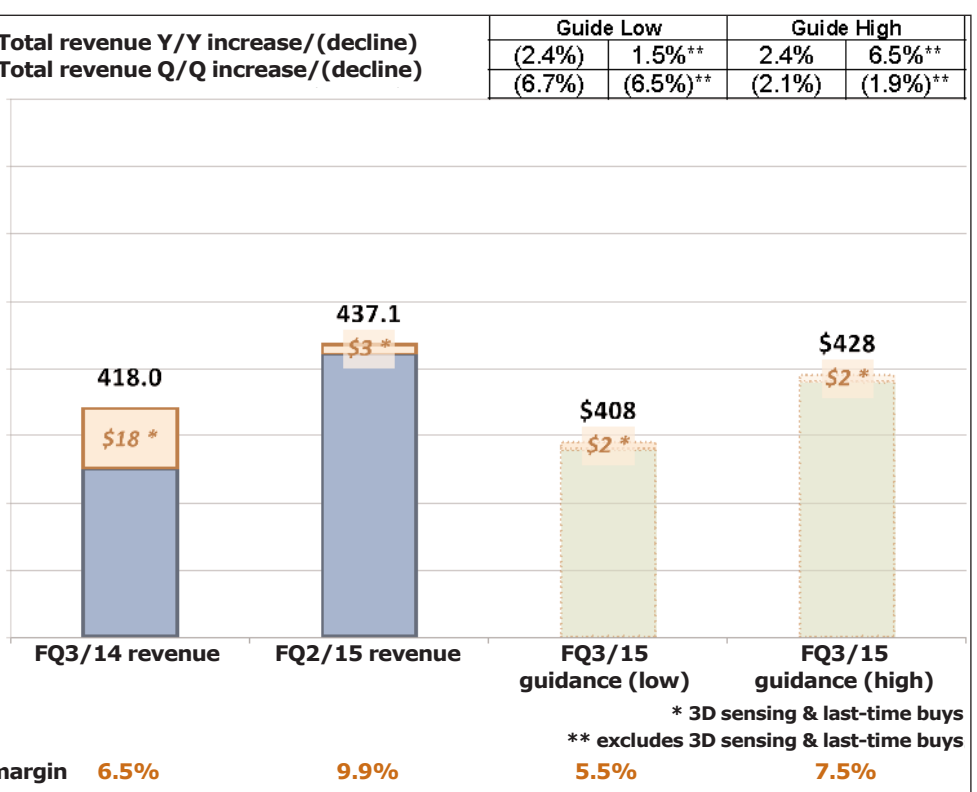
Operating cash flow generation has fallen from \$54.4m a year ago and \$40.8m last quarter to \$16.6m (due principally to lower collections during the quarter and higher payables entering the quarter). ➤

► During the quarter, total cash and investments fell from \$880.9m to \$867.6m.

For fiscal third-quarter 2015 (ending 28 March), JDSU expects revenue of \$418m±10m, seasonally down on last quarter but level with \$448.6m a year previously. However, excluding about \$16m in revenue a year ago due to 3D sensing and OSP last-time buys, revenue should be up 4% for the core networking and commercial laser business. In particular, for CCOP, JDSU expects revenue of \$195m±\$5m (compared with \$194.6m a year previously, with increased Optical Communications revenue replacing \$8m

lower 3D sensing revenue) and CCOP operating margin of 9.5%±1% (below target, due to lower Commercial Lasers revenue, reflecting seasonally soft micro-machining sales as well as lighter fiber-laser revenue due to near-term product mix shifts and demand from 4kW to 2kW lasers). Overall company operating margin should fall to 6.5%±1%. Earnings per share should fall to \$0.09±\$0.02.

"While the March quarter is seasonally weak quarter, there are encouraging macro trends that are expected to benefit our business in calendar 2015," says Waechter. "Investment spending in the 100G metro market appears likely to begin this year, while Web 2.0 providers are continuing to deploy



JDSU's guidance for the March quarter.

significant capital in both 40G and 10G infrastructure upgrades," he adds. "In lasers, we recently announced the 2kW direct-diode laser that is expected to replace many CO₂ lasers used in sheet metal cutting," Waechter continues. "Additionally, our 6kW fiber laser product will enable us to expand the same opportunity in the welding market."

On 10 September, JDSU announced plans to separate into two publicly traded companies (to be named at a later date): an optical components and commercial lasers company ('SpinCo') consisting of JDSU's CCOP segment, and a network and service enablement

company ('NewCo') consisting of JDSU's NE, SE and OSP segments. JDSU expects the separation to be completed by calendar third-quarter 2015. "We plan to file a Form-10 registration statement for SpinCo and to announce a new branding for both companies later this quarter," says executive VP & chief financial officer Rex Jackson. JDSU reckons it is on track to execute on \$50m of annual cost reductions, once restructuring is complete. The estimated cash requirements for the separation remains \$75–100m. "Our goal is to take substantially all associated charges in fiscal 2015," says Jackson.

www.jdsu.com

JDSU receives Fujitsu's 2015 Distinguished Partner Award

Japanese electronics firm Fujitsu has granted JDSU of Milpitas, CA, USA its 2015 Distinguished Partner Award at its recent supplier event in Tokyo, Japan (which included more than 600 attendees).

JDSU was the only optical solutions vendor recognized out of a base of about 300 suppliers. Only 15

suppliers were recognized overall.

JDSU received the award for its "long-standing relationship with Fujitsu and for its continued contribution of next-generation optical solutions to Fujitsu's network business". JDSU provides a wide range of technology to Fujitsu that support increasingly flexible and faster

network architectures.

"We look forward to continuing our long and close partnership with Fujitsu to help them stay ahead of the rapid pace of change happening in optical networks today," says Alan Lowe, president of Communications and Commercial Optical Products at JDSU.

JDSU launches five kW-class turnkey laser systems for materials processing

JDSU of Milpitas, CA, USA is introducing five new kilowatt-class turnkey fiber laser and direct-diode laser systems for use by machine tool manufacturers for macro-materials processing applications.

The new turnkey products were designed by cutting machine manufacturer AMADA, a JDSU collaborative partner. The new systems include JDSU's CORELIGHT Series fiber laser and direct-diode laser engines. Products will be available in second-half 2015.

At the 2015 SPIE Photonics West exhibition in San Francisco (10–12 February), JDSU showcased the CORELIGHT AJ 2, 4 and 6 kW turnkey fiber laser systems for high-speed sheet metal cutting, precision welding and a broad range of additional macro materials processing applications. Each AJ system incorporates JDSU's CORELIGHT YLE Series fiber laser engine and includes an industry-standard electrical and optical interface.

JDSU is also showcasing the CORELIGHT ExC 2 kilowatt and 4 kilowatt turnkey direct-diode laser systems for improved high-speed

thick sheet metal cutting, welding, and surface treatment applications. Each ExC system incorporates JDSU's CORELIGHT DLE Series direct-diode laser engine and also includes an industry-standard electrical and optical interface.

JDSU notes that fiber lasers and direct-diode lasers are gaining momentum over CO₂-based cutting systems for metal processing because of the advantages they provide, including higher cutting speeds, improved cutting quality, increased energy efficiency and lower maintenance requirements. These benefits in turn result in significantly lower overall costs for metal processing manufacturers, adds the firm.

According to Strategies Unlimited, direct-diode lasers are growing as one of the solutions to replace traditional CO₂ lasers for metal processing and the market is projected to increase at a compound annual growth rate (CAGR) of 15.3% from 2012–2017, to \$237m. The industry analyst firm also reports that the benefits of kW fiber lasers over CO₂ are driving them to grow at a

projected CAGR of 17.5% from 2012–2017, to revenue of \$780m.

"For more than seven years, JDSU and Amada have collaborated on developing the industry's most innovative laser solutions for macro materials processing," says Alan Lowe, president of JDSU's Communications and Commercial Optical Products (CCOP) business segment. "The new turnkey fiber laser and direct-diode laser systems complement our innovative fiber laser and direct-diode laser engine portfolio and provide the ability for end-users to cost effectively improve production speed and processing quality," he adds.

High-power fiber laser and direct-diode laser systems are used to cut parts from sheets of aluminum and steel for the manufacturing of automobiles, aircraft and commercial and consumer appliances. They are increasingly used for welding, material deposition (cladding) and large-scale surface treatment applications in a significantly more efficient manner compared with traditional non-laser processes.

www.jdsu.com

GigOptix launches 32G quad-channel linear modulator driver for coherent CFP and CFP2 modules in metro applications

GigOptix Inc of San Jose, CA, USA (a fabless supplier of analog semiconductor and optical communications components for fiber-optic and wireless networks) has launched the GX62476 linear quad-channel modulator driver for low-power coherent metro applications.

The firm says that the GX62476 extends its telecom driver market leadership position into metro applications with a quad-channel, 32Gbps solution offering what is claimed to be the lowest power dissipation of less than 1.1W/channel

at a 5V_{pp} swing using a 5V supply voltage and 0.75W/channel at a 3V_{pp} swing using a 3.3V supply.

The GX72476 linear driver is optimized for use with available low-drive-voltage lithium niobate and indium phosphide (InP) optical modulators, requiring single-ended drive to provide low power consumption with what is claimed to be the best linearity solution in a small-form-factor SMT package for coherent CFP and CFP2 modules.

The GX62476 was designed for very low total harmonic distortion,

at both 5VPP and 3VPP, and very low group delay variation to address linear coherent metro applications. It also has a 27GHz typical 3dB bandwidth and provides for adjustable output voltage. The miniaturized SMT package is suitable for the high level of integration required by the CFP2 form factor and reduced power operation requirements.

The GX62476 is sampling now and will ship in full production volumes from second-quarter 2015.

www.gigoptix.com

Emcore's quarterly revenue grows 28.7% to \$18.4m Better-than-expected results for Broadband Fiber Optics business, following sale of PV and Telecoms Fiber Optics businesses

For its fiscal first-quarter 2015 (to end-December 2014), optical component, subsystem and system maker Emcore Corp of Alhambra, CA, USA has reported revenue from continuing operations of \$18.4m, up 28.7% on the September quarter's \$14.3m and up 25.6% on \$14.7m a year ago (and better than the initial guidance of \$14.3m given at the end of September).

"The team put in a solid quarter operationally, while finishing a massive realignment of the business," says Jeffrey Rittichier (CEO since 3 January). Emcore completed its sales of its Space Photovoltaics business on 10 December to SolAero Technologies Corp (for \$150m) and of its Telecommunications Fiber Optics business (tunable laser and transceiver product lines) on 2 January to NeoPhotonics Corp of San Jose, CA, USA (for \$17.5m, comprising \$1.5m in cash and a

note from NeoPhotonics with a two-year maturity and an escalating interest rate). The continuing Broadband Fiber-Optics business includes products for cable television (CATV) and fiber-to-the-premise (FTTP) networks as well as satellite communications, video transport and specialty photonics.

Gross margin has risen from 16.3% a year ago and 14.4% last quarter to 28.1%. This was despite an increase in selling, general & administrative (SG&A) expenses from \$5.7m to \$8.6m due to higher stock-based compensation and severance and compensation expense associated with the sale of the Photovoltaics business.

Operating loss was \$5m, cut from \$5.1m a year ago. On a non-GAAP basis, loss from continuing operations was \$0.9m (\$0.03 per share), an improvement from \$3.9m (\$0.13 per share) a year ago (and

slightly better than the expected \$1–2m). However, including income from discontinued operations of \$59.3m (\$1.90 per share), GAAP net income was \$56.1m (\$1.80 per share), an improvement on a loss of \$2m (\$0.07 per share) a year ago.

During the quarter, cash and cash equivalents rose by \$126.9m to \$147.6m (excluding any consideration from the sale of the Telecommunications Fiber Optics business in January).

For its continuing Broadband Fiber Optics business, for fiscal second-quarter 2015 Emcore expects revenue of \$17–19m.

"With the divestitures of the Photovoltaics business and the Telecommunications business, Emcore has a solid financial foundation and renewed focus on meeting the needs of its customers," comments Rittichier.

www.emcore.com

VLC Photonics introduces multi-project wafer standard design services SOI, PLC, TriPleX, InP custom PIC manufacturing at fixed price per area

Fabless design house VLC Photonics of Valencia, Spain — which provides optical integration solutions and services including photonic integrated circuit (PIC) design or in-house chip characterization and test, together with fabless manufacturing and packaging services — is now offering access to multi-project wafer (MPW) shuttle runs on different generic manufacturing platforms including indium phosphide (InP), silicon-on-insulator (SOI), photonic lightwave circuit (PLC), and LioniX's TriPleX technology.

Currently, MPW manufacturers offer a set of fabrication cells with different areas and prices. VLC is hence introducing what it says is a new concept in custom PIC design — 'MPW Standard Design' — where

service costs for each manufacturer and cell size are offered at a fixed price per area.

"After several years in the market, by serving customers and performing our own R&D using all the MPW manufacturers around the globe, we are ready to offer a frozen price, independent of the chip functionality," explains VLC's founder Pascual Muñoz. "This is the equivalent to generic manufacturing, where costs are fixed by chip area independently of its content and end functionality, but at a design level," he adds.

"The wide range of integration technologies and fabrication platforms makes selecting the best manufacturing approach for each application and device quite difficult

for our customers," states CEO Iñigo Artundo. "We learned our customers value an easy and straight-forward solution that allows them to directly choose the most suited way to prototype their PICs," he adds. Any company with some basic experience of photonic integration will be able to navigate all the MPW design and manufacturing options currently offered by VLC, asserts Artundo. "Customers will also be able to get approximate costs and manufacturing times to configure their own projects immediately," he continues. "Furthermore, they will directly interface our engineers one click after, to clear out any hurdles they may find when facing any integration project".

www.vlcp Photonics.com/mpw

First Solar's revenue grows 13.4% in Q4 to \$1bn

Earnings per share, operating cash flow and bookings exceed guidance

First Solar Inc of Tempe, AZ, USA — which makes thin-film photovoltaic modules based on cadmium telluride (CdTe) as well as providing engineering, procurement & construction (EPC) services — has reported full-year net sales growth of 2.5% from \$3.309bn for 2013 to \$3.392bn in 2014 (below the revised guidance of \$3.6–3.9bn).

For fourth-quarter 2014, net sales were \$1008m, up 13.4% on \$889m last quarter (due to the sale of the Solar Gen 2 project, initial revenue recognition on the Silver State South project, and other projects under construction) and up 31.2% on \$768.4m a year ago. Revenue recognition from the Desert Sunlight and Topaz projects were lower as the projects reached completion.

Net income was \$192m (\$1.89 per fully diluted share), more than doubling from \$88.4m (\$0.87 per fully diluted share) last quarter (due to higher profit from the sale of the Solar Gen 2 project and project cost improvements) and almost tripling from \$65.3m (\$0.64 per fully diluted share) a year ago. Full-year net income has grown from

\$353m (\$3.70 per fully diluted share) in 2013 to \$396.9m (\$3.91 per fully diluted share) to 2014.

Compared with \$47m of cash flow used in operations last quarter, in Q4/2014 cash flow generated from operations was \$928m, up from \$192m a year ago. However, this was due largely to the sale of the Solar Gen 2 project and the collection of retention payments on the Topaz and Desert Sunlight projects. Cash and marketable securities hence rose by \$876m during the quarter to about \$1.991bn. Net cash was \$1.8bn.

"We have exceeded the earnings per share, operating cash flow and bookings targets that we set at our 2014 Analyst Day," notes CEO Jim Hughes. "In addition, we have announced another new record cell efficiency [of 21.5% in February]."

Full-year bookings have grown by 46% from 1.7GW_{DC} in 2013 to 2.5GW_{DC} in 2014. Year-to-date bookings in 2015 so far are 311MW_{DC}. "With our strong bookings, we are well positioned as we enter 2015 and remain focused on executing to our strategy," says Hughes.

First Solar has also announced that it is in advanced negotiations to form a joint YieldCo vehicle with SunPower Corp into which each company expects to contribute a portfolio of selected solar generation assets from their existing portfolio of assets. Additional details about the joint venture will be provided when they become available.

For first-quarter 2015, First Solar expects net sales of \$550–650m, and a net loss of \$0.25–0.35 per fully diluted share. Cash used in operating activities should be \$400–500m. Guidance for revenue, earnings and operating cash flow is lower due primarily to completion of the Desert Sunlight and Topaz projects and the retention of projects on the balance sheet in relation to the plan to pursue a joint YieldCo vehicle with SunPower. This is also expected to weigh on financial results in future quarters over the near-term. However, First Solar believes this strategy will generate significant value for shareholders over the long-term.

www.firstsolar.com

First Solar commits to 5GW investment in India

At the 1st Renewable Energy Global Investors Meet & Expo (RE-INVEST 2015) in New Delhi, India (15–17 February), First Solar announced a Green Energy Commitment to develop 5GW of capacity by 2019, joining India's vision to ramp up solar energy capacity in its total energy mix to 10% to meet the country's increasing demand for sustainable renewable energy.

Total global installed PV solar capacity jumped from 3.7GW in 2004 to 135GW at the end of 2013. Following that lead, India's plan to install 100GW capacity of solar-generated electricity by 2022, with R&D bringing about

more efficiencies to support even larger growth.

"India remains one of our most important global markets," says First Solar's CEO James Hughes. "Given its economic growth and the need for energy security and energy access, solar presents a very compelling opportunity to the government and the industry today, to demonstrate how it enables a sustainable and affordable energy solution for the 1.2bn people of this country," he adds. "Our commitment demonstrates our intent to work with the government in achieving this goal."

The announcement is part of a broader commitment that First

Solar made last year when it announced plans to build utility-scale solar projects in India. "We are one of the lowest-cost producers of solar energy in India, with a development pipeline of over 200MW of projects in AP and Telengana," says Sujoy Ghosh, country head for First Solar India. "The overall commitment is of course contingent upon the government providing PPA [power purchase agreement] allocations from utilities by way of enforcing RPOs [requests for purchase orders] as well as the land/evacuation infrastructure under the solar park policy."

www.re-invest.in

First Solar raises its CdTe PV solar cell conversion efficiency record to 21.5%

First Solar Inc of Tempe, AZ, USA has raised its world record for cadmium telluride (CdTe) photovoltaic (PV) research cell conversion efficiency from 21% (reported last August) to 21.5%, as certified at the Technology and Applications Center (TAC) PV Lab of Newport Corp. The latest record places First Solar ahead of its established research cell roadmap.

The record cell was fabricated at First Solar's manufacturing factory and R&D Center in Perrysburg, OH, using processes and materials suitable for commercial-scale manufacturing. The record has been documented in the US Department of Energy's National Renewable Energy Laboratory (NREL) 'Best Research Cell Efficiencies' reference chart. It is the eighth substantial update to CdTe record efficiency since 2011.

"Our latest research cell efficiency record is a result of continued learning in the material science and device physics of CdTe solar cells," says First Solar's chief technology officer Raffi Garabedian. The work is "in part a result of the many fruitful collaborations we have with academia, national labs, and our industrial partners, most notably GE Global Research," he adds. "The learning has enabled us to further optimize our fabrication processes and thereby boost the performance of practical devices further towards the theoretical limit."

The true value of improved cell efficiency comes from the translation of the science into commercially viable product with improved power output and energy density, says Garabedian. "By virtue of our adaptable thin-film manufacturing process and our dedication to science-based design-for-reliability, First Solar is unique in its ability to rapidly scale such new developments into cost-effective and reliable product," he claims.

Garabedian emphasizes that First Solar's sustained investment in CdTe technology development has enabled it to meet or exceed its aggressive projections for improvements in research cells and modules, as well as commercialized technology. In March 2014, the firm presented a technology roadmap anticipating a 22% research cell efficiency milestone in 2015. "Given the slope of our research cell improvements and the fact that it is still February, we remain confident that we'll meet or exceed our roadmap expectations," Garabedian says.

Atlas 25+ certification

First Solar also says that its focus on module durability is continuing to yield results for commercially available products. In late January, its production PV modules achieved Atlas 25+ certification status following a rigorous series of long-term combined-stress environmental exposure tests.

Atlas 25+ certification stresses durability and degradation against accelerated environmental conditions experienced in long-term service. According to Azmat Siddiqi, senior VP for Quality and Reliability, First Solar modules passed the Atlas 25+ stress tests for all parameters, including power output, insulation resistance and visual damage in the hot/arid, subtropical, temperate and 'global composite' climate simulations.

"The modules were tested against the most stringent standards available," says Siddiqi. "Performance of our production modules is evolving hand in hand with other technology advances." Testing was conducted by Atlas Material Testing Technology, and formal certification documentation will be issued by SGS, an inspection, verification, testing and certification organization recognized for providing global benchmarks for quality and integrity, says Siddiqi.

First Solar says that the Atlas 25+ results and recent 1500V PID Free certification add to its list of extended module reliability accolades, which include what are claimed to be market-leading results in Thresher, Long Term Sequential and IEC 60068 Desert Sand Resistance tests that independently confirm suitability for sustained operation in the world's harshest climates.

www.nrel.gov/ncpv/images/efficiency_chart.jpg

First Solar and SunPower to partner to form joint venture

First Solar says it is in advanced negotiations with solar panel and system maker SunPower Corp of San Jose, CA, USA to form a joint YieldCo vehicle, to which they each expect to contribute a portfolio of selected solar generation assets from their existing portfolio of assets.

SunPower manufactures solar panels and systems for residential,

business, government and utility customers. The firm has offices in North and South America, Europe, Australia, Africa and Asia.

Upon the execution of a master formation agreement, the parties intend to file a registration statement with the US Securities and Exchange Commission (SEC) for an initial public offering (IPO) of limited partner interests in the YieldCo.

Formation of the YieldCo and completion of the IPO are subject to (among other things) the execution of definitive documentation, each party's board approval, and regulatory approval. The firms say that there is no assurance that the YieldCo will be formed or that the IPO will be consummated or that any other transaction will occur.

www.firstsolar.com

First Solar showcases Series 4 module and launches first PV project assessment application

At the 2015 World Future Energy Summit (WFES) in Abu Dhabi, United Arab Emirates (19–22 January), First Solar Inc of Tempe, AZ, USA, which makes thin-film photovoltaic modules based on cadmium telluride (CdTe) as well as providing engineering, procurement & construction (EPC) services, has launched its Energy Capacity Assessment Tool, which is claimed to be a first for the solar energy industry,

The interactive Assessment Tool allows developers and investors to evaluate the feasibility and energy output of ground-mounted utility-scale projects, using First Solar's advanced thin film technology, anywhere in the world. Users will be able to plot potential sites on a mapping interface; design a plant, while adjusting configurations to maximize energy output; and generate a report that includes site-specific estimated capacity and energy yield, while factoring in irradiation levels, average temperatures, project construction timing and more. The application can be accessed online on

www.firstsolar.com/energycapacity.

At WFES, First Solar is also showcasing its next-generation Series 4 thin-film photovoltaic (PV) module and AC Power Block solar power plant solution (launched last June

at Intersolar Europe 2014 in Munich, Germany). The new Series 4 PV module is claimed to offer up to 8% more energy than conventional crystalline silicon modules with the same power rating, and is compatible with 1500V plant architectures. The AC Power Block is a configurable, pre-engineered system based on First Solar's proven PV plant design and energy prediction model, and is available in modular units ranging from 800kW to 3.8MW.

