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COMPOUNDS & ADVANCED SILICON

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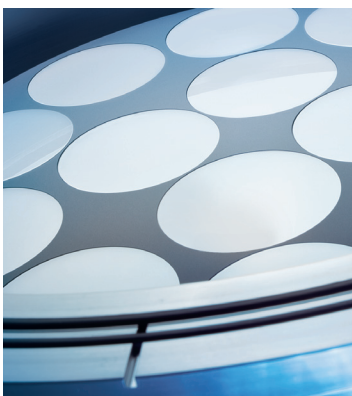
IEDM report part 2: compound semiconductor logic development

Development of new form of hafnium oxide boosts dielectric constant

Bridgelux raises \$25m • Plessey buys start-up CamGaN
Veeco sells CIGS PV assets • IQE invests in Solar Junction

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contents

News

Markets

HB-LED market to grow 13.4% in 2012 • GaAs device revenue grows 6% in 2011 • Cellular PA market to reach \$4bn in 2016

Microelectronics

New form of hafnium oxide boosts dielectric constant • Black Sand closes \$10m Series C funding round

Wide-bandgap electronics

Cree launches packaged 1700V SiC Schottkys • GaN nanowires show six-fold stronger 3D piezoelectric effect than bulk GaN

Materials and processing equipment

Ceres acquires Veeco's CIGS PV equipment assets • Aixtron allies with Minsheng Financial Leasing in China • Palomar develops wire-bond-free direct attach for LEDs • Nitride Solutions raises \$2.5m

LEDs

Verticle enters mass production of hexagonal LED chip • SemiLEDs achieves 40% EQE for UV LED chips • Toyoda Gosei sues Forepi • Plessey buys CamGaN • Bridgelux gains \$25m from China's Kaistar

Optoelectronics

Thorlabs completes new headquarters

Optical communications

Optical communications component firms recovering from Thailand flood

Photovoltaics

IQE raises £10.5m; invests in Solar Junction • Semprius sets record 33.9% CPV module efficiency • Nanosolar raises \$20m

Technology focus: Photovoltaics

Honeycomb sweetens nitride solar cell performance

Technology focus: Silicon optoelectronics

All-silicon light emission through nanocrystal confinement

Technology focus: UV LEDs

Growth-mode transition to higher UV output

Technology focus: LEDs

SiO₂/GaN nano-rods give new base for high light output power

Technology focus: Nitride materials

Increased mobility and reduced residual electron concentration indium nitride

Technology focus: Nitride transistors

Aluminum oxide passivation reduces off-current in AlN/GaN transistors

Research review: Nitride transistors

IMEC/AMAT produce first crack-free MOCVD nitride DH-structures on 200mm Si

Conference report: IEDM (part 2)

Compound semiconductor logic development intensifies

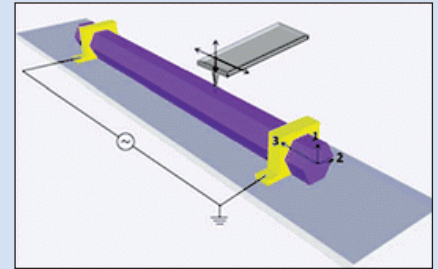
Suppliers' Directory

Event Calendar and Advertisers' Index

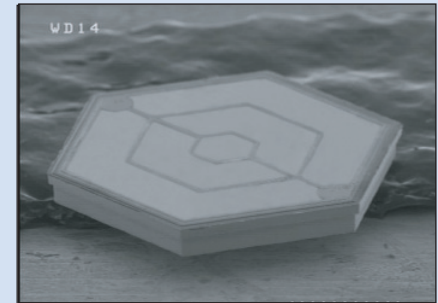
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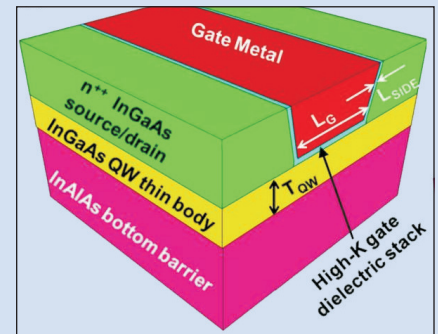
Vol. 7 • Issue 1 • February 2012



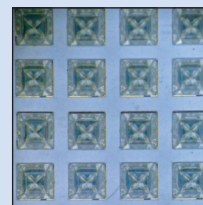
p25 GaN nanowires exhibit piezoelectricity, enabling energy-harvesting applications for self-powered devices.



p42 Scanning electron micrograph of Verticle's hexagonal LED chip, now in production.



p91 Intel/IQE thin-body planar InGaAs QWFET with high-k dielectric gate stack and body thickness of 10–50nm.



Cover: Direct-attach LED die, mounted bondpad-down (using eutectic Au/Sn solder) to a single 50mm metal core carrier. Direct-attach eutectic bonding eliminates wire bonds yet improves thermal management, while Palomar's Pulsed Heat System allows more effective control of LED exposure. **p39**

Economies of scale

On page 88 of this issue, the second part of our report on December's IEEE International Electron Devices Meeting focuses on the large-scale integration of high-performance logic and analog devices based on compound semiconductor materials (e.g. using III-V and germanium channels in MOSFET devices on silicon substrates).

In addition, both in these devices and in conventional silicon CMOS transistors, silicon oxide can be replaced by higher-dielectric-constant hafnium oxide as the gate oxide dielectric in order to boost performance and allow greater miniaturization. Now, the University of Cambridge has developed a new form of hafnium oxide that raises its dielectric constant, from 20 to 30, boosting scaling and hence performance further (page 16).

Also, on page 18–21 we report developments by firms commercializing RF CMOS for applications such as power amplifiers. A market report from Strategy Analytics discusses how W-CDMA PAs fabricated in