Additionally, First Solar is spotlighting its Module Plus System (featuring optimized fixed-tilt and single-axis tracker designs) and its range of operations and maintenance (O&M) services. Also, skytron energy of Berlin, Germany (acquired by First Solar in mid-2014), which provides integrated monitoring, control and supervision systems is making its WFES debut with its PVGuard SCADA platform.

"As the energy transition ratifies solar power's role in the global generation portfolio, there has never been a greater emphasis on maximizing energy yield in real-world conditions," says First Solar's chief commercial officer Joseph Kishkill. "Our mission - reflected in the range of solutions on show at the World Future Energy Summit - is to

respond to our customers' energy yield priorities with singular solutions designed to address specific challenges," he adds.

"The Middle East is fast evolving into a sophisticated market for solar energy, driven by long-term diversification and energy security strategies," says Ahmed S. Nada, VP for the Middle East. "It is in this context that we've focused our efforts on building on our track record and optimizing energy output for the region's unique environmental conditions," he adds.

As a fully vertically integrated solar energy company, First Solar's capabilities span the entire solar value chain. The firm has over 9000MW of installed capacity worldwide and a contracted pipeline of projects that exceeds 2600MW. It has been selected as a finalist in the 2015 edition of the Zayed Future Energy Prize. In the Middle East, First Solar has built the 13MW first phase of the Mohammed bin Rashid Al Maktoum Solar Park in Dubai, currently the Middle East and North Africa region's largest facility, and will be constructing the 52.5MW Shams Ma'an solar plant in Jordan.

www.worldfutureenergysummit.com
www.firstsolar.com/Home/Solutions/Utility-Scale-Generation/eCAT

Desert Sunlight Solar Farm starts commercial operation

US Secretary of Interior Sally Jewell — along with 150 federal, state and local officials, and energy industry leaders — gathered to commission the 550MW Desert Sunlight Solar Farm, located on about 3600 acres of land managed by the US Bureau of Land Management in Desert Center, Riverside County, California.

Project owners NextEra Energy Resources LLC (a subsidiary of NextEra Energy); GE Energy Financial Services (a unit of GE); and Sumitomo Corporation of

Americas all helped flip the switch for the plant's official commissioning.

First Solar permitted, constructed and is now operating the plant, which uses over 8 million CdTe PV modules. Development began in 2008. Desert Sunlight received its right-of-way grant from the Bureau of Land Management in August 2011. Since breaking ground, the project employed an average of 440 construction workers who logged more than 3.6 million man-hours of work at the facility.

Capable of generating enough energy to power about 160,000 California homes, the Desert Sunlight Solar Farm's environmental benefits including displacing about 300,000 metric tons of carbon dioxide per year (equal to removing more than 60,000 cars from the road). The power generated is being provided to Pacific Gas & Electric Company and Southern California Edison, both under long-term contracts.

www.firstsolar.com

First Solar and Apple strike industry's largest power deal for commercial end-user

First Solar Inc of Tempe, AZ, USA, which makes thin-film photovoltaic modules based on cadmium telluride (CdTe) as well as providing engineering, procurement & construction (EPC) services, says that Apple has committed \$848m for clean energy from its California Flats Solar Project in Monterey County, CA, USA. Apple will receive electricity from 130MWAC of the solar project under a 25-year power purchase agreement (PPA), the industry's largest agreement for providing energy to a commercial end-user.

"Apple is leading the way in addressing climate change by showing how large companies can serve their operations with 100% clean, renewable energy," says First

Solar's chief commercial officer Joe Kishkill. "Apple's commitment was instrumental in making this project possible and will significantly increase the supply of solar power in California," he adds. "Over time, the renewable energy from California Flats will provide cost savings over alternative sources of energy as well as substantially lower environmental impact."

The 2900-acre California Flats Solar Project occupies 3% of a property owned by Hearst Corporation in Cholame, CA. Construction is expected to begin in mid-2015, and to be completed by the end of 2016. The output of the remaining 150MW of the project will be sold to Pacific Gas & Electric under a separate long-term PPA, and the project

is fully subscribed between the Apple and PG&E PPAs.

In January, the Monterey County Planning Commission unanimously approved the California Flats Solar Project, sending the project to the Monterey County Board of Supervisors to consider final approval of the project.

Building on its proven record of developing, building and operating utility-scale solar power plants, First Solar has placed a strategic focus on directly providing large commercial and industrial customers with wholesale electricity through long-term agreements. The latest deal marks the first wholesale commercial and industrial PPA executed by First Solar.

www.firstsolar.com

ZSW raises efficiency of cadmium-free thin-film solar cells to record 21%

CdS and ZnO replaced by zinc oxysulfide and zinc magnesium oxide, boosting blue-wavelength absorption

ZSW (Zentrum für Sonnenenergie- und Wasserstoff-Forschung — or Center for Solar Energy and Hydrogen Research — Baden-Württemberg) of Stuttgart, Germany has boosted the efficiency of cadmium-free copper indium gallium diselenide (CIGS) thin-film solar cells to a record 21%.

The researchers achieved this performance by replacing the system of intermediate films consisting of cadmium sulfide (CdS) and zinc oxide (ZnO) with a combination of zinc oxysulfide and zinc magnesium oxide. This combination promises to harvest even more light than the material used in earlier CIGS cells, it is reckoned.

The record for conventional CIGS solar cells made of 21.7% was set last September by ZSW, which has now come very close to matching that with the new type of cell. Pro-

fessor Michael Powalla, ZSW board member and head of the Photovoltaics division, believes that the lack of heavy metals in the new cell's buffer layer is an advantage, but not the key benefit. The metal in conventional CIGS modules is chemically bound. "First and foremost, the buffer layer transmits more light without the cadmium sulfide," he says. "In theory, we could use it to achieve even higher efficiency than with previous CIGS cells," Powalla adds. "The alternative buffer layer and the cadmium sulfide buffer are both deposited in a chemical bath, so a transition to manufacturing is possible without requiring additional processes."

As a buffer layer, zinc oxide-sulfide is more transparent to light in the blue wavelength range. So, more sunlight penetrates to the underlying CIGS absorber layer, which then

converts more light energy into electricity. Another innovation in the cell is its improved front contact, made with zinc magnesium oxide in place of the high-resistance thin zinc oxide film. Made in a ZSW manufacturing lab, the solar cell has a surface area of 0.5cm² (a standard size for experimental cells). The results were confirmed by the Fraunhofer Institute for Solar Energy Systems ISE.

Alternative CIGS technology is still in the initial stages of development, so a further significant increase in efficiency is possible, reckon the researchers. ZSW's industry partner Manz AG of Reutlingen, Germany has already made the first test modules. ZSW expects that the modules made in southwest Germany can be brought to market within a few years.

www.zsw-bw.de

Siva Power wins \$3m SunShot grant from US DOE

Copper indium gallium diselenide (CIGS) solar panel developer Siva Power of San Jose, CA, USA has received an award from the US Department of Energy (DOE) SunShot Initiative recognizing its innovative technology and processes that, it is claimed, will enable it to manufacture solar panels in the USA at the world's lowest cost.

SunShot is a national effort to make solar energy cost-competitive with traditional energy sources by the end of the decade. Ten US firms recently received cooperative awards under the Solar Manufacturing Technology funding program, which aims to bridge the gap from invention to commercialization, bringing innovative technology to scale. Siva was the only thin-film panel awardee.

SunShot's goal is to reduce the average selling price of solar panels to under \$0.50 per watt by 2020. The Chinese currently sell the cheapest solar panels, averaging about \$0.70/watt. While the lowest Chinese manufacturing costs are close to \$0.50/watt, they need a little profit, so the selling price is still about 40% over the SunShot goal. Siva plans to build a production line with costs of \$0.40/watt within the

first year of operation, and achieving \$0.28/watt two years after that. Siva reckons it could profitably — and sustainably — sell solar panels at less than the \$0.50/watt SunShot goal, and that these record-breaking numbers could be achieved while manufacturing in the USA.

The DOE's \$3m award to Siva supports the firm's plans to demonstrate a CIGS co-evaporation source with 12x higher manufacturing throughput (m^2/min) than currently available sources, enabling a fully automated CIGS deposition system at a 3x reduction in capital expenditure (CapEx), labor, and overhead costs per watt, it is reckoned. Siva expects that this CIGS system — along with other high-speed tools — will allow it to build the world's largest production line, at 300MW.

SunShot employs a fair, unbiased and rigorous selection process (including peer reviews by DOE scientists and industry professionals) to select the most meritorious projects for funding.

"This award will help us scale our proprietary co-evaporation process to build a 300MW production line, about 10x the output of typical solar production lines," says Siva

Power's CEO Brad Mattson (a Silicon Valley veteran and former founder of Novellus Systems and Mattson Technology). "That 10x advantage is the key to reducing costs, enabling Siva Power to beat the ambitious SunShot targets and to do it ahead of schedule," he adds.

"We look forward to continuing a research partnership with Siva Power as part of the Energy Department's SunShot Solar Manufacturing Technology program," says Dan Arvizu, director of the DOE's National Renewable Energy Laboratory (NREL). "CIGS cell efficiency has risen to nearly 22%, and this is an opportune time for companies to accelerate commercialization efforts in the USA," he adds.

"There are two parts to the solution," says Siva Power's chief technology officer Dr Markus Beck. "You need to have the right technology, but also the right processes to enable the efficient scaling of product in order to make a huge difference in the solar industry," he adds. "I dedicated my career to seeing CIGS make it, and now we have the team and support to make it happen."

www.energy.gov/sunshot

www.sivapower.com

Siva raises Series D funding round to \$10m to begin building plant

Siva Power has closed a Series D funding round that includes converting \$3m in debt financing received in May 2014 from four current investors — Trident Capital, DBL Investors, Medley Partners, and Acero Capital — and the city of Wuxi, China as a new investor. An extra \$4m is being committed by DBL, Medley, and Acero. This is on top of Siva's \$3m award by the US DOE's SunShot Initiative, bringing new capital to \$10m.

The new funding enables Siva to start building what is reckoned to be the world's highest capacity co-evaporation source. This will enable Siva to construct the rest of its full-scale production line for a

300MW factory. Siva is considering various sites — with California and other global sites on the short list — evaluating criteria including ease-of-manufacturing and favorability towards solar energy.

Siva also announced that Dr Bulent Basol is joining Dr Charlie Gay, Dr Rommel Noufi, John Benner, and Dr Markus Beck on its Technical Advisory Board.

With over 160 patents and 100 publications to his name, Basol has been a pioneer in thin-film PV for over 30 years. He started his career in 1980 with Monosolar Inc (one of the first solar companies) and later co-founded both ISET and SoloPower. He most recently

founded EncoreSolar, an integrated cadmium telluride firm targeting costs of less than \$0.50/watt.

"I have developed almost every type of thin-film solar technology over the last 30 years and now know that what Siva is driving at will not only achieve the lowest thin-film costs, but should surpass traditional crystalline silicon," says Basol.

"Adding another technology expert like Bulent, plus this new capital financing, mark important milestones for Siva's forward momentum, moving us closer to building the solar industry's largest manufacturing facility," says CEO Brad Mattson. "We will need to raise more capital later to build out the rest of our factory."

Ascent Solar's preliminary 2014 revenues quadruple year-on-year to \$5.3m

Ascent Solar Technologies Inc of Thornton, CO, USA, which makes lightweight, flexible copper indium gallium diselenide (CIGS) thin-film photovoltaic modules integrated into off-grid applications and its EnerPlex series of consumer products, has announced its preliminary results for fourth-quarter 2014. "\$5M of annual revenue is a significant milestone for Ascent Solar and is the first year in the Company's history to have reported such robust results"

Revenue was \$2.4m, more than doubling from last quarter's \$1.1m and quadrupling from \$0.6m a year ago. EnerPlex-branded consumer product revenue was \$2.3m, up on

\$1m last quarter and \$0.5m a year ago.

For full-year 2014, revenue was \$5.3m, more than quadrupling from 2013's \$1.3m. Product revenue was \$5m, up on \$1.1m in 2013.

"The strong revenue growth again validates our revised strategy that began in the second half of 2012," says president & CEO Victor Lee. "We are extremely encouraged by the rapid growth of EnerPlex and we expect to see sales continue to grow rapidly as we continue to expand our distribution channels domestically and internationally," he adds. "In Q4 we also experienced growing acceptance in our focused high-value PV market,

which we believe will add to our top-line growth in 2015," he continues.

"The rapid year-over-year revenue growth demonstrates the acceptance by the market of Ascent's superior products, the expansion of our distribution capacity, and the persistence of our employees in transitioning our company," says chairman Dr Amit Kumar. "We expect 2015 to be another year of rapid growth with continued new product launches, increased distribution, the transition of some manufacturing to Asia, and an increase in awareness of our EnerPlex brand."

www.AscentSolar.com

EnerPlex brand exhibits new portable power solutions at CES 2015

Ascent Solar Technologies Inc of Thornton, CO, USA, which makes lightweight, flexible copper indium gallium diselenide (CIGS) thin-film photovoltaic modules integrated into off-grid applications and its EnerPlex series of consumer products, says that its consumer products division EnerPlex exhibited at the 2015 International Consumer Electronics Show (CES) in Las Vegas (6-9 January), introducing previously unannounced products.

Ascent is showcasing its full line of EnerPlex-branded solar integ-

rated and portable power solutions, ranging from portable power banks such as the Jumpr line to its lightweight Commandr solar chargers.

The EnerPlex product line-up encompasses portable charging solutions for a wide range of consumers, from those who want to be outdoors and truly off-the-grid, to those in urban environments, who need a charge on the go to keep powered up throughout the day. Uniquely integrated with Ascent's thin-film solar technology,

EnerPlex's solar-integrated charging products are said to be lighter, more powerful and more rugged than any other currently available.

"This year at CES we will also showcase some truly amazing and unique applications for which Ascent Solar's revolutionary CIGS solar technology can provide power ranging from military command stations to unmanned aerial vehicles (UAVs)," says Justin R. Jacobs, manager of brand development for EnerPlex.

www.AscentSolar.com

Ascent Solar's EnerPlex brand launches on BestBuy.com

Ascent Solar Technologies Inc of Thornton, CO, USA, which makes lightweight, flexible copper indium gallium diselenide (CIGS) thin-film photovoltaic modules integrated into off-grid applications and its EnerPlex series of consumer products, says that it is now offer EnerPlex products on BestBuy.com.

"EnerPlex has uniquely positioned ourselves as a premium power solution and green alternative to the outlet; providing power for

devices which all consumers use, whether it be phones, tablets, cameras, wearables or other devices," says EnerPlex general manager Richard Hashim.

Ascent says that, for solar-integrated consumer electronics, EnerPlex provides lightweight, powerful and durable charging solutions for portable electronics. Surfr, a line of solar and battery integrated phone cases, allows users to charge their phone anywhere and in cases of

emergency. Kickr, a line of portable solar chargers, provides a charging solution for most USB-enabled devices, enabling power to be generated almost anywhere and in nearly every situation, suiting emergency preparedness. With the addition of the Jumpr line of portable batteries, EnerPlex now provides a complete, integrated, solar charging and storage solution, says the firm.

www.bestbuy.com

Terahertz radiation from mid-infrared quantum cascade lasers

Northwestern researchers claim a dramatic increase in tuning range compared with any other electrically tunable terahertz source.

Northwestern University's Center for Quantum Devices in USA has developed a monolithic room-temperature terahertz (THz) source based on quantum cascade lasers (QCLs) [Q. Y. Lu et al, Appl. Phys. Lett., vol105, p201102, 2014]. The resulting device is tunable over the range 2.6–4.2THz, i.e. 47% of the central frequency.

The researchers comment: "This dramatic increase in the tuning range compared with any other electrically tunable THz source will lead to new opportunities for THz spectroscopy and sensing."

Many biochemical molecules have strong spectral fingerprints in the THz region. In astronomical research, the interstellar medium contains a number of atomic and molecular emission lines in the THz range.

The device consisted of mid-infrared (mid-IR) QCL devices with two sampled grating distributed feedback (SGDFB) and one distributed bragg reflector (DBR) sections (Figure 1a). The THz radiation was produced through intra-cavity difference

frequency generation (DFG) from two mid-IR QCL regions in the structure.

The wavelength of one QCL was controlled by the DBR. The other QCL wavelength was controlled by the SGDFB sections.

The team claims that the device is the first room-temperature, multi-section, two-color SGDFB-DBR structure to realize a monolithic tunable THz source.

The DBR had patterned grating lines with a uniform period. The DFB section was electrically isolated and

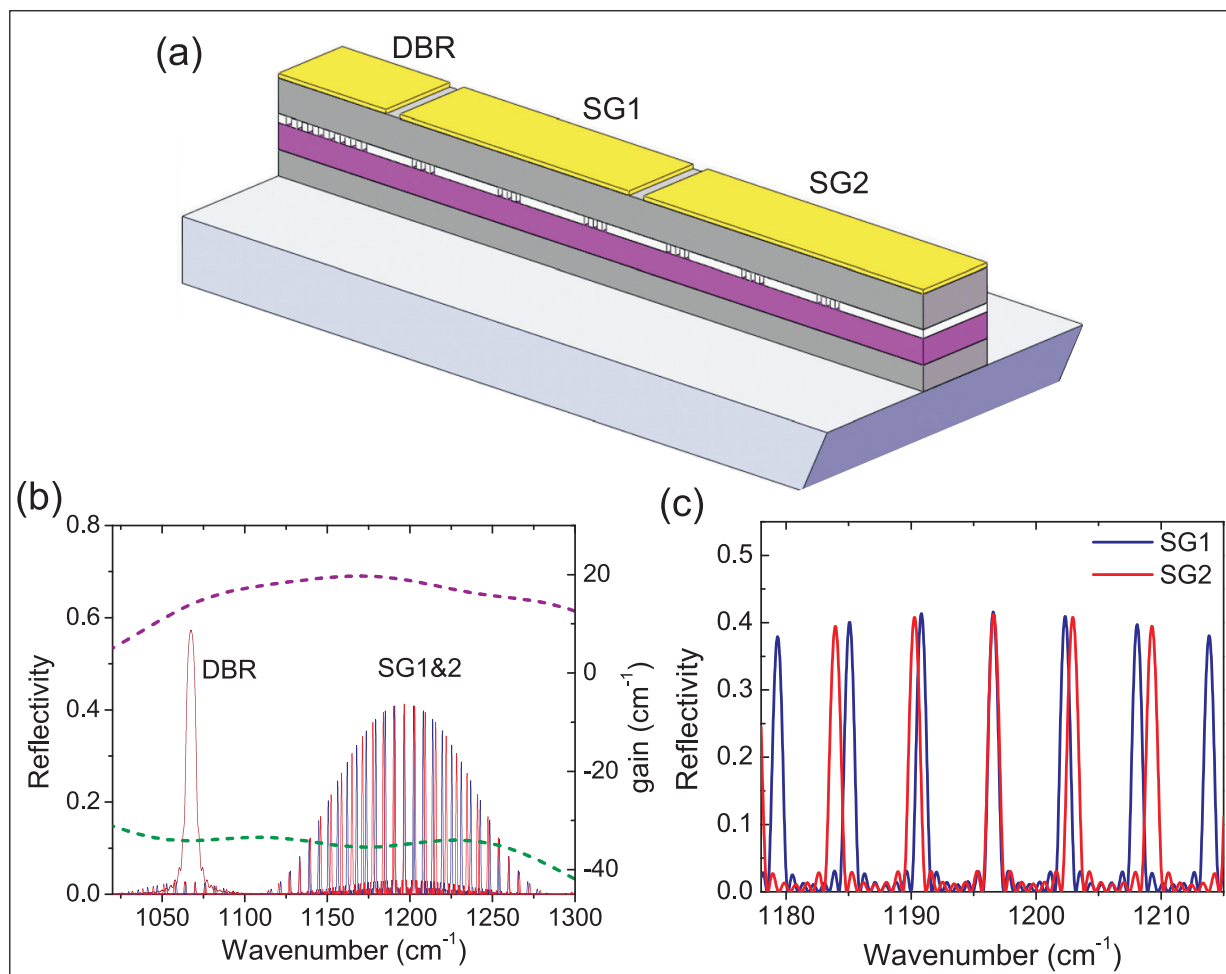


Figure 1. (a) Schematic of three-section device. (b) SGDFB and DBR reflectivity spectra corresponding to calculated gain spectra at 0V (green line) and 12V (purple line) biases. (c) Detailed view of SGDFB reflectivity combs.

wavelength tuning was provided by a DC bias that affected the refractive index of the DBR material. The wavelength tuning of the DBR had limited range.

The SGDFB structures were more complicated, with series of short gratings giving a comb-like reflectivity response with wavelength (Figure 1b). Again, biasing gave tuning of the reflectivity with wavelength. The interplay of the two SGDFB sections gives a Vernier-type tuning mechanism. The tuning is not continuous, but the gaps could be filled by nudging the DBR reflection maximum or by changing the biases on the SG1 and SG2 sections simultaneously.

The QCL wafer that was used had a broadband dual-core active region. The material had large optical non-linearity in the 1–5THz range to enable DFG. The gratings were etched into a 500nm InGaAs layer located about 100nm from the active core.

The reflectivity peak of the SGDFB combs was arranged to be close to that of the gain peak of the laser core. The DBR peak corresponded to a gain at 75–80% of the maximum.

The material was formed into double-channel ridge waveguide laser diodes. The ridge was 22 μ m wide. The laser sections were electrically isolated by etched 2 μ m-deep channels. The final laser bars were 6.3mm long: 1mm for the DBR, 2mm for SG1, and 3.3mm for SG2 and an amplifying section. The bar was coated with 1.1 μ m yttrium oxide as an anti-reflective layer. The front facet for THz-out-coupling was polished at a 30° angle with the cleavage plane.

The device was mounted epi-up on a copper heat-sink. The bond between device and heat-sink was indium solder. Testing was performed with pulsed mode operation. The QCL structure was designed for epi-down mounting and the epi-up configuration was likely to suffer from thermal management problems.

The tuning injection current of the SG1 and SG2 sections was in the ranges 40–290mA and 40–360mA, respectively. The DBR bias resulted in 50mA current injection. The reflectivity of the DBR section was somewhat affected by the biasing on the other sections, particularly on the adjacent SG1. The heating of the DBR from self-heating of SG1 also shifted the DBR reflectivity maximum.

The total power of the mid-IR radiation was 1.32–1.58W. With the two SGDFB sections connected

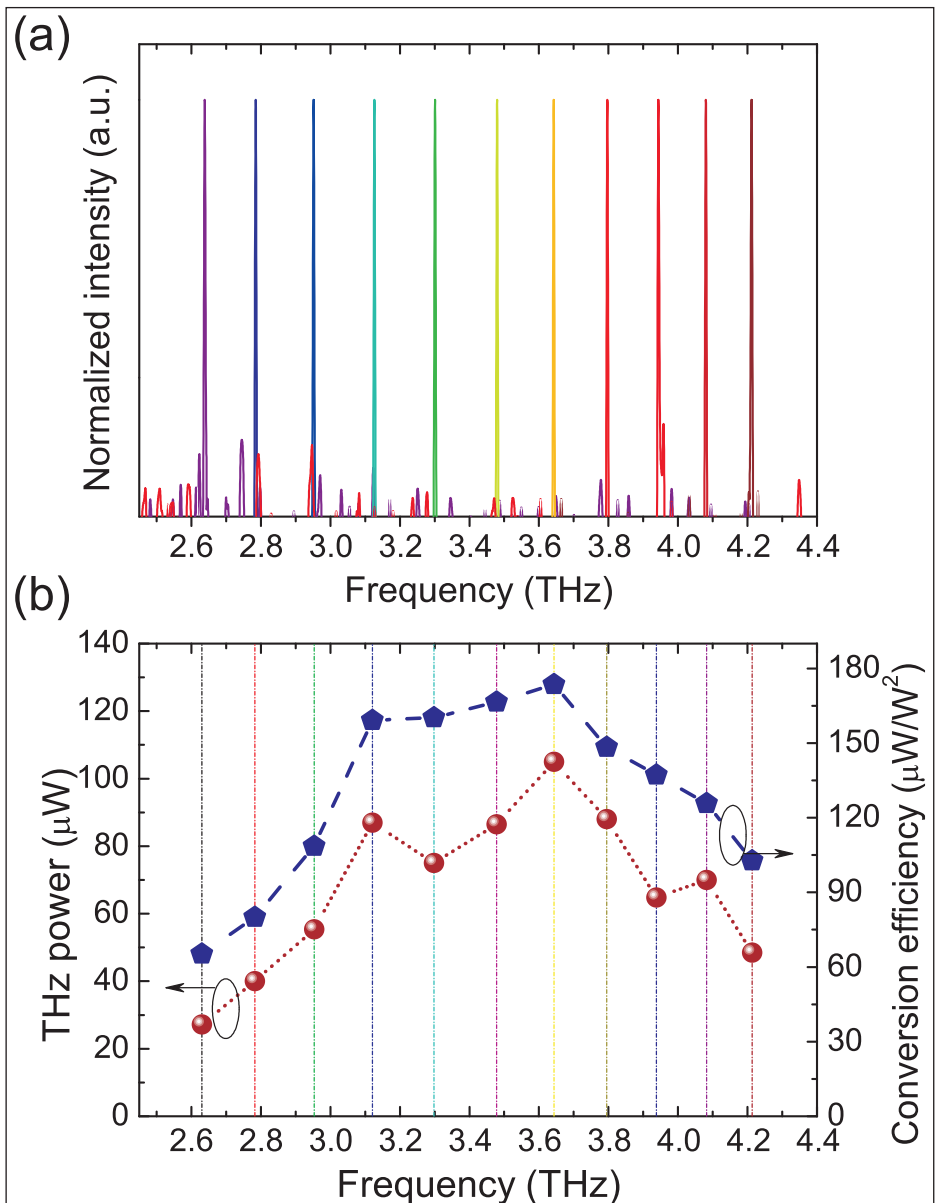


Figure 2. (a) Combined THz spectra obtained via Vernier tuning mechanism. (b) THz power and conversion efficiency in tuning range as a function of THz frequency.

at the same bias the output was 2.1W with current density threshold for lasing of 3.18kA/cm². Connecting the DFB to SG1 and SG2 gave 2.7W with 3.0kA/cm² threshold.

THz output was available in the range 2.6–4.2THz, i.e. 47% of the central frequency (Figure 2). The peak performance was in the range 3.2–3.8THz. The output power was 26 μ W at 2.6THz and 105 μ W at 3.64THz.

The researchers believe: "Higher THz power and continuous-wave operation can be further obtained by using a device structure with a higher THz conversion efficiency and better thermal packaging."

The devices broke down under 13V bias, corresponding to 850–900mA injection. The breakdown input power was ~11.5W. ■

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Author: Mike Cooke

First 250nm-wavelength nanowire LEDs claimed

Polarization effects used to improve hole density and injection.

Ohio State University and University of Illinois at Chicago have developed deep ultraviolet (DUV) light-emitting diodes (LEDs) based on III-nitride nanowires [Thomas F Kent et al, *Nanotechnology*, 25, 455201, 2014]. The team says of one device emitting 250nm radiation: "This is to our knowledge the shortest operating wavelength nanowire LED yet reported."

DUV LEDs are being developed to avoid the use of bulky, fragile lamps based on poisonous mercury. However, the efficiencies of LEDs at wavelengths shorter than 270nm are very low. Potential applications include killing microbes and spectral analysis of biological material.

Using nanowires rather than layers of III-nitride material allows the aluminium gallium nitride (AlGaN) material to vary over a wider range of composition without concerns arising from strain relaxation effects such as dislocation formation. Also, high-Al-content AlGaN in DUV LEDs suffers from problems in doping for hole majority carriers and in light extraction due to photon polarization effects.

Creating p-type hole injecting regions is difficult, and for DUV emission compromises have to be made. Either highly resistive p-AlGaN or photon-absorbing lower-resistance p-GaN is used. The problem with p-AlGaN is that the activation energy of the magnesium doping used is much higher than for p-GaN. On the other hand, GaN's bandgap is smaller than the energy of DUV photons.

The Ohio/Chicago team used the polarization contrast of the chemical bonds of differing Al-content AlGaN to reduce the need for doping in the p-type region of their "polarization-induced nanowire light-emitting diodes" (PINLEDs).

The III-nitride nanowire heterostructures (Figure 1) were grown using RF nitrogen plasma source molecular beam epitaxy (MBE) on p-type silicon (111) substrates. Silicon nitride formation was avoided by rotating the substrate away from the sources during plasma lighting, tuning and the initiation of III-nitride growth.

The heterostructure began with GaN nucleated at 710°C in nitrogen-rich conditions. The devices con-

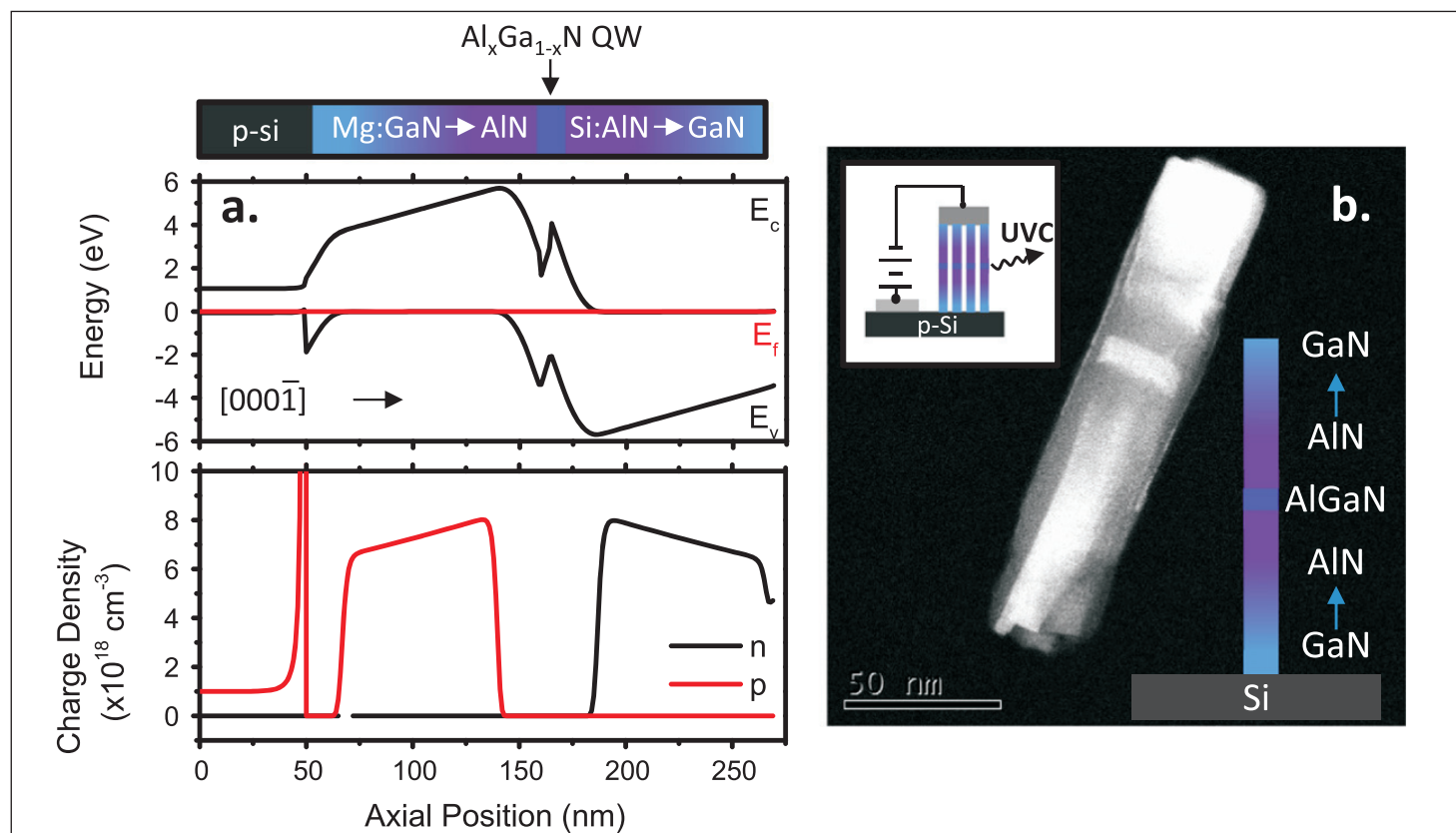


Figure 1. Polarization-induced nanowire light-emitting diodes. (a) Band diagram showing p- and n-type regions as well as the AlGaN QW active region. (b) HAADF-mode STEM micrograph showing individual heterostructure nanowire. Insert shows heterostructure schematic and device schematic.

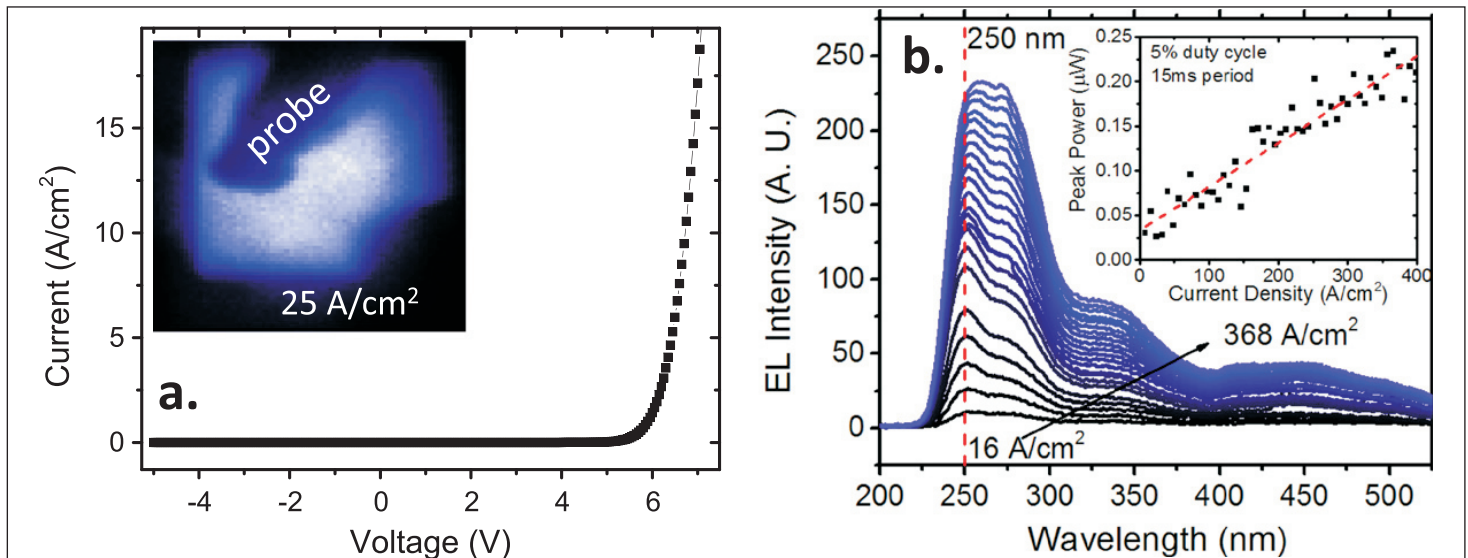


Figure 2. (a) Device I–V curve showing 6V turn-on and rectification. Inset shows image of the active device collected with an ultraviolet microscope. (b) Electroluminescence spectra of high-temperature active region device showing evolution with increasing current density. Inset: peak power versus current density.

sisted of a 100nm linearly graded GaN to AlN region, an active region of one or more quantum wells, and a 100nm linearly graded AlN to GaN region.

Growth of the p- and n-type graded regions occurred at 790°C. Also, in some devices 790°C was used for the active region, but improved performance at shorter wavelengths was found from 840°C growth.

Assuming N-polar nanowires, the first and second graded composition regions were expected to give p- and n-type contacts, respectively. Although there was some magnesium doping in the p-type region, the concentration was much reduced from that used in commercial III-nitride DUV LEDs. The n-contact region was silicon-doped.

The LEDs were fabricated with pressed-on indium contacts to the silicon substrate and electron-beam evaporation of titanium/gold to a thin n-GaN layer on the upper tips of the nanowires.

Electroluminescence studies on a variety of AlGaIn quantum wells grown at 790°C showed the expected monotonic blue-shift of wavelength with increasing Al-content down to 290nm. However beyond 40%-Al, the wavelength became pinned at 290nm.

Photoluminescence spectral analysis showed two peaks: one that shifted to higher photon energy with increasing Al-content, and a broader composition-independent peak around 3eV. The lower energy peak was attributed to a trap state. As the higher energy peak became pinned around 4eV, its intensity declined beyond 50% Al-content of the well. The quenching of the high-energy peak is "indicative of the presence of a deep level in the active region of the device which is dominating over radiative band-to-band recombination processes".

The researchers then produced devices with higher substrate temperature during growth of the active region with a view to avoiding oxygen incorporation that can lead to deep levels. The temperature was

ramped to 840°C towards the end of the p-region growth. The quantum well region consisted of three Al_{0.8}Ga_{0.2}N wells with AlN barriers. The final part of the heterostructure was grown by ramping down to 790°C toward the end of the active region growth.

Contacts were made to the p-Si substrate and to a gridded pad on a 350μm×350μm region on the nanowire tips. Current-voltage measurements showed turn-on at 6V, corresponding to the ~6eV AlN bandgap.

The new device emitted 250nm-wavelength radiation, unlike the 290nm for similar AlGaIn composition devices with active regions grown at 790°C (Figure 2). However, the radiation of the new device red-shifted to 280nm as current injection increased. This was due to a second peak at 280nm that grew as current increased. The two peaks had equal intensity at 368A/cm² current density. The two-peak spectral structure is suggest to be due to carrier overflow/overshoot.

Output power was 2nW with 400mA injection and the external quantum efficiency (EQE) was estimated at 2μ% (2×10⁻⁶%). The researchers comment: "Although this is a very small efficiency, it is emphasized that the device geometry for such devices is far from optimized, causing a low percentage of nanowires to be contacted and requiring thick, absorbing contact layers to form coalesced tops that contact all nanowires in parallel, suggesting that significant improvements can be made with future process development."

Optimized commercial devices at 250nm achieve efficiencies around 0.2%. Under pulsed operation to avoid self-heating, these devices achieve 0.22μW at 400mA.

The team thinks that higher growth temperatures may result in shorter emission wavelengths, but a number of challenges must be overcome to achieve this. ■

<http://dx.doi.org/10.1088/0957-4484/25/45/455201>

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UV LED market to grow from \$90m to \$520m in 2019

Applications are expanding from UV curing into UVC disinfection and purification by 2017/2018, says Yole Développement.

Due to their compactness and low cost of ownership, UV LEDs continue to penetrate the booming UV curing business, through replacement of incumbent technologies such as mercury lamps, according to 'UV LED - Technology, Manufacturing and Application Trends 2015' report by Yole Développement, which says that the market for ultraviolet light-emitting diodes (UV LEDs) increased at a compound annual growth rate (CAGR) of 28.5% from just \$20m in 2008 to about \$90m in 2014.

Such growth is likely to continue as LED-powered UV curing spreads across ink, adhesive and coating industries, forecasts the market research firm. By 2017/2018, the UV LED market should also see part of its revenues coming from UVC disinfection and purification applications, for which device performance is not yet sufficient, it adds. The UV LED business is therefore expected to grow from \$90m in 2014 to about \$520m in 2019.

But this is only if we take into account standard applications, where UV LEDs replace UV lamps. The potential is even greater if we consider the ability of UV LEDs to enable new concepts in areas like general lighting, horticultural lighting, biomedical devices, and in fighting hospital-acquired infections (HAIs). Even this is just scratching the surface of the real potential of UV LEDs,

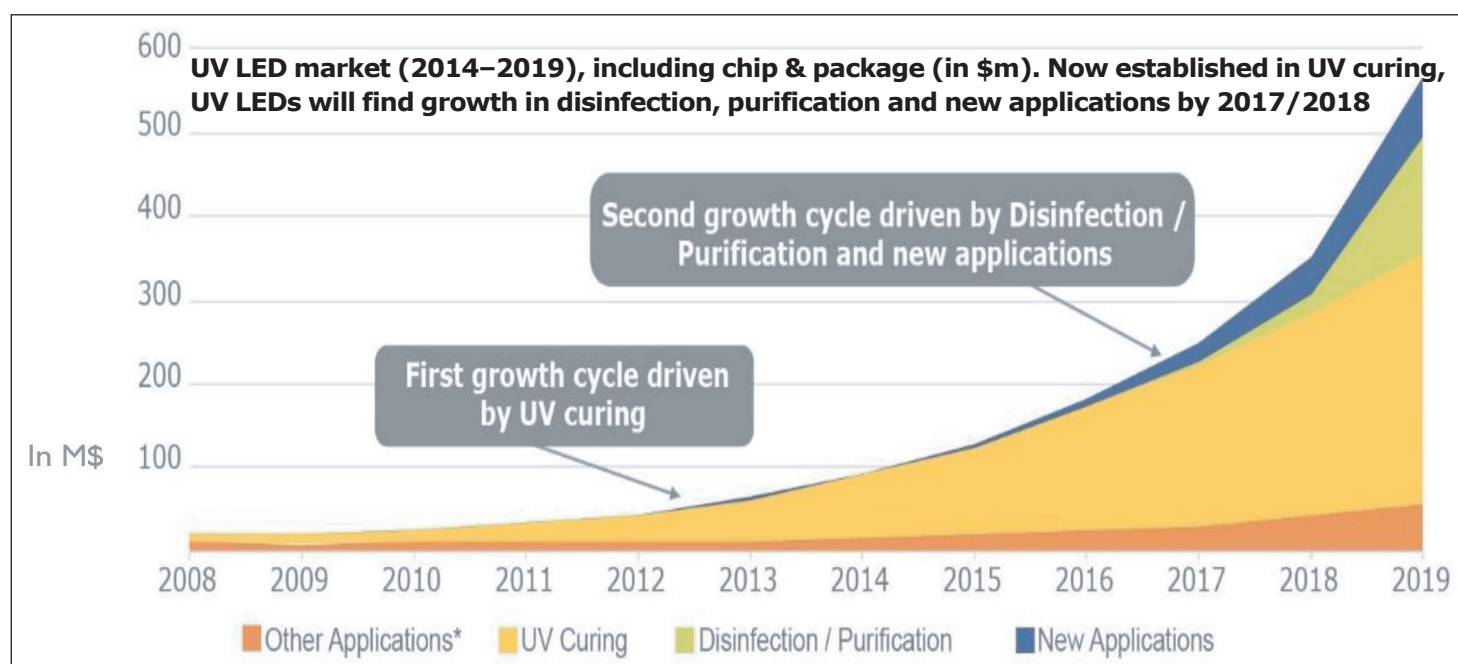
says Yole. While the new applications do not yet have a strong impact on market size, Yole expects them to possibly count for nearly 10% of the total UV LED market by 2019.

Entry of visible LED giants to speed UV LED industry maturation

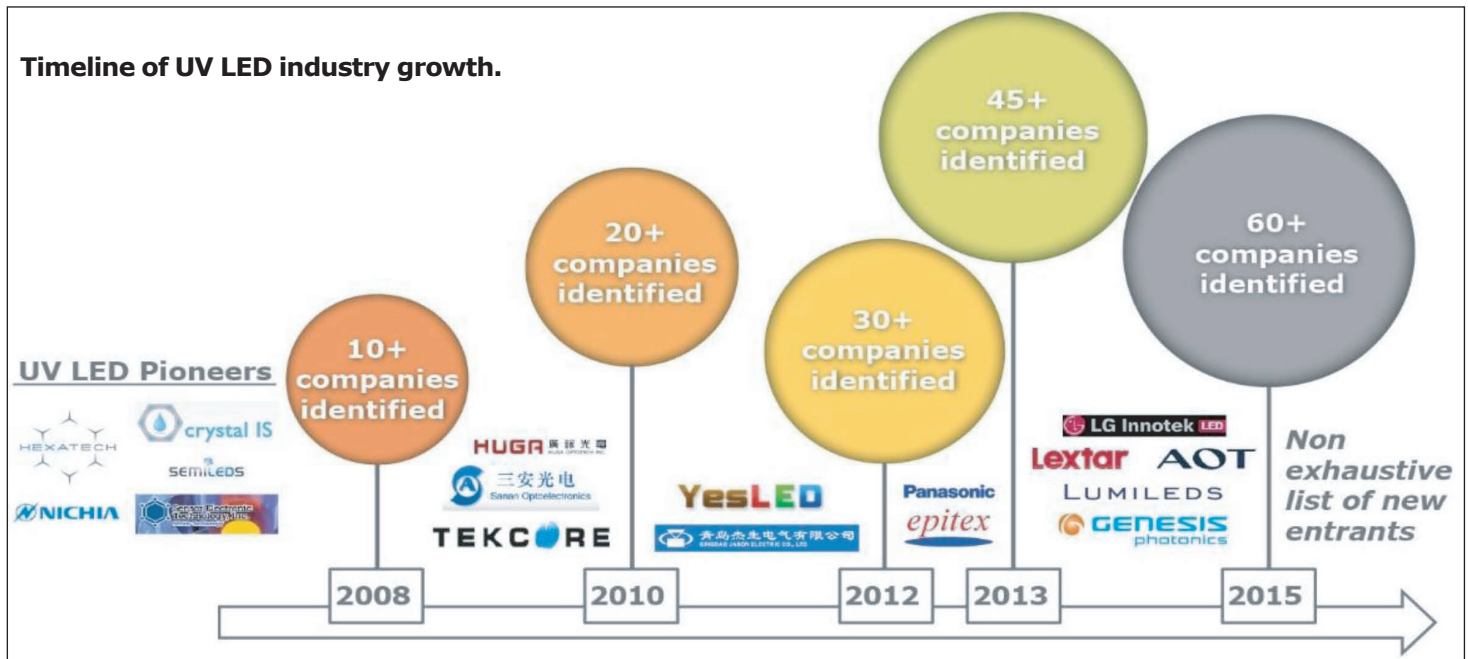
In 2008, fewer than ten companies were developing and manufacturing UV LEDs. Since then, more than 50 firms have entered the field, over 30 of these between 2012 and 2014, mostly attracted by the high margin when overcapacity and strong price pressure from the 'LED TV crisis' had taken its toll on the visible LED industry.

These firms were mostly small and medium enterprises (SMEs), but recently some big firms from the visible LED industry — namely Philips Lumileds and LG Innotek — have also secured a foothold in the UV LED business.

The entry of these two giants will help to further develop the industry, the market and the technology based on their strong experience of the visible LED industry, reckons Yole. A good example of this is that they have made a nearly full transition of their process to 6" sapphire substrates. Compared to a process based on 2" substrates, this can provide an overall productivity increase of at least 30%, which would help to further reduce manufacturing cost.



Timeline of UV LED industry growth.



In addition, front-end and packaging expertise will help to increase UV LED device performance and provide invaluable improvements in terms of \$/W, says Yole.

UV LED chip making a bottleneck for high-performance devices

With the external quantum efficiency (EQE) of UV LEDs ranging from a few percent in UVC LEDs to 40–50% in UVA and near-UV LEDs, R&D directed at efficient chip manufacturing will be key for UV LED market development, says Yole. Indeed, such issues have a direct impact on the technology's penetration, mostly for UVC where LED performance is not yet sufficient to trigger adoption in purification and disinfection applications.

To increase EQE, manufacturers need to develop techniques for each efficiency parameter: internal

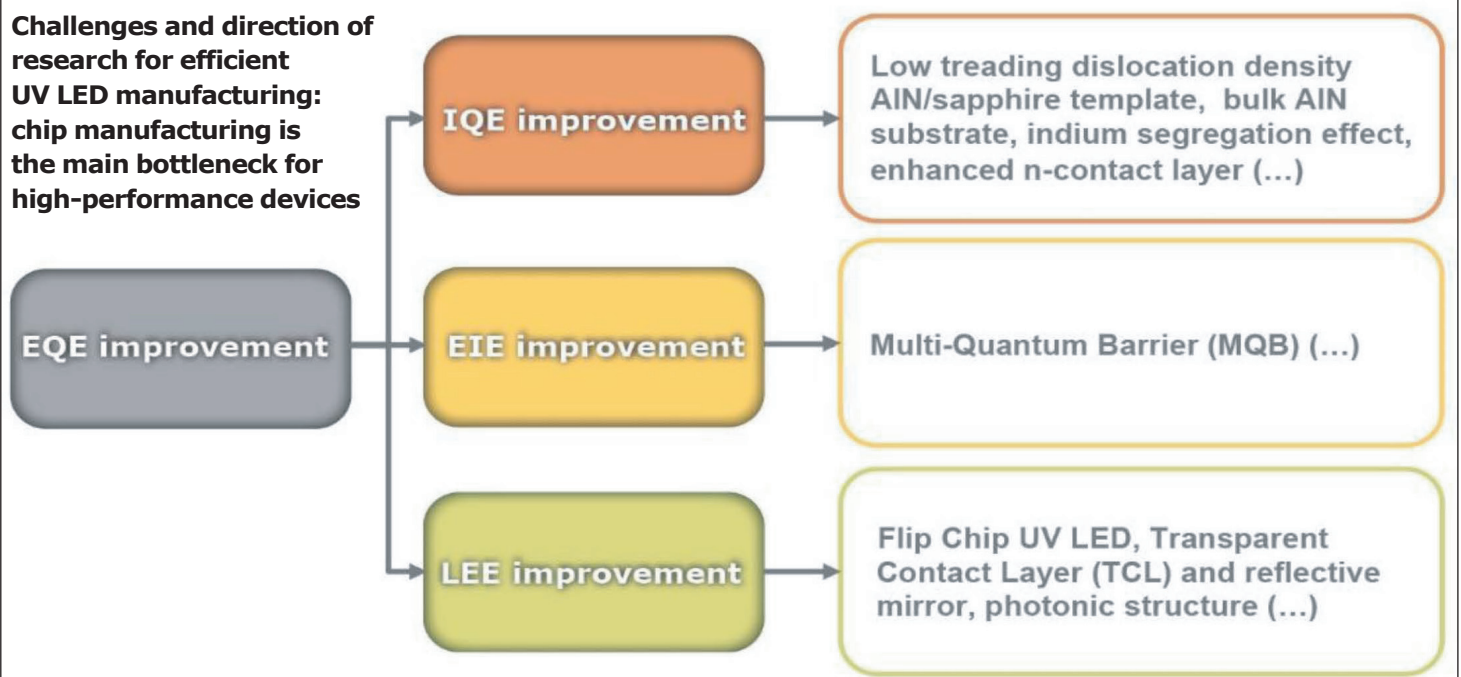
quantum efficiency, electron injection efficiency and light extraction efficiency.

Approaches such as flip-chip and photonic structures can be taken directly from the visible LED industry and its decade-plus of experience. However, UV LEDs also have specific challenges arising from their In/AlGaIn-based epilayers that require dedicated R&D at the substrate and epitaxy levels.

As well as the low power output of UV LEDs, their low efficiency creates additional difficulties at the packaging level. With most of the input power being transformed into heat, thermal management represents a key topic for reliability in devices and associated systems. Here too, expertise developed in the visible LED industry will help to accelerate UV LED development, concludes Yole. ■

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Challenges and direction of research for efficient UV LED manufacturing: chip manufacturing is the main bottleneck for high-performance devices



Thicker InGaN wells enabled by semi-polar (303̄1) substrate

UCSB produces device with less efficiency droop at high currents and temperatures.

University of California Santa Barbara (UCSB) and Mitsubishi Chemical Corp have reported indium gallium nitride (InGaN) light-emitting diodes (LEDs) with thicker active regions enabled by growing the crystal on the semi-polar (303̄1) plane [Daniel L. Becerra et al, Appl. Phys. Lett., vol105, p171106, 2014].

Normal InGaN devices grown on the polar c-plane are restricted to well thicknesses of a few nanometers. These thicknesses are required to avoid the electron-hole separation arising from the high electric fields that result from the strong polarization of the bonds in III-nitride materials — giving rise to the quantum-confined Stark effect (QCSE).

The need to confine the carriers in thin wells results in high carrier densities that encourage alternative non-radiative ('Auger-like') recombination, reducing the conversion efficiency of electrical power into light ('efficiency droop').

The use of (303̄1) material allowed the researchers to create wells between 10nm and 100nm thick, while maintaining electron-hole wavefunction overlap. The device material (Figure 1) was grown on semi-polar (303̄1) free-standing GaN substrates by metal-organic chemical vapor deposition (MOCVD). The substrates came from Mitsubishi Chemical.

Calculations of the band structure for a 10nm-thick In_{0.12}Ga_{0.88}N active region suggested that the single well structure would have a much

Contact	p-GaN Mg-doped	60nm
Electron blocking	p-Al _{0.15} Ga _{0.85} N Mg-doped	16nm
Barrier	GaN	10nm
Active	InGaN	10nm-100nm
Barrier	GaN	15nm
Superlattice	10x(InGaN/GaN) Si-doped	10x(3nm/3nm)
Buffer	n-GaN Si-doped	1μm
Substrate	(30-3-1) GaN	

Figure 1. Heteroepitaxial structure.

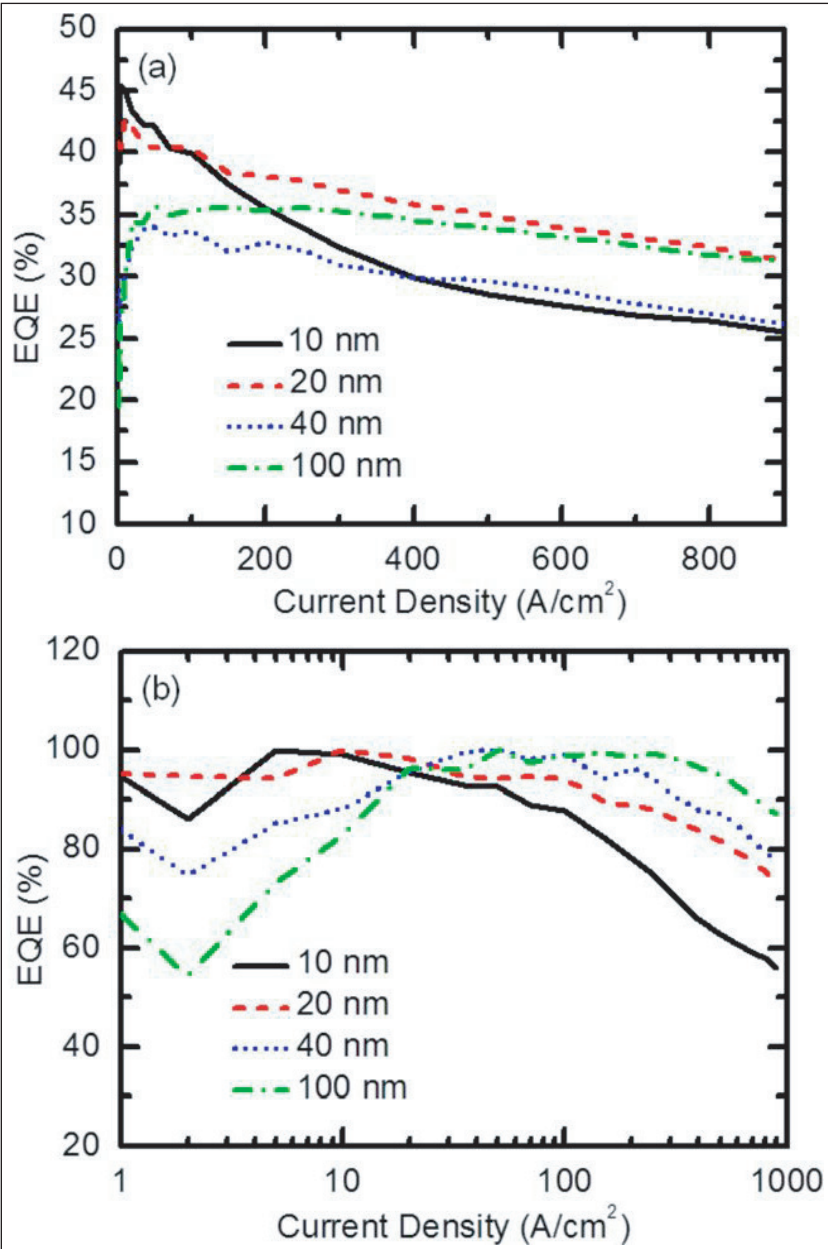


Figure 2. (a) Absolute EQE versus current density and (b) normalized EQE versus current density on a logarithmic scale for LED devices with active region thickness 10–100nm (pulsed condition, 1% duty cycle).

better electron-hole overlap compared with the same structure grown on c-plane material. Theoretical considerations also suggested that thicker layers of InGa \bar{N} could be grown on (30 $\bar{3}\bar{1}$) material before misfit dislocation formation at heterointerfaces would become a problem.

In fact, the researchers found an increased critical thickness for misfit dislocation formation of 30nm for (30 $\bar{3}\bar{1}$) In $_{0.1}$ Ga $_{0.9}$ N, compared with 20nm for semi-polar (20 $\bar{2}\bar{1}$) InGa \bar{N} — a crystal orientation that UCSB has experimented with extensively. Further, the impact on electroluminescence of increasing the active region thickness beyond the critical value was much less severe when comparing (30 $\bar{3}\bar{1}$) with (20 $\bar{2}\bar{1}$) devices.

LEDs were formed with 0.1mm 2 rectangular active region mesas. The p-contact was covered with indium tin oxide (ITO) transparent current-spreading material. The n-contact metals were titanium/aluminium/nickel/gold. Contact pads consisted of chromium/nickel/gold. The back-side of the device was roughened, presumably to improve light extraction. The LEDs were mounted on silver headers and encapsulated in silicone.

Although 10nm single wells demonstrated the peak external quantum efficiency (EQE) under pulsed current operation, devices with 20–40nm demonstrated higher EQEs at higher injection currents (Figure 2). Pulsed current operation is used to avoid performance degradation from self-heating effects.

The thermal droop effect was also measured by subjecting the devices to different temperatures (Figure 3). The ratio of EQEs at 100°C and 20°C ('hot/cold factor') was around 0.9 for well thicknesses in the range 10–40nm. Thicker wells of 100nm had more thermal droop with a 0.8 hot/cold factor.

A 15nm-well device was assembled into an optimized vertical transparent package, achieving an EQE of more than 50%. At 1kA/cm 2 current density, the device had an EQE of 33% and light output power of 1008.7mW. The wavelength of the emission was around 412nm with a narrow linewidth of ~16nm,

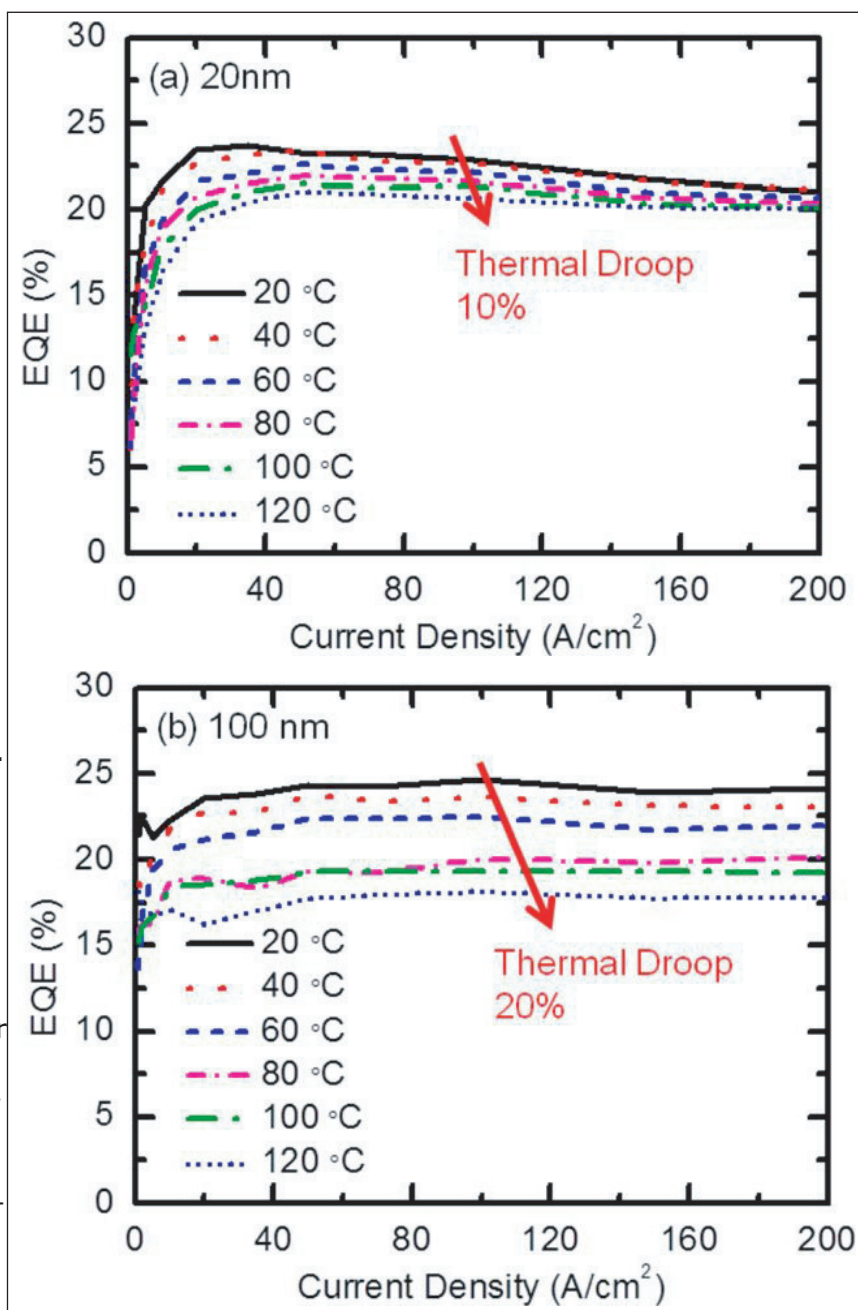


Figure 3. EQE versus current density measured at different temperatures for devices with (a) 20nm- and (b) 100nm-thick active regions.

full-width half maximum. Up to 1kA/cm 2 , the wavelength shift was small, of the order of nanometers. ■

<http://dx.doi.org/10.1063/1.4900793>

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Staircase quantum barriers to improve LED efficiency at high current

Efficiency droop of only 3.3% at 200A/cm² current density has been achieved in a 450nm-wavelength InGaN LED.

Researchers based in China have found "remarkably reduced efficiency droop" from staircase (SC) thin indium gallium nitride (InGaN) quantum barrier (QB) light-emitting diodes (LEDs) [Kun Zhou et al, Appl. Phys. Lett., vol105, p173510, 2014]. The 200A/cm² droop for a SC-QB LED was just 3.3% from the peak value. The light output power for the SC-QB LED was 47% higher than for a thin QB device, also at 200A/cm².

InGaN LEDs suffer from a fall-off of efficiency at high currents.

Researchers have found that one particular problem in such devices is the poor injection of holes into the light-emitting multiple quantum well (MQW) region. The holes that do get into the MQW tend to be concentrated toward the p-GaN contact end of the device. Non-uniform concentration results in high-carrier-density regions where non-radiative Auger-like recombination mechanisms could sap efficiency.

Attempts have been made to improve hole injection into and distribution across the MQW by thinning the barriers between wells. These efforts have met with some success by other groups, but the team from Chinese Academy of Sciences' Suzhou Institute of Nano-tech and Nano-bionics (with members also variously associated with Key Laboratory of Nanodevices and Applications and Suzhou Nanojoin Photonics Co Ltd) did not find any significantly improved droop behavior by thinning barriers.

Instead, the researchers used a design with quantum barriers that changed in composition so that the barrier height varied between the various wells in a staircase-like manner to encourage more uniform hole distributions. The LED structures (Figure 1) were grown on flat (0001) c-plane sapphire using metal-organic vapor phase epitaxy. The buffer consisted of 30nm low-temperature GaN nucleation and 1μm unintentionally doped uGaN layers. The nGaN contact layer was 4μm thick. The electron-blocking layer (EBL) was 20nm aluminium gallium nitride (pAl_{0.2}Ga_{0.8}N). The pGaN contact layer was 120nm.

The multiple quantum well (MQW) light-emitting active region consisted of either a standard 5-period In_{0.16}Ga_{0.84}N/GaN or In_{0.16}Ga_{0.84}N/In_xGa_{1-x}N well/barrier structure. The wells were 2.5nm, while the barrier

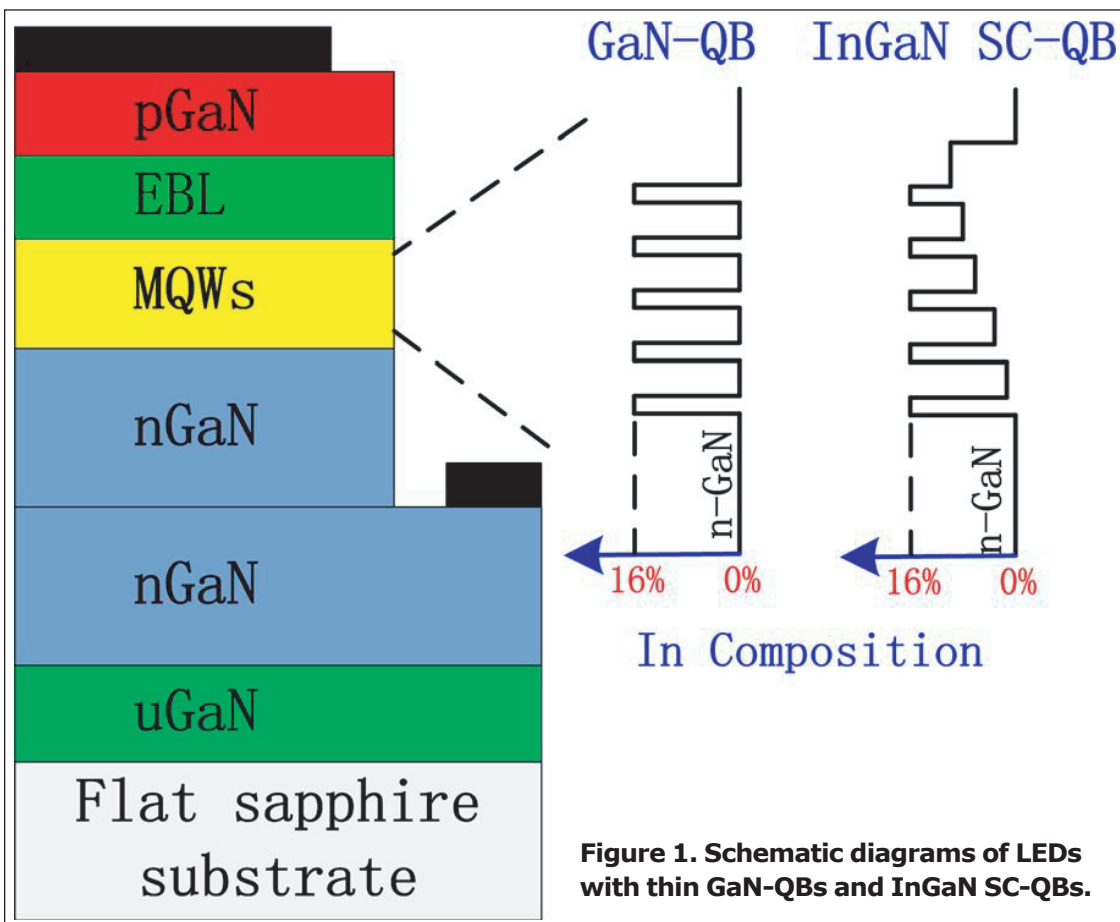


Figure 1. Schematic diagrams of LEDs with thin GaN-QBs and InGaN SC-QBs.

thickness and composition was varied.

MQWs with $\text{In}_{0.16}\text{Ga}_{0.84}\text{N}/\text{GaN}$ structure had barriers in the range 3nm–6nm. Standard 450nm LEDs often have thicker barriers of more than 10nm.

The staircase quantum barriers (SC-QBs) in the $\text{In}_{0.16}\text{Ga}_{0.84}\text{N}/\text{In}_x\text{Ga}_{1-x}\text{N}$ MQWs were fixed in thickness at 5nm. The SC-QB indium composition was varied between 2% and 10% (0.02–0.10) in steps of 2% from the nGaN to pGaN ends of the structure.

The researchers also produced samples with 'monitor wells' of 480nm wavelength replacing one of the 450nm wells. The aim of the monitor wells was to gauge the success in improving hole transport through the structure.

The epitaxial material was annealed to activate the magnesium doping of the p-type layers. Standard LED fabrication resulted in $250\mu\text{m} \times 400\mu\text{m}$ chips. The p-contact included an indium tin oxide (ITO) transparent electrode layer.

The devices with thin GaN QBs demonstrated similar droop behavior with the best external quantum efficiency (EQE) for the thickest barrier of 6nm under pulsed operation (20 μs). For 3–6nm barriers the peak efficiency occurred in the range 15–24A/cm². The droop from maximum at 200A/cm² was in the range 23–30.6%. The smaller droop was from the 3nm device, but this was more the result of having a lower peak EQE.

The thinner barriers also reduced the blue-shift of the peak wavelength with increasing current, possibly due to smaller (strain-dependent) piezoelectric fields in the wells, according to the researchers. Thick quantum barriers impose the lattice constant of GaN more rigidly on the intervening wells.

Thin barriers should improve tunneling of holes and, since the droop is not significantly improved, the researchers conclude that tunneling is not the main mechanism for hole transport in thin GaN-QB LEDs.

The researchers then compared a 5nm thin GaN QB LED with a SC-QB device (Figure 2, Table 1). The SC-QB LED performs better when the current injection increases beyond 35A/cm². While the thin QB LED EQE peaks at 22.1A/cm², the maximum for the SC-QB device occurs at 95.1A/cm².

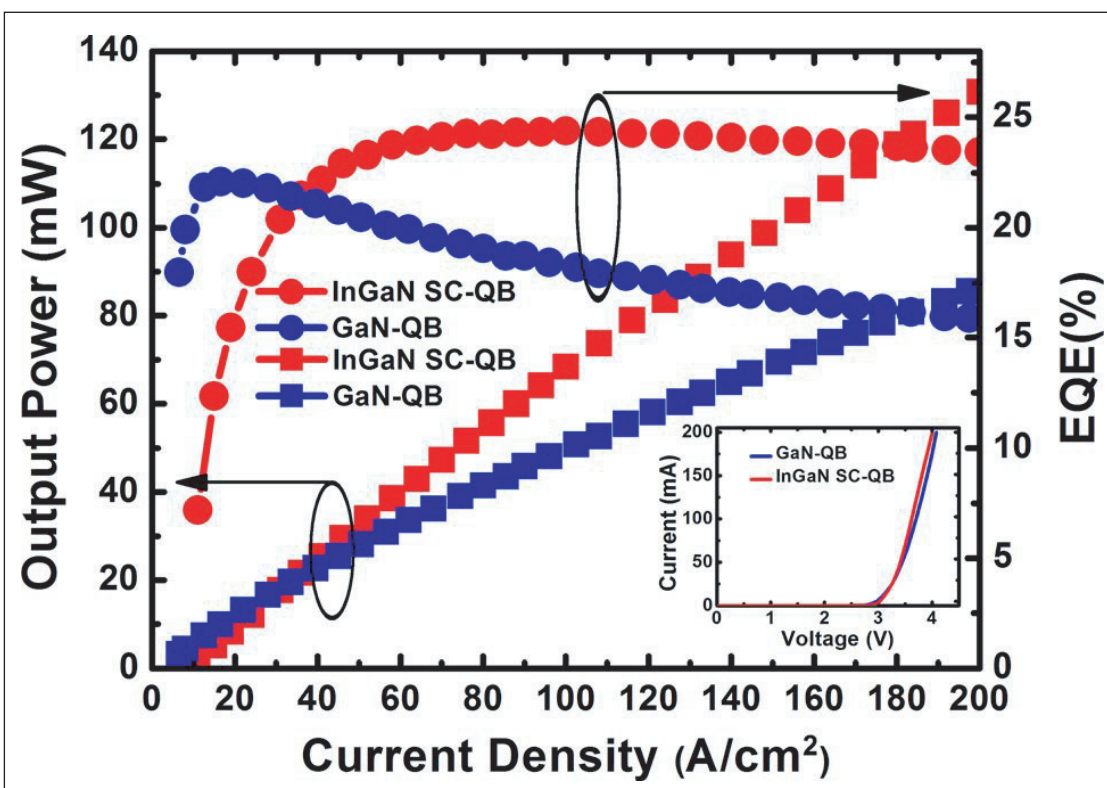


Figure 2. Electroluminescence output power and EQE versus injected current density for GaN-QB and InGaN SC-QB LEDs. Inset: corresponding current–voltage curves.

The 200A/cm² droop values were 28.4% and 3.3% for the thin QB and SC-QB devices, respectively. The light output power for the SC-QB LED was 47% higher than for the thin QB device at 200A/cm². The researchers attribute the improved droop to lower carrier densities in the individual wells of the SC-QB structure.

LEDs with monitor wells suggested that the thin QB devices had a steady descent in intensity from well 1 to well 5 (pGaN to nGaN end) for an injection current of 200A/cm². Well 5 had an intensity that was a factor of 4.5 down on that of well 1.

With SC-QBs, the least intensity came from well 4, which was a factor of 1.7 down on well 1. The more uniform distribution of the light emission across the wells in the SC-QB supports the idea that the reduction in droop results from the holes more effectively penetrating the MQW structure, giving lower carrier density in the individual wells. ■

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Author: Mike Cooke

Table 1. Power and efficiency values.

Device	Injection current density	Output power	EQE
GaN-QB LED	20A/cm ²	12.0mW	22.0%
InGaN SC-QB LED	20A/cm ²	9.0mW	16.4%
GaN-QB LED	100A/cm ²	50.0mW	18.3%
InGaN SC-QB LED	100A/cm ²	68.4mW	24.4%

Resistance memory with all-nitride structure

Research could lead to monolithic transistor–resistor memory devices using III-nitride high-electron-mobility transistors.

Chinese Academy of Science researchers have developed a memory resistor (memristor) based on III-nitride semiconductors with a metal-insulator-semiconductor (MIS) structure [Yiren Chen et al, Appl. Phys. Lett., vol105, p193502, 2014].

The team from State Key Laboratory of Luminescence and Applications, Changchun, believes that the structure could result in monolithic integrated one-transistor-one-resistor (1T1R) memory in conjunction with III-nitride high-electron-mobility transistors (HEMTs).

Similar devices are being developed in mainstream silicon technologies as an alternative to the capacitance-based structures used commercially.

The nitride memristor had two resistance levels that could be set or reset to provide bipolar memory states. The device (Figure 1) was based on an n-type aluminium nitride (AlN) on gallium nitride (GaN) structure grown on c-plane sapphire through metal-organic chemical vapor deposition (MOCVD).

The sapphire was subjected to thermal desorption of hydrogen before the MOCVD processing. The GaN consisted of a 36nm low-temperature 550°C nucleation layer, 1µm of undoped buffer material, and 200nm of silicon-doped n-GaN. The non-nucleation layers were

grown at 1050°C. The final 80nm AlN insulator layer was grown at 1100°C.

The memory device was fabricated by creating an AlN mesa through inductively coupled etch, depositing and annealing a titanium/aluminium ohmic electrode on the n-GaN surface and a Schottky nickel contact on the AlN mesa.

Decreasing the voltage across the device to -8V caused the structure to switch from a high resistance state (HRS) to a low resistance state (LRS) at -3V (Figure 2). The researchers designated this as the 'SET' process. 'RESET' occurred through sweeping up through a negative differential resistance region between +1.7V and +2.2V.

Repeating the SET/RESET processes for 100 cycles with -0.5V as the reading voltage, the researchers found a "slight" degradation in the separation between the LRS and HRS. This is attributed to increased leakage through dislocations in the III-nitride materials. The researchers say that the device needs improvement in this respect.

The researchers, on the basis of space-charge-limited current theory, believe the memristor effect is related to traps in the AlN layer. The AlN growth temperature

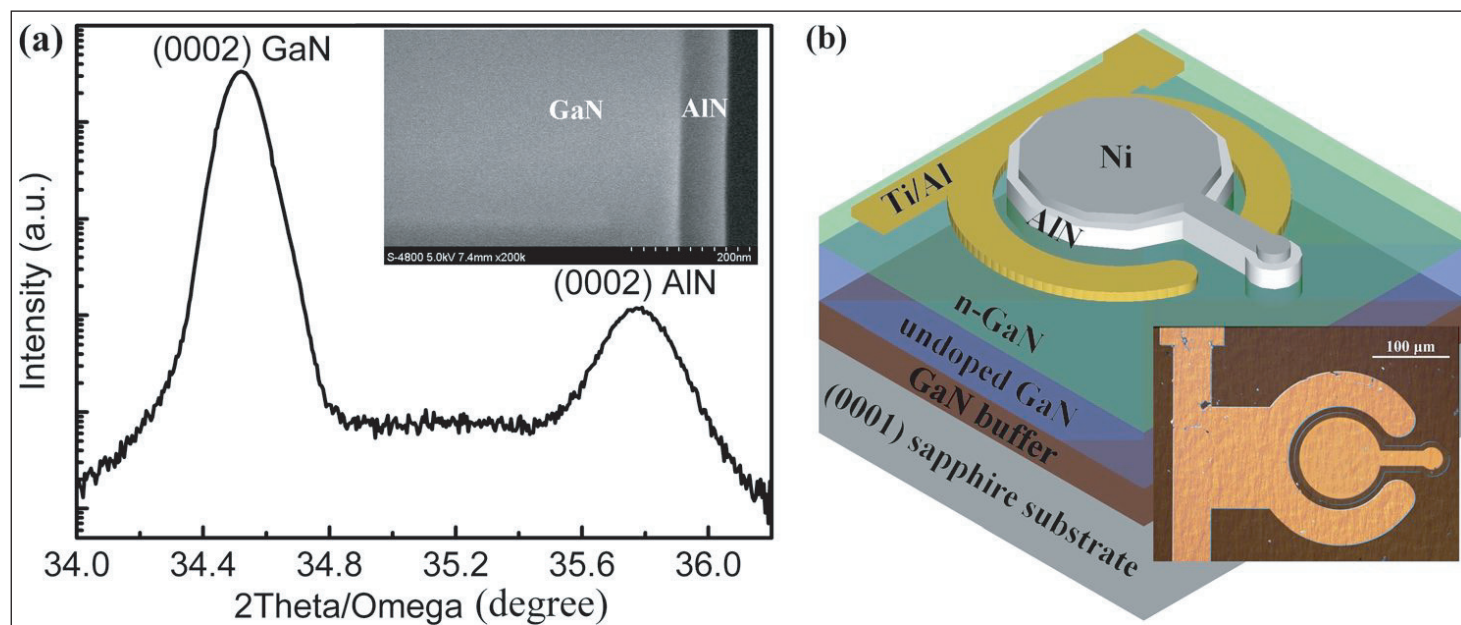


Figure 1. (a) (0002) plane 2θ - ω scan of AlN/n-GaN structure x-ray analysis. Inset: cross-sectional SEM image. (b) Schematic configuration of AlN/n-GaN MIS device. Inset: metallographic micrograph of MIS cell.

of 1100°C is relatively low, leading to a large number of traps.

Analysis of temperature-dependent measurements suggested that the traps were mainly nitrogen vacancy energy levels. The researchers also think that the charge polarization of the chemical bond in AlN creates an electric field that tilts the potential wells of the traps, facilitating transport of injected carriers.

Negative voltages fill up the traps, allowing a hopping current. A positive voltage bends the GaN conduction band downward toward the AlN interface, creating a well where electrons accumulate, inhibiting current flow by space-charge effects. Also, the field direction enhances the tilting arising from the spontaneous polarization. The trap levels empty, cutting off the hopping current.

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 Author:
 Mike Cooke

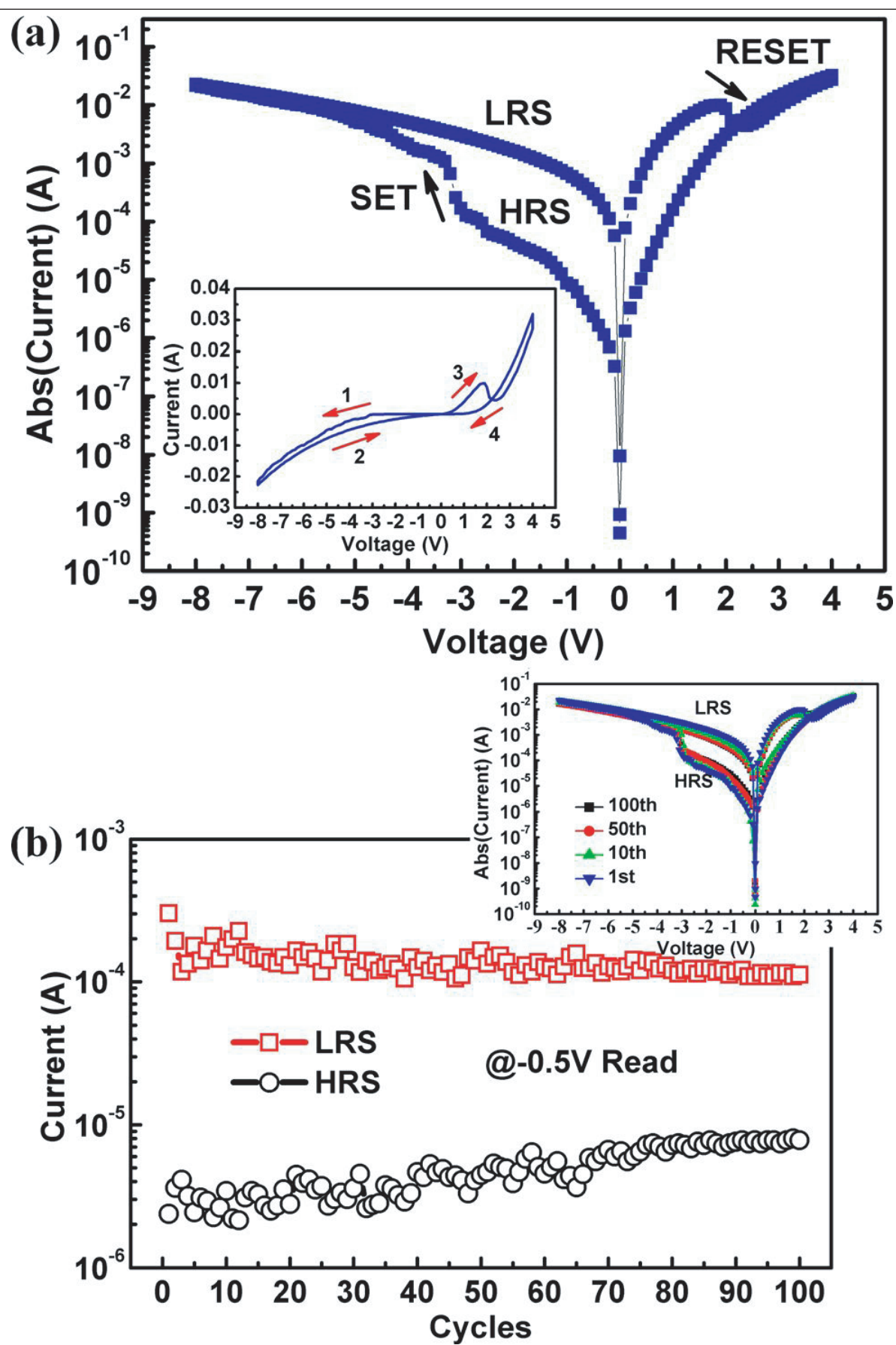


Figure 2. (a) Typical current-voltage (I-V) curve of pristine AlN/n-GaN MIS device shown in semi-logarithmic scale. Direction pointed by red arrows numbered 1 to 4 in inset is sequence of sweeping voltage. (b) Endurance performance of AlN/n-GaN MIS device. Inset: representative I-V curves of 100 sweeping cycles.

Double heterostructure with InGaN channel demonstrates high mobility

InGaN channels have been developed with better high-temperature performance than double heterostructures with GaN channels.

China's Xidian University has been developing III-nitride double heterostructures (DHs) with indium gallium nitride (InGaN) channels with a view to high-electron-mobility transistors (HEMTs) [Yi Zhao et al, Appl. Phys. Lett., vol105, p223511, 2014]. The resulting structures boast the highest reported mobility for InGaN channels and superior transport at high temperature, according to the research team. Nitride semiconductor HEMTs are being developed for microwave power and power switching applications. High-temperature operation could reduce expensive thermal management measures such as cooling or the need for high-thermal-conductivity substrates.

Although single heterostructures (SH) with just a barrier on a buffer/channel layer can achieve higher mobility, high-frequency transistors with short gates fabricated from such materials can suffer short-channel effects that reduce the actual performance far from the ideal. Double heterostructures add a back barrier to block off leakage currents and improve carrier confinement. The DH formation can also reduce short-channel effects such as drain-induced barrier lowering (DIBL) and low punch-through voltages.

The samples (Figure 1) were grown on c-plane sapphire through metal-organic chemical vapor deposition (MOCVD). The transition AlGaIn layer was compositionally graded with increasing aluminium content to avoid the formation of a parasitic two-dimensional

Barrier	InAlN	13nm	
Interlayer	AlN	1nm	
Channel	InGaN	10nm	720°C
Back barrier	AlGaIn	150nm	1050°C
Transition	AlGaIn	30nm	940-1050°C
Buffer	GaN	1500nm	940°C
Nucleation	AlN	60nm	1075°C
Nucleation	AlN	20nm	620°C
Substrate	c-plane sapphire		

Figure 1. InGaN DH sample structure.

electron gas (2DEG) in the GaN buffer beneath. The composition grading was also designed to improve the crystal quality of the back-barrier layer. The carrier gas of the precursors into the MOCVD chamber was changed from hydrogen to nitrogen after the back-barrier was deposited. The AlN interlayer between the channel and top barrier was designed to suppress alloy scattering from the InAlN. Reduced electron scattering should improve carrier mobility. The top InAlN barrier was grown using pulsed MOCVD, alternating the injection of metal-organic precursors and ammonia nitrogen source. X-ray and photoluminescence analysis suggested that the AlN mole fraction of the AlGaIn bottom barrier was

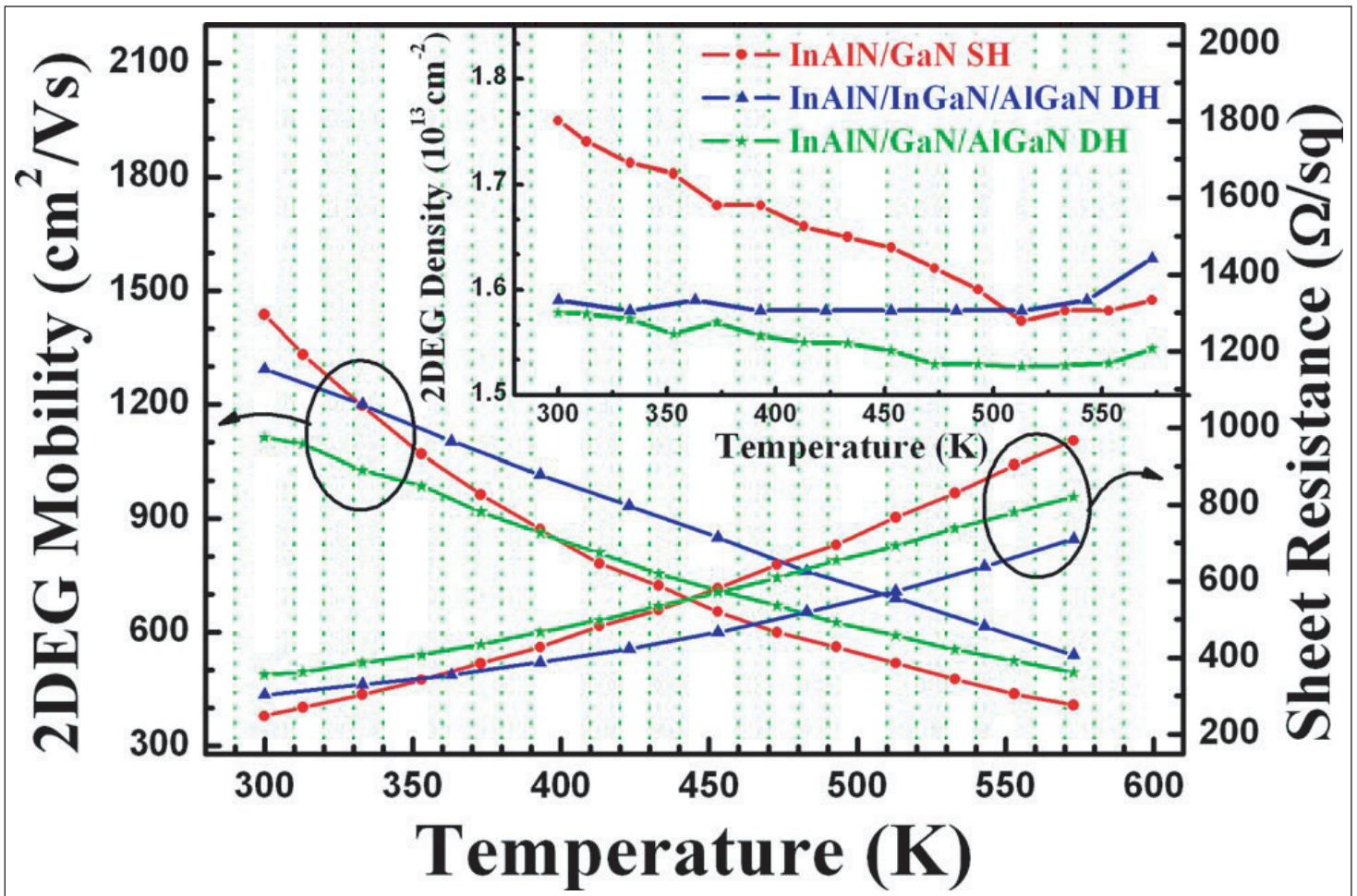


Figure 2. Temperature dependences of Hall mobility and sheet resistance in traditional InAlN/GaN SH sample, InAlN/InGaN/AlGaIn DH sample, and InAlN/GaN/AlGaIn DH sample. Inset: carrier concentration as a function of temperature.

13%. Photoluminescence spectroscopy gave an InN mole fraction of 10% for the InGaN channel.

Room-temperature Hall measurements resulted in an electron mobility value of 1293cm²/V-s – claimed as the “highest reported for an InGaN-channel heterostructure”. Sheet resistance from contactless eddy current resistance mapping tests averaged at 289Ω/square with 1.6% wafer uniformity. Capacitance–voltage measurements placed the peak electron density at about 14nm below the sample surface, which corresponds with the 13nm+1nm of the top barrier and interlayer, respectively. The C–V measurements also showed effective suppression of a possible parasitic 2DEG channel in the GaN buffer.

With a view to power HEMT operation, the researchers also tested the robustness of the channel mobility at elevated temperatures up to 573K (300°C). The sample was compared with InAlN/GaN single- and InAlN/GaN/AlGaIn double-heterostructures (Figure 2). At room temperature (300K), the InAlN/GaN single-heterostructure provided the highest mobility of 1437cm²/V-s (247Ω/square sheet resistance). This higher performance is attributed to the absence of a back-barrier and thus of a source of alloy scattering.

All samples showed reduced mobility at high temperature. This was attributed to increased polar optical phonon scattering of electrons. The mobility (and carrier density) of the single-heterostructure sample degraded faster than for the double-heterostructure samples. At 573K, the single-heterostructure mobility was 407cm²/V-s (-70%). The lower mobility and carrier density reduced the conductivity of the single-heterostructure sample, leading to increased sheet resistance at 966Ω/square.

The carrier densities of the double heterostructures were fairly constant over the measured temperature range, indicating good carrier confinement. The InGaN-channel double heterostructure had the higher mobility and carrier density over the range. At 573K, the mobility was 539cm²/V-s, giving a sheet resistance of 711Ω/square. The corresponding values for the GaN double heterostructure were 493cm²/V-s and 820Ω/square.

The researcher suggest that “InGaN channels have the potential to further improve the 2DEG mobility above that of the traditional GaN channels in DHs”. ■

<http://dx.doi.org/10.1063/1.4903293>

Author: Mike Cooke

Boron nitride releases GaN transistors from self-heating degradation

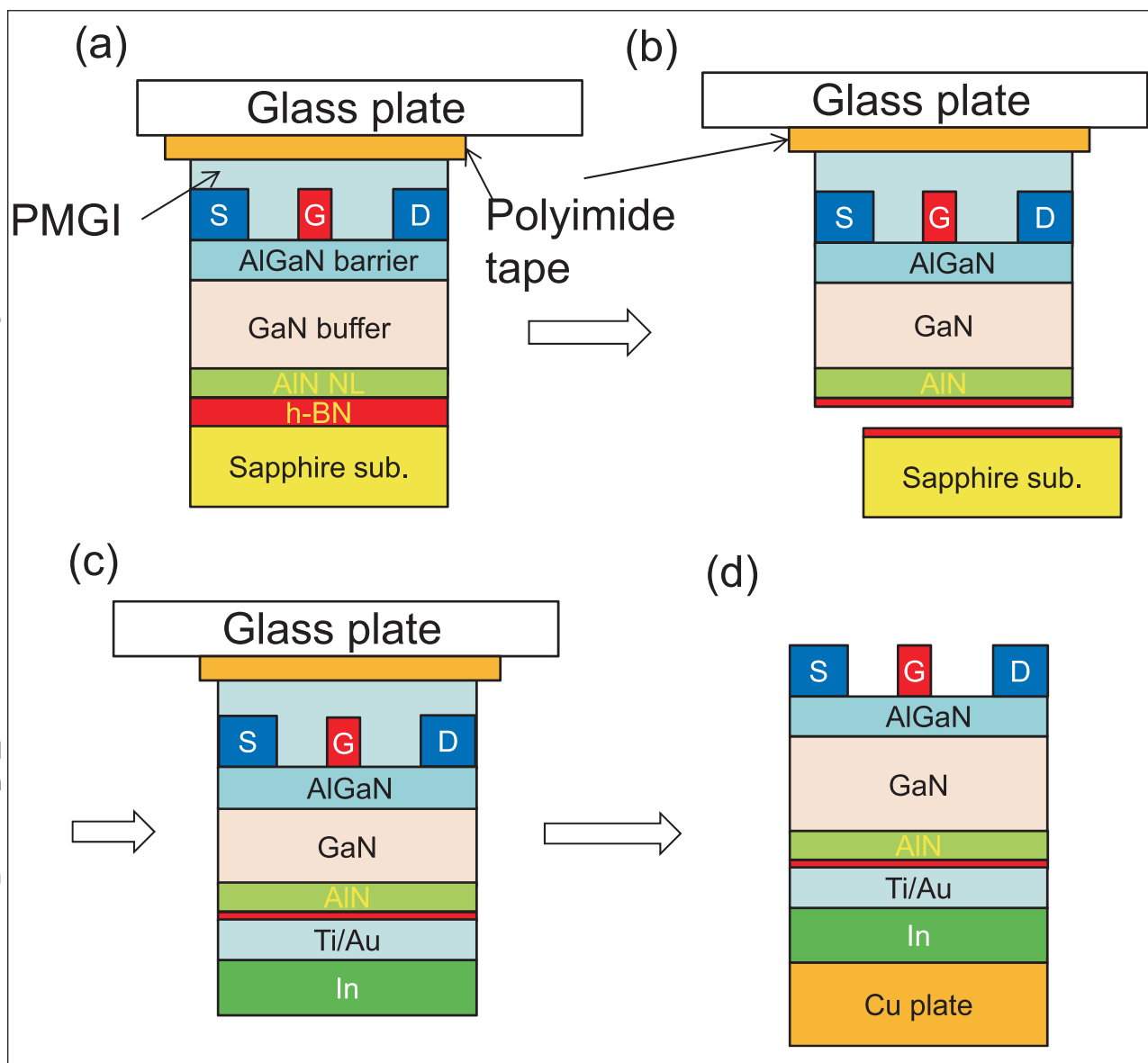
Transfer to copper plate improves thermal dissipation and increases drain current at high bias.

NTT Basic Research Laboratories in Japan has used a hexagonal boron nitride (h-BN) layer to release and transfer gallium nitride (GaN) high-electron-mobility transistors (HEMTs) from sapphire substrate to thermally conducting copper, improving performance [Masanobu Hiroki et al, Appl. Phys. Lett., vol105, p193509, 2014]. The same team has previously used h-BN to grow and transfer GaN-based LEDs in a

similar manner [www.semiconductor-today.com/features/PDF/SemiconductorToday_MayJune2012_Mechanicalreleaseofnitride.pdf].

The researchers used c-plane sapphire as the growth substrate. Although GaN growth on sapphire is well established, self-heating effects in the operation of the resulting devices can cause degradation of performance. Sapphire has a low thermal conductivity of 40W/mK,

Figure 1. Schematic process sequence for transfer of AlGaIn/GaN HEMT from sapphire substrate to copper plate. (a) Temporary adhesion of HEMT to glass plate with polyimide tape. (b) Mechanical release of HEMT from sapphire by cleavage of h-BN layer. (c) Ti/Au and In deposition on backside of sample. (d) Adhesion of sample to copper plate by thermal bonding and release from glass.



compared with 150W/mK for silicon, 350W/mK for silicon carbide, or 600–2000W/mK for diamond. However, these alternatives either suffer from a poor lattice match with GaN or are extremely expensive.

The h-BN layer was grown using triethyl-boron and ammonia (NH_3) as precursors for metal-organic vapour phase epitaxy. Hexagonal BN has a similar crystal structure to graphite, allowing easy cleavage. The further device layers consisted of 100nm aluminium nitride (AlN) nucleation, 3 μm GaN buffer, and 32nm $\text{Al}_{0.27}\text{Ga}_{0.73}\text{N}$ barrier.

The transistor fabrication included mesa etch for electrical isolation, and ohmic contact and Schottky gate formation. The titanium/aluminium/nickel/gold ohmic contacts were annealed. The gate metals were nickel/gold. The gate was 1.5 μm long and 100 μm wide. The source-drain spacing was 6 μm .

The transfer process consisted of coating the sample with polymethylglutarimide (PMGI) and attaching it to glass with polyimide tape (Figure 1a). The sapphire substrate was then mechanically removed, cleaving the h-BN release layer (Figure 1b). The titanium/gold was deposited on the backside of the sample, followed by electroplating 1 μm of indium (Figure 1c). Thermal fusion bonding at 180°C was then used to attach the devices to thermally conductive copper (Figure 1d). The bonding temperature was above the melting point of indium. Thermal conductivity of the copper was 390W/mK. The glass was removed by dissolving the PMGI in organic solvent.

Growing nitride semiconductor materials on h-BN was found to increase dislocation densities by about an order of magnitude, according to x-ray analysis. However, the increase in dislocation density was not found to impact the Hall mobility of 1360 $\text{cm}^2/\text{V}\cdot\text{s}$ or sheet electron density of $7.4 \times 10^{12}/\text{cm}^2$. The researchers point out that dislocations are not believed to be the dominant electron scattering mechanism at the dislocation density estimated.

The transfer to copper plate improved the drain current flow at high drain bias (Figure 2). Before transfer to copper, the drain current peaks — giving 'saturation' — and then falls off significantly (negative differential resistance). With a 2V gate potential, the fall from saturation to 20V drain bias was 30%. In a device on copper, the fall was only 8%. The negative differential resistance effect is typically attributed to self-heating.

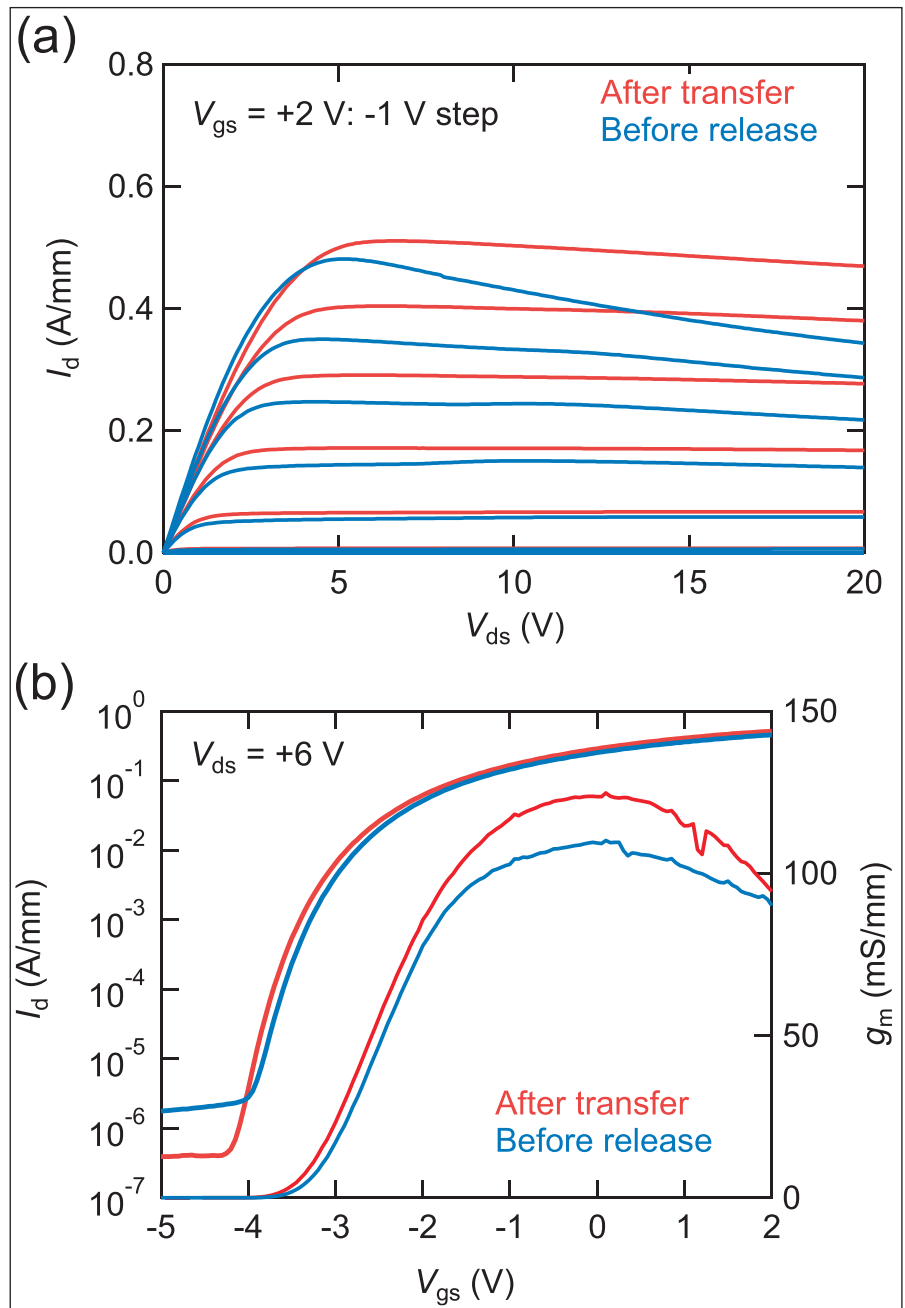


Figure 2. Drain current–voltage (I_d – V_{ds}) characteristics of AlGaN/GaN HEMTs before release from sapphire (blue line) and after transfer to a copper plate (red line). (b) Drain current- and transconductance–gate voltage (I_d – V_{gs} , g_m – V_{gs}) transfer characteristics at 6V drain bias.

Another benefit of transfer to copper was an increased transconductance: 120mS/mm with 6V drain bias, compared with 100mS/mm before transfer. The threshold voltage of the devices was –3.5V, both before and after transfer.

Infrared images suggested that the peak temperature of transistors at 20V drain bias was 50°C before and 30°C after transfer to copper. The drain currents were 40mA and 50mA, respectively. The corresponding power dissipations were 0.8W and 1W. ■

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Author: Mike Cooke

Millimeter-wave performance of gallium nitride transistors on silicon substrates

The first large-signal measurements at 94GHz have been reported for AlInN/GaN HEMTs on high-resistance silicon.

Researchers in Switzerland have reported the first large-signal 94GHz operation of aluminium indium nitride/gallium nitride (AlInN/GaN) high-electron-mobility transistors (HEMTs) on high-resistance (HR) silicon [Diego Marti et al, IEEE Electron Device Letters, published online 4 November 2014]. The team was based at ETH-Zürich and École Polytechnique Fédérale de Lausanne.

Better performance has been achieved in AlInN/GaN HEMTs on the extremely expensive silicon carbide (SiC) substrates due to the better lattice match between SiC and GaN. However, the team believes that GaN transistors built on silicon could lead to low-cost millimeter-wave applications.

The 94GHz frequency falls in the W-band (75–110GHz), which is used for satellite communications, millimeter-wave radar research, military radar targeting and tracking, and some non-military applications. There is an atmospheric window at 94GHz. One 94GHz application is passive cameras for concealed weapon detection. Cruise control radar for automobiles uses 77GHz.

Up to now, GaN HEMTs on silicon have been restricted to K/Ka-band (less than 40GHz) performance. The epitaxial material (Figure 1) was grown on 50mm float-zone-refined high-resistance (10kΩ-cm) silicon (111) substrates. The two-dimensional electron gas (2DEG) channel near the aluminium indium nitride (AlInN)/gallium nitride barrier/buffer interface had a Hall mobility of 1190cm²/V-s. Van der Pauw measurements gave a sheet resistance of

Figure 1. Epitaxial material structure.		
Cap	GaN	2nm
Barrier	Al _{0.83} In _{0.17} N	3.5nm
Spacer	AlN	1nm
Buffer/channel	GaN	1µm
Transition	Graded AlGaIn	1µm
Nucleation	AlN	
Substrate	HR-Si (111)	

328Ω/square, corresponding to a sheet carrier density of 1.6x10¹³/cm². Transistors were fabricated through plasma etch mesa isolation, source-drain contact re-growth of

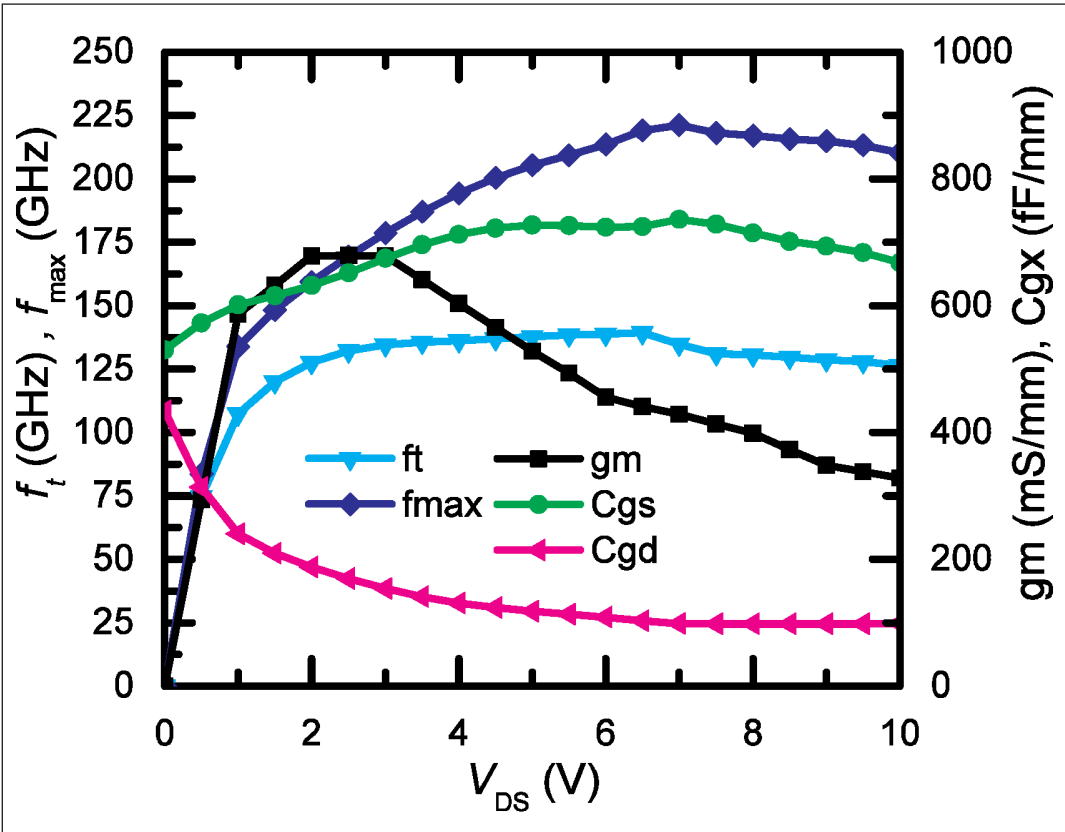


Figure 2. Drain voltage (V_{DS}) dependence of small-signal performance at a gate potential (V_{GS}) of -1.25V.

n^+ -GaN, deposition of titanium/platinum/gold metal ohmic contacts, and nickel/platinum/gold T-gate formation.

The re-growth used a silicon dioxide mask and ammonia molecular beam epitaxy (MBE). The gate footprint was 50nm long and 2x50 μ m wide. The gate stem and head were 200nm high and 500nm wide, respectively.

The source-drain and source-gate separations were 2 μ m and 0.5 μ m, respectively. The relatively large source-drain separation and short gate length were chosen to reduce current-collapse effects of pulsed/high-frequency operation. Although field plates are often used to avoid current collapse, the ETH/EPFL device did not have any.

A 75nm layer of silicon nitride was deposited for passivation. Contact pads consisted of titanium/gold.

A maximum DC drain current of 1.6A/mm was achieved at +2V gate potential. The peak transconductance was 650mS/mm at 5V drain bias and -1.5V gate potential. The on-resistance was 1.19 Ω -mm. Gate leakage with a -5V gate potential was 250 μ A/mm.

The researchers comment: "Because the gate length is only 50nm and because of the lack of a channel back-barrier, the channel pinch-off is incomplete at higher V_{DS} , though it remains adequate for the class A operating voltages considered here."

Pulsed measurements gave a higher maximum drain current of 2A/mm —

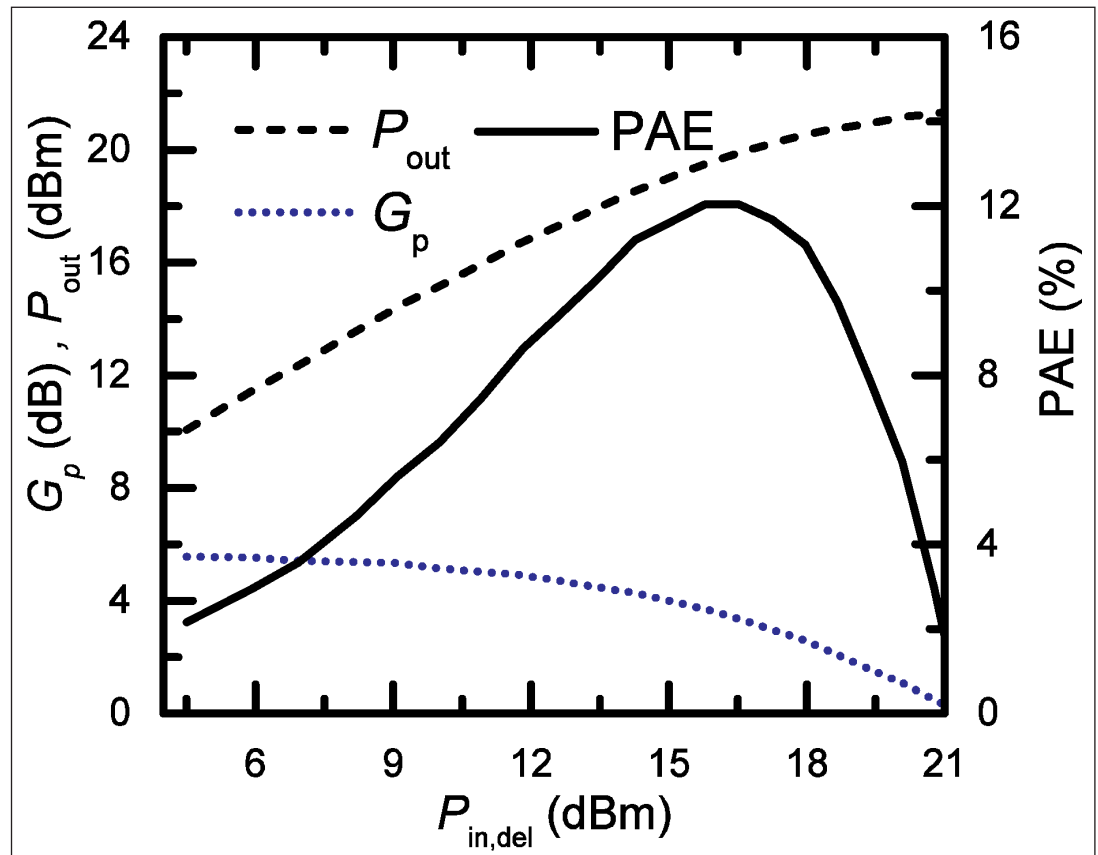


Figure 3. Power sweep of HEMT at 94GHz.

The 94GHz frequency falls in the W-band (75–110GHz), which is used for satellite communications, millimeter-wave radar research, military radar targeting and tracking, and some non-military applications. There is an atmospheric window at 94GHz. One 94GHz application is passive cameras for concealed weapon detection. Cruise control radar for automobiles uses 77GHz

the lower value for the DC measurement is attributed to self-heating effects.

Small-signal frequency analysis of the performance (Figure 2) gave a peak cut-off frequency (f_T) of 118GHz and maximum oscillation (f_{max}) of 210GHz. De-embedding the parasitic effect of the pads upgrades these values to 141GHz and 232GHz, respectively.

The 94GHz large-signal performance (Figure 3) showed a maximum power gain of 6dB. The peak power-added efficiency (PAE) of 12% was achieved with 1W/mm output power and 4dB associated power gain. The saturated output power was 1.35W/mm. The bias conditions were 1.2V on the gate and 9V on the drain.

A 3-stage power amplifier consisting of GaN transistors built on silicon carbide has achieved a PAE of 19% with 2.138W output power at 93.5GHz.

"The chosen bias point results from a trade-off between maximizing the drain-source voltage and keeping the current collapse reasonably small," the researchers write.

The researchers believe that further refinement of the epitaxial structure and passivation aimed at reducing current collapse and short-channel effects could further improve performance. ■

<http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=6945795>

Author: Mike Cooke

Power & speed highlights for compound semiconductors

Mike Cooke reports on presentations given at the recent IEEE International Electron Devices Meeting.

High mobility and high breakdown voltages are key factors that different compound semiconductors offer future electronics, promising high speed and high power handling. However, wide-ranging commercial application is waiting for the right mix of technological advance and economic cost breakthrough.

The annual IEEE International Electron Devices Meeting (IEDM 2014) in San Francisco, CA, USA in December is

a key event where such progress can be gauged. This year saw many reports of compound semiconductor research. Here we focus on power and high-speed electronics developments, along with optoelectronics. Finally, we look at some research into devices based on two-dimensional transition-metal dichalcogenide (TMDC) semiconductor layers – a topic that has recently become popular.

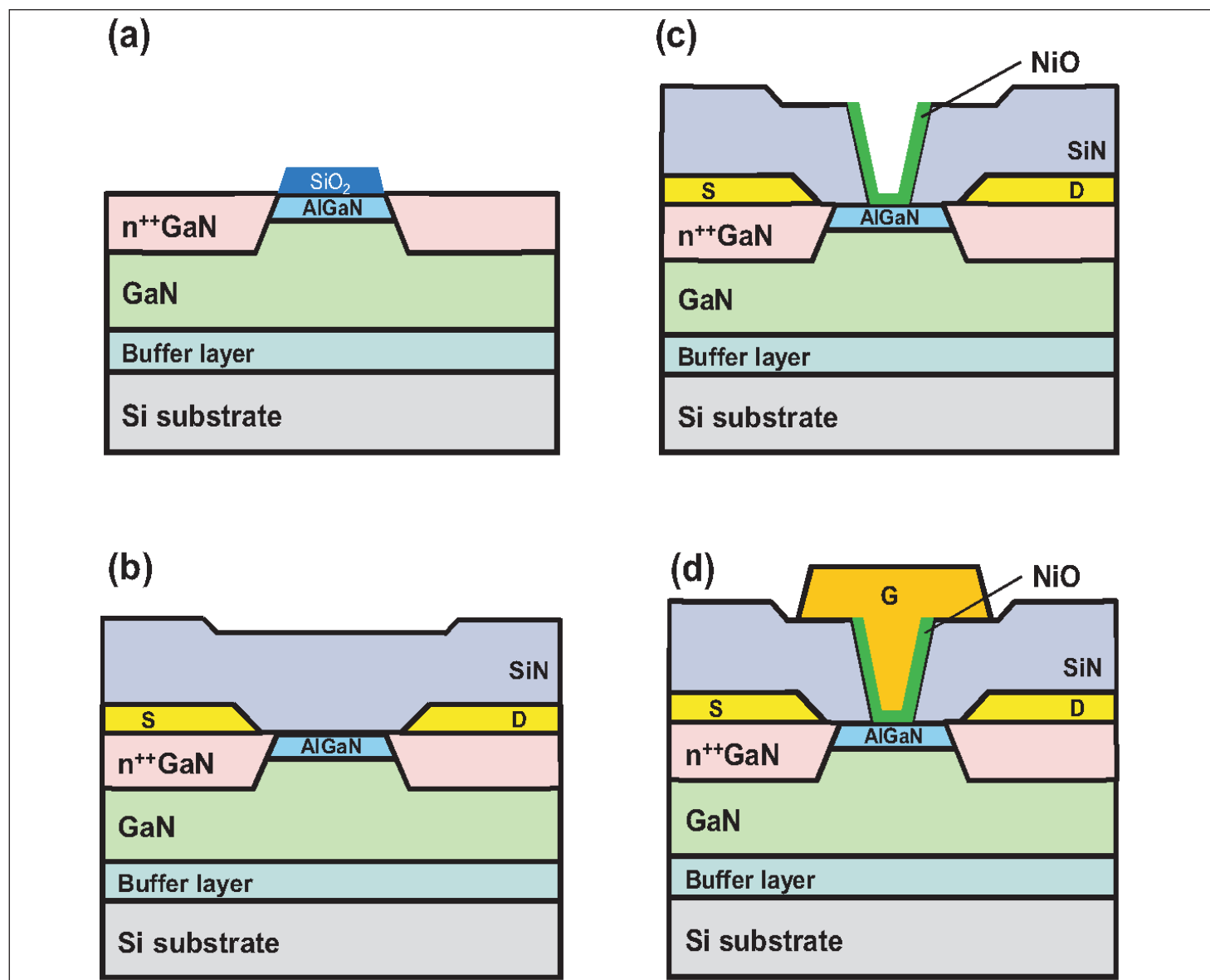


Figure 1. Processing steps of Panasonic/Kyoto normally-off GaN transistor: (a) selective re-growth of Ge-doped n++GaN layer, (b) silicon nitride (SiN) deposition on device surface, (c) lift-off formation of NiO film using ALD, (d) gate metal deposition.

Power

Gallium nitride (GaN) is one compound semiconductor that is being developed for high power – both in terms of power switching and power amplification of radio-frequency/microwave signals. There is also much interest in growing the material on large-area silicon substrates to enable cost reduction.

For power-efficient fail-safe switching, normally-off transistors are desired — but difficult to arrange in GaN-based devices. Japan's Panasonic Corp and Kyoto Institute of Technology presented a normally-off GaN-based transistor with germanium (Ge) doped n^{++} GaN re-grown ohmic contact [session 11.1]. The researchers claimed a record-breaking on-resistance (R_{on}) of $0.95\Omega\text{-mm}$ for their fabricated device. The maximum drain current and transconductance were 1.1A/mm and 490mS/mm , respectively. The threshold voltage was $+0.5\text{V}$ and the on/off current ratio 5×10^6 .

The device (Figure 1) featured p-type nickel oxide (NiO) as part of the gate structure selectively grown using atomic layer deposition (ALD) in the $1\mu\text{m}$ source-drain gap. The nickel oxide gate footprint was 400nm . The presence of nickel oxide shifts the threshold to positive voltages, giving the desired 'normally-off' characteristic. The germanium doping allows electron carrier densities of $10^{20}/\text{cm}^3$, beyond those achieved with silicon doping.

Panasonic/Kyoto grew the heterostructure on silicon using metal-organic chemical vapour deposition (MOCVD). The ohmic contact re-growth was also through MOCVD. The barrier layer was 10nm aluminium gallium nitride ($\text{Al}_{0.3}\text{Ga}_{0.7}\text{N}$).

The researchers comment: "We believe the proposed GaN-based transistor will contribute to the drastic increase of conversion efficiency in DC-to-DC converters represented by POL (Point Of Loads)."

Another Panasonic group reported an extension of its GaN-based normally-off gate injection transistor (GIT) technology to 8-inch (200mm) silicon wafers and shorter gate lengths [session 11.3]. This Panasonic team also used indium aluminium gallium nitride (InAlGaN) quaternary alloy to reduce series resistance. Gate driver integration and flip-chip assembly were applied to deliver faster switching.

In terms of edging towards commercial acceptance, Transphorm Inc researchers in Japan and the USA claimed the first GaN HEMT on Si based cascode packages to

pass Joint Electron Devices Engineering Council (JEDEC) qualification [session 2.6]. The researchers developed highly reliable 600V GaN HEMTs on silicon substrates. The devices in a cascode configuration package with high-voltage GaN HEMT and low-voltage Si MOSFET showed high breakdown voltages beyond 1700V with stable dynamic on-resistance. The researchers estimate a "conservative" mean time to failure (MTTF) of more than 10^7 hours at 600V .

Also, researchers from the wafer foundry giant Taiwan Semiconductor Manufacturing Co (TSMC) reported CMOS-compatible $100/650\text{V}$ enhancement-mode FETs and 650V depletion-mode MISFETs fabricated on 6-inch AlGaIn/GaN-on-Si wafers [session 17.6]. The devices demonstrated high breakdown voltages of more than 820V and a low specific on-resistance of $4\times 10^{-6}\Omega\text{-cm}^2$ with good wafer uniformity. The researchers stressed the need to optimize the epitaxial layers for improved device reliability.

Silicon carbide (SiC) is another popular material for potential future power electronics. Researchers at Toyota Central R&D Labs Inc, Japan's National Institute of Advanced Industrial Science and Technology (AIST) and the University of Yamanashi in Japan have been working to reduce feedback capacitance in SiC vertical junction field-effect transistors (VJFETs) [session 2.2]. Given the first listed organization, it is no surprise that potential applications include power conversion systems for hybrid electric vehicles (DC/DC converters, DC/AC inverters).

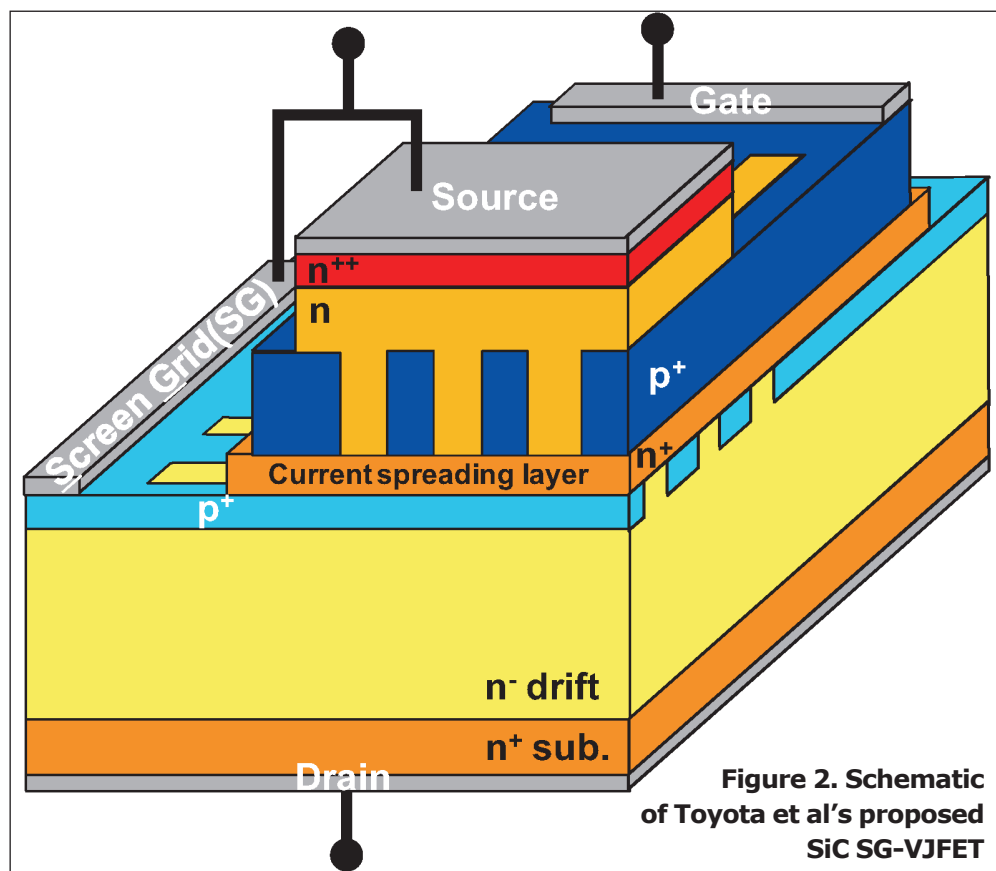


Figure 2. Schematic of Toyota et al's proposed SiC SG-VJFET

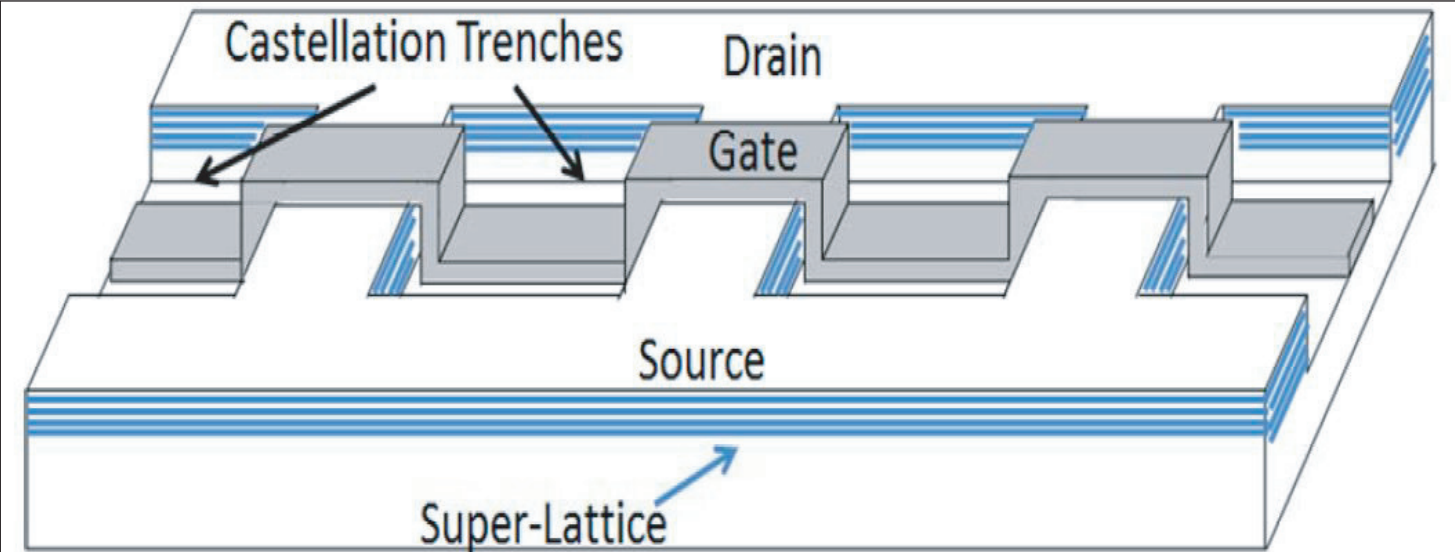


Figure 3. NGES' SLCFET device structure combining a super-lattice epitaxial channel with three-dimensional 'castellated' gate.

► Feedback capacitance slows down the performance of VJFETs, compared with traditional MOSFETs. However, VJFETs tend to have better reliability and long-term stability. The new 'screen-grid' (SG-)VJFET (Figure 2) used a p⁺ structure inserted between gate and drain to reduce feedback capacitance by about 80%, compared with a conventional VJFET (0.19nF/cm² versus 0.97nF/cm²). The SG-VJFET also had lower feedback capacitance than a traditional MOSFET (0.38nF/cm²). In inductive-load double pulse tests the low feedback capacitance and high switching speed capability of the SG-VJFET enabled the lowest total power dissipation compared with traditional SiC devices.

RF GaN

Northrop Grumman Electronic Systems (NGES) presented a 'super-lattice castellated field-effect transistor' (SLCFET) [session 11.5]. The device features a GaN super-lattice channel with a 3D gate. The median maximum drain current was more than 2.7A/mm. The pinch-off voltage was -8V. The on-resistance (R_{on}) was 0.41Ω-mm and the off-capacitance (C_{off}) was 0.19pF/mm.

The researchers see the device being used in phase shifters, attenuators, true time delay, filters and transmit/receive (T/R) RF switches. Such systems are applied to advanced phased-array radars, multi-function sensors, and wireless consumer electronics.

FETs are desirable to achieve low power consumption, fast switching, modest control voltages and reliability (features that are lacking in RF MEMS or diode systems).

Switch applications need low insertion loss (when on) and high isolation (when off). FETs tend to offer poorer performance when compared with RF MEMS and diode devices. Attempts to improve insertion loss (R_{on}) tend to adversely impact isolation (C_{off}), leading to a figure of merit F_{CO} ($1/2\pi R_{on}C_{off}$).

NGES' SLCFET had an F_{CO} of 2.1THz, compared with 2.4THz for diodes and 3.8THz for RF MEMS. Slow phase-change switches can have F_{CO} up to 12.5THz. Transistor-based devices tend to have F_{CO} of the order of hundreds of gigahertz — e.g. 840GHz for indium phosphide (InP) HEMTs.

The superlattice channel stacks a series of two-dimensional electron gas (2DEG) conducting layers to reduce on-resistance. A three-dimensional (3D) gate with a series of 'castellation trenches' ensures that the channel can be turned off (Figure 2). The gate wraps around the channel, allowing the electric field to penetrate into the channel layers. The structure reduces R_{on} while maintaining the C_{off} value.

"The combination of this super-lattice epitaxial structure in conjunction with the castellated, three-dimensional gate is, to the best knowledge of the authors, a new device topology for FETs," the NGES team writes.

NGES demonstrated the device using an AlGaIn/GaN heterostructure grown by metal-organic chemical vapor deposition on semi-insulating SiC. A single heterostructure had a sheet resistance of 300Ω/square — this was reduced to 60Ω/square for a superlattice structure.

Although the structure was not designed or optimized for high-frequency performance, the f_T cut-off frequency was 52GHz and the f_{max} maximum oscillation was 53GHz.

Wideband single-pole double-throw (SPDT) RF switch monolithic microwave integrated circuits (MMICs) for 1–18GHz operation in a series-shunt circuit topology achieved insertion loss less than 0.1dB and isolation greater than 26dB. The researchers say that this compares favorably with the performance of RF MEMS and diodes.

"By combining excellent RF switching performance with the numerous desirable aspects of FET based switching, the SLCFET is a key enabling technology for next-generation RF systems," the researchers conclude.

High speed

Indium gallium arsenide (InGaAs) is the most common compound semiconductor option being explored for high-mobility electronics. Massachusetts Institute of Technology (MIT) claimed a record transconductance ($g_{m,max}$) of $3.1\text{mS}/\mu\text{m}$ and R_{on} of $190\Omega\cdot\mu\text{m}$ in 80nm -gate-length self-aligned tight-pitch InGaAs quantum-well MOSFETs (QW-MOSFET) [session 25.1]. The result came as part of study led by Jesús A. del Alamo into the effect of scaling channel thickness (t_c) and metal contact length (L_c) using a fabrication process that features precise dimensional control. The channel thickness for the record transconductance was 9nm . The drain bias was 0.5V . The researchers believe their work could lead to III-V MOSFET high-performance applications.

In particular, the MIT team also claimed the first working front-end device structures with 40nm contacts and 150nm gate-to-gate pitch. The researchers say sub- 150nm pitch "is a significant leap in an effort to meet the requirements of the ITRS 2013 roadmap for III-V CMOS logic." Up to now, the densest III-V devices have tended to have around 500nm pitch.

Thick t_c (11nm) allowed increased mobility to $8800\text{cm}^2/\text{Vs}$. "To the authors' knowledge, this is the highest μ_{eff} in an InGaAs/InAs-channel MOSFET," the team writes. By contrast, a thin t_c gave better control of short-channel effects (SCEs). A 4nm t_c enabled a reduction in subthreshold swing to $111\text{mV}/\text{decade}$, compared with $159\text{mV}/\text{decade}$ for a 9nm t_c .

The devices (Figure 4) used a contact-first technology developed at MIT. The channel thickness t_b was controlled by reactive-ion and digital etching. The digital etch process allows nanometer-scale precision. The initial 10nm composite channel consisted of (top to bottom) 3nm $\text{In}_{0.7}\text{Ga}_{0.3}\text{As}$, 2nm InAs , and 5nm $\text{In}_{0.7}\text{Ga}_{0.3}\text{As}$. Above the channel was a 3nm InP barrier.

The contacts consisted of molybdenum on n^+ -InGaAs cap with a resistivity of $(8\pm 2)\times 10^{-9}\Omega\cdot\text{cm}^2$. Studies of the effect of scaling the contact length gave a contact resistance of $70\Omega\cdot\mu\text{m}$ for 40nm -long contacts. "These are encouraging results but more research is required to attain the required R_c in nanometer-scale contacts," the researchers comment.

Another group led by Jesús A. del Alamo at MIT claimed the first InGaAs/InAs heterojunction single nanowire (NW) vertical tunnel FETs fabricated by a top-down approach [session 25.5]. The fabrication involved III-V dry etching and a new technique for gate-source isolation.

The resulting devices were 50nm -diameter NW TFETs with a channel length of 60nm and equivalent oxide thickness of 1.2nm . The average subthreshold swing of the devices was $72\text{mV}/\text{decade}$ at 0.5V drain bias over

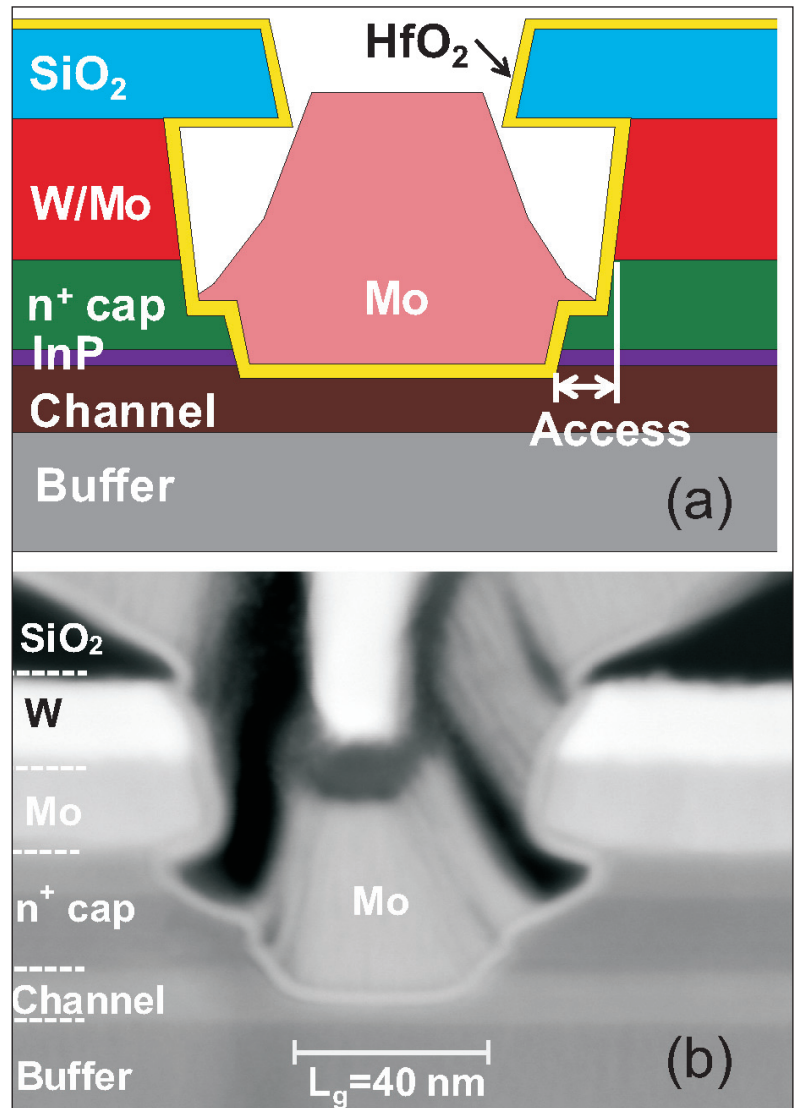


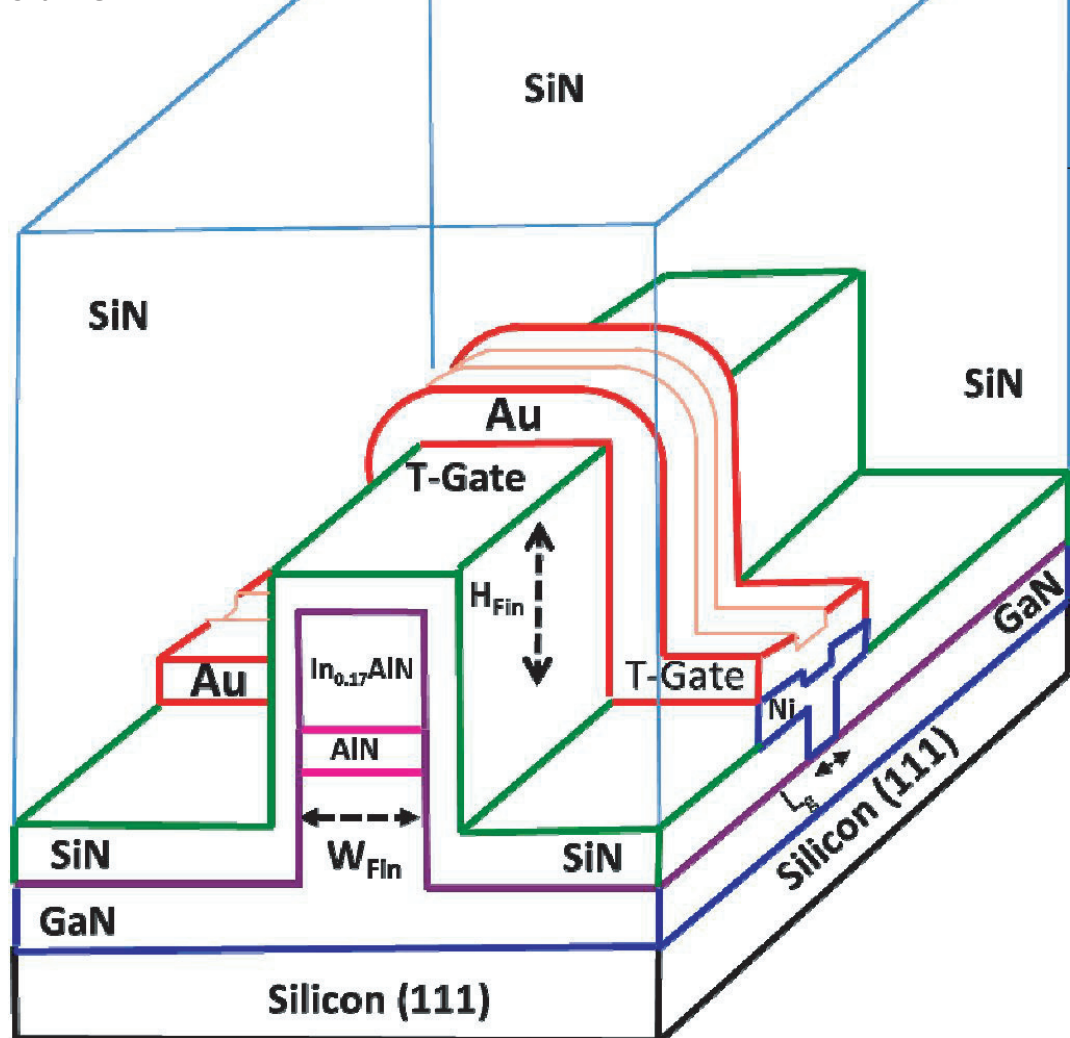
Figure 4. (a) MIT InGaAs MOSFET cross-section schematic, and (b) TEM of complete device with 40nm gate length and 2.5nm hafnium dioxide (HfO_2) gate dielectric.

two orders of magnitude of current. At 0.3V operating voltage, the on-current was $0.27\mu\text{A}/\mu\text{m}$ with a fixed off-current of $10^{-4}\mu\text{A}/\mu\text{m}$. The researchers comment: "This is the highest on-current demonstrated at this off-current level in NW TFETs with III-V materials."

Short-channel effects are often tackled using three-dimensional structures such as gates that wrap around a fin (fin-FET). Unusually, Singapore's Nanyang Technological University and Institute of Materials Research and Engineering (IMRE), along with Ohio State University in the USA, used stress engineering to achieve simultaneous high performance in triple-gate fin-HEMTs (Figure 5) produced using InAlN/GaN on silicon substrate rather than in InGaAs fin-FETs [session 25.6]. The stress was introduced using a silicon nitride passivation layer.

The on-current, off-current, extrinsic transconductance, SS and drain-induced barrier lowering (DIBL) demonstrated record values of $1.03\text{A}/\text{mm}$, $1.13\mu\text{A}/\text{mm}$, $645\text{mS}/\text{mm}$, $82\text{mV}/\text{decade}$ and $28\text{mV}/\text{V}$, respectively,

Figure 5. 3D schematic of NTU et al triple T-shape gate InAlN/GaN nano-channel fin-HEMT



at 0.5V drain. The researchers pointed out that their high-performance device used more relaxed device geometries such as 170nm T-gate compared with ~80nm I-gates on 88nm fins. The effective nano-channel width was 200nm. The researchers see their devices as promising for future ultra-high-speed device applications.

The team also claims its work as the first report of a T-gate approach on GaN-based fin-HEMTs. The maximum Q-factor consisting of the transconductance to subthreshold swing ratio was 7.9 at 0.5V drain, compared with less than 2 for a conventional GaN HEMT.

Opto

Another unusual report was of light emission from metal/semiconductor 'Schottky' junctions rather than the usual heterostructures of semiconductor materials. Hong Kong University of Science and Technology (HKUST) reported on its work generating GaN band-edge ultraviolet electroluminescence at 364nm from a forward-biased metal-AlGaIn/GaN Schottky junction at

room temperature [session 11.4]. A Schottky-on-heterojunction light-emitting diode (SoH-LED) in combination with a GaN HEMT driver achieved switching at up to 120MHz, "adequate for providing optical control signals for GaN high-side power switches," according to HKUST.

The team sees the technology as having potential for high-speed on-chip light-sources integrated with GaN electronics. The researchers have also demonstrated an AlGaIn/GaN high-electron-mobility light-emitting transistor (HEM-LET).

The AlGaIn/GaN heterostructure is being widely developed for power high-frequency and switching electronics (see above). Optocouplers are applied in high-voltage switching circuits, providing isolation between low-voltage control circuitry and high-voltage drive currents. The HKUST team comments: "An opto-cou-

pler that is material/process compatible and can be seamlessly integrated with the AlGaIn/GaN-based power electronic devices/circuits is highly desirable for an all-GaN solution that promises reduced parasitics, compact size and enhanced reliability."

Although photodetectors for AlGaIn/GaN circuit integration have been developed, until recently compatible light sources have not been available. "For the first time, we demonstrated that the metal-AlGaIn/GaN Schottky diode is capable of producing GaN band-edge UV emission at 3.4eV/364nm under forward bias larger than ~2V at room temperature," the HKUST team maintains.

The devices (Figure 6) were grown on (111) silicon using metal-organic chemical vapour deposition. The AlGaIn barrier surface was plasma treated before anode deposition to remove native oxide and for nitridization. The devices were also annealed after fabrication.

Spectral analysis of the electroluminescence (EL) showed that the source of the emission was the GaN

part of the heterostructure, with no light coming from the AlGa_N barrier layer. The current and light thresholds for the diode were at 1.1V and 2V, respectively.

The light threshold is about 1.4V lower than would be naively expected from the GaN bandgap of 3.4eV, indicating “an abnormal anti-Stokes light emission process”. Anti-Stokes processes are usually associated with photons that pick up energy from lattice vibrations/phonons in addition to the energy change of the generating electron.

The researchers suggested two possible models for the anti-Stokes effect: “one electron ionizes the upper (Fermi-level de-pinning) or lower (Auger process) surface-band state, inducing the generation/injection of one hole to recombine with another electron. This 2e⁻1h process maintains energy conservation and explains the anti-Stokes characteristic of EL emission.”

2D semiconductors

Although graphene has for a while dominated 2D electronics research, interest is growing in transition-metal dichalcogenide (TMDCs) such as molybdenum or tungsten compounds with sulfur or selenium to give MoS₂, MoSe₂, WS₂ or WSe₂.

One challenge has been to make low-resistance contacts

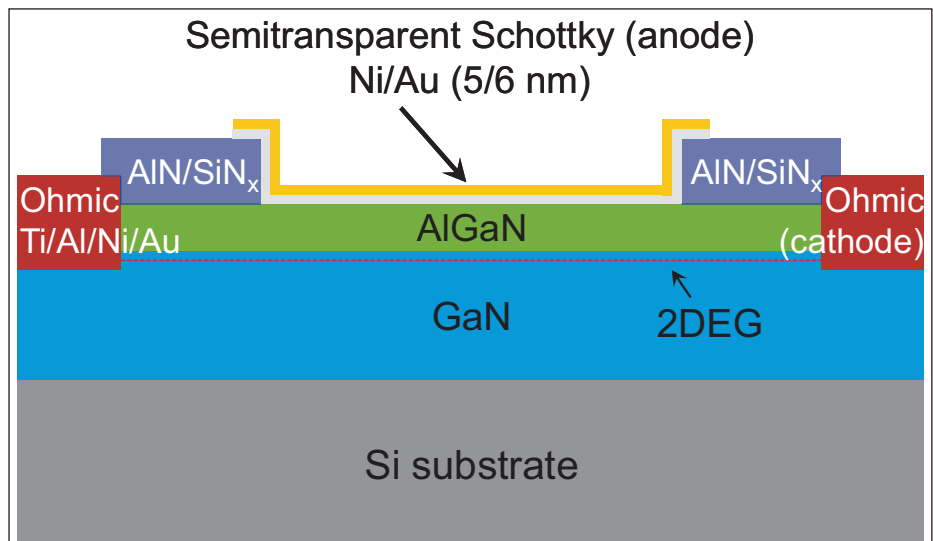


Figure 6. Cross-section of HKUST SoH-LED on AlGa_N/GaN-on-Si.

with external probes. Gwangju Institute of Science and Technology in South Korea achieved a low contact resistance for MoS₂ FETs using an interlayer of titanium dioxide (TiO₂) to achieve Fermi level de-pinning [session 5.1]. The value of contact resistance was ~5.4kΩ·μm, about five times lower than for devices without an interlayer. Maximum drain current was increased up to 2.51μA/μm with 0.5V drain bias — 10–20 times higher current drivability compared with prior results, say the researchers. The gate voltage was 20V above threshold.

The devices were produced by mechanical exfoliation using Scotch tape onto silicon/silicon dioxide substrates

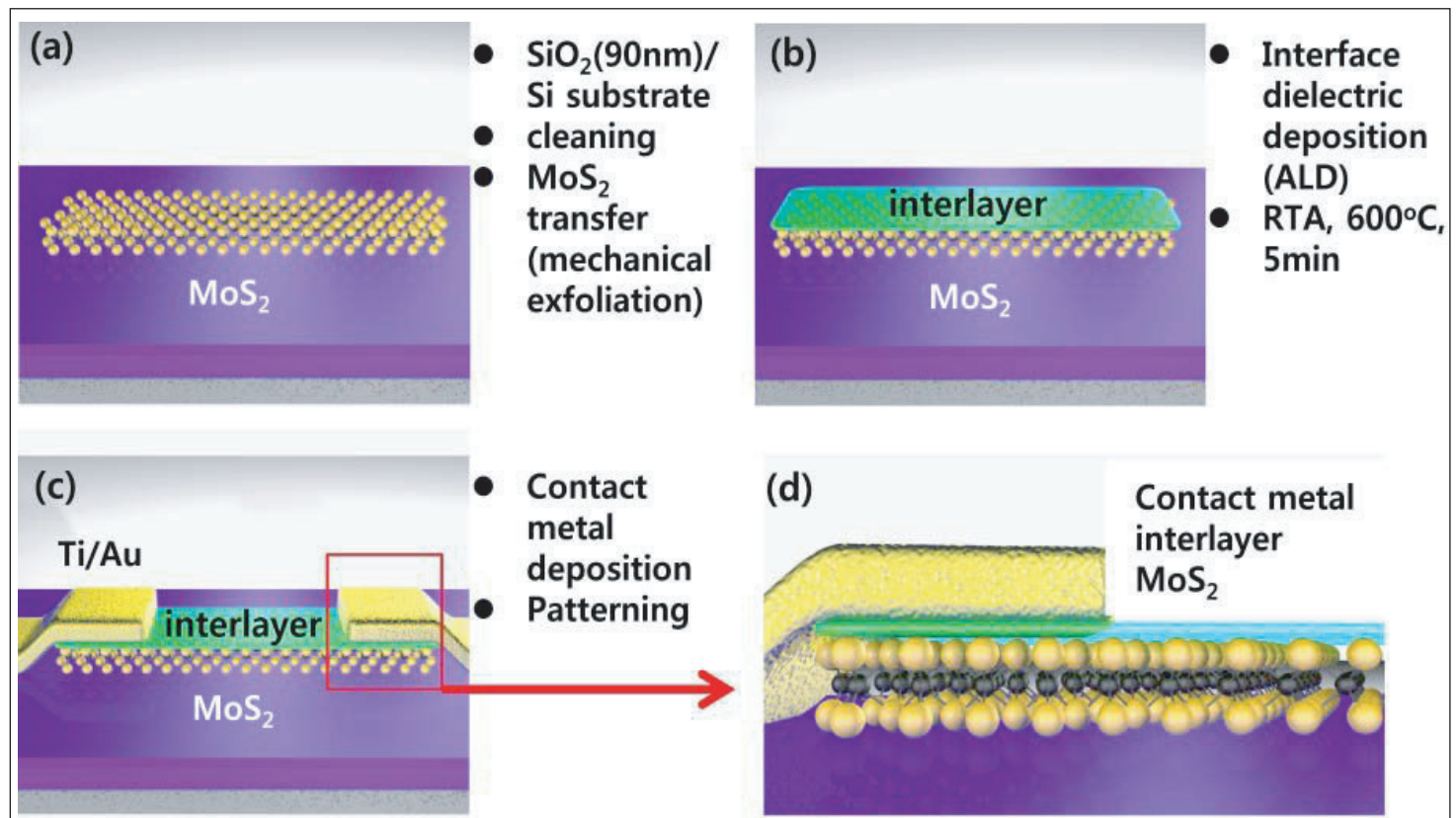


Figure 7. Gwangju fabrication flow and schematic of MoS₂ back-gate FET with insulating interlayer.

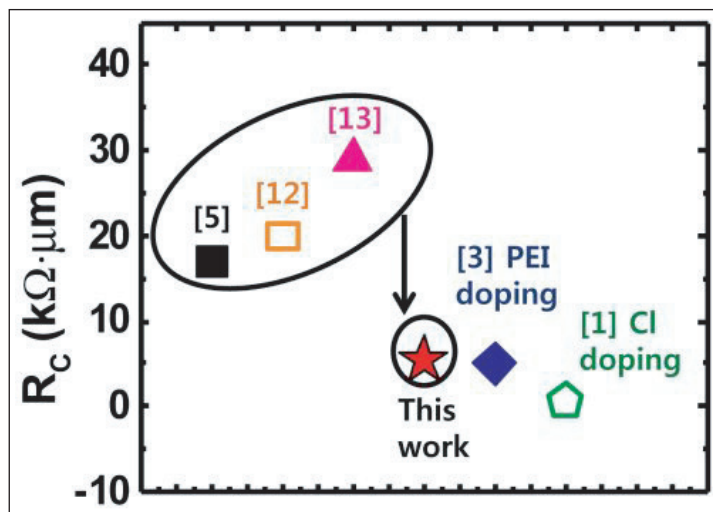


Figure 8. Benchmarking of Gwangju contact resistance against the achievements of other groups.

(Figure 7). The Scotch tape residues were removed with isopropyl alcohol (IPA) and rapid thermal annealing.

The best results were for a 2nm TiO₂ interlayer, although the researchers also tried aluminium oxide (Al₂O₃). The 2nm TiO₂ interlayer transistors had a 90nm equivalent oxide thickness for the gate insulation and a channel length of 3μm.

The Schottky barrier height was measured at 0.09eV for a 2nm TiO₂ interlayer, compared with 0.18eV for no interlayer and 0.13eV for a 2nm Al₂O₃ interlayer. The improvement of TiO₂ over Al₂O₃ was attributed to differences in the interface dipole layer.

Some groups have reported lower contact resistances

(Figure 8), but the Gwangju group point out that they did not use any doping of the MoS₂ to improve the contact. "We expect further improvement with addition of a proper doping process on the MoS₂ side," the researchers say.

Taiwan's National Chiao Tung University, Academia Sinica, and National Chiao Tung University claimed the first p-channel metal dichalcogenide ultrathin-body phototransistor (UTB-PT) with a response time as fast as 100μs [session 5.7]. The dichalcogenide channel material was large-area WSe₂ produced using CVD on sapphire. The researchers believe the device has "excellent compatibility with mass production", and propose its use in high-speed proximity interactive displays.

Collaboration between researchers based in Taiwan, Saudi Arabia and USA has resulted in CMOS-compatible stackable hybrid Si/MoS₂ 3DFETs [session 33.5]. The various institutions involved were National Nano Device Laboratories in Taiwan, King Abdullah University of Science and Technology in the Kingdom of Saudi Arabia, Tamkang University in Taiwan, National Chiao-Tung University in Taiwan, Academia Sinica in Taiwan, and University of California Berkeley in the USA.

These researchers used Si/MoS₂ structures to produce double-channel fin- and nanowire-FETs (Figure 9). The MoS₂ consisted of between 3 and 16 molecular layers. The addition of MoS₂ increased the on-current by 25% over a pure silicon nanowire-FET.

The researchers believe that heterogeneous hybrid Si/2D electronic double-channel 3DFETs could enhance scaled device performance in applications that require technology more advanced than 7nm CMOS technology. ■

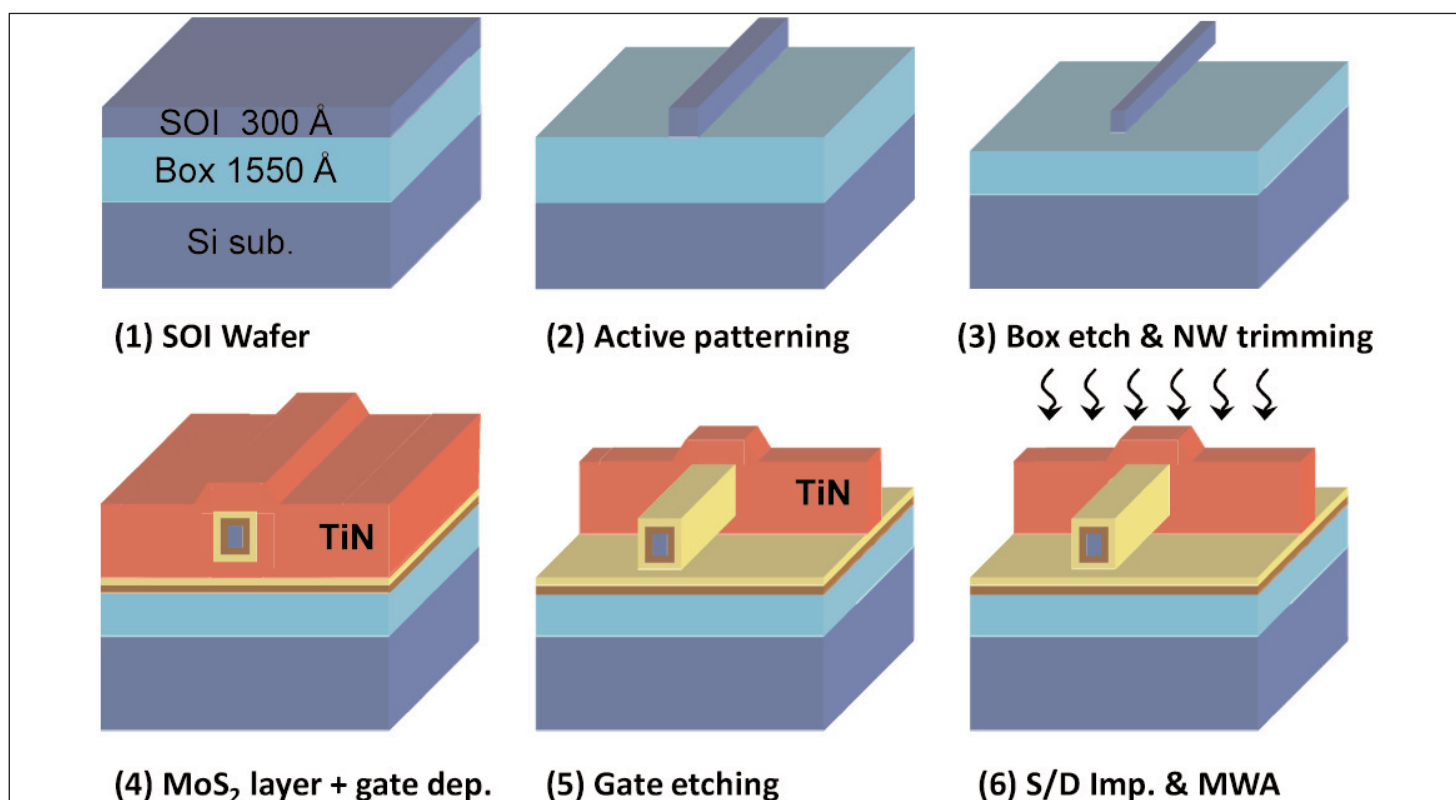


Figure 9. Schematic of nanowire FET with hybrid Si/MoS₂ channels.



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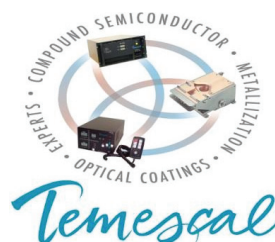
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www.LEDChina-gz.com

17–19 March 2015

SEMICON China 2015

Shanghai New International Expo Centre, China

E-mail: semichina@semi.org

www.semiconchina.org

22–26 March 2015

Optical Fiber Communication Conference & Exposition (OFC 2015)

Los Angeles Convention Center, CA, USA

E-mail: info@ofcconference.org

www.ofcconference.org

31 March – 1 April 2015

Intersolar China 2015

China International Exhibition Center (CIEC), Beijing, China

E-mail: maas@intersolarchina.com

www.intersolarchina.com

13–15 April 2015

CPV-11 (11th International Conference on Concentrator Photovoltaics)

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E-mail: info@cpv-11.org

www.cpv-11.org

13–16 April 2015

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Clarion Congress Hotel, Prague, Czech Republic

E-mail: info@spieurope.org

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E-mail: apec@apec-conf.org

www.apec-conf.org

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ECPE SiC & GaN User Forum 2015 — Potential of Wide Bandgap Semiconductors in Power Electronic Applications

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Shenzhen, China

E-mail: cioe@cioe.cn**www.cioe.cn/EN****3 September 2015****1st International Forum on Sapphire Market & Technologies**

Shenzhen, China

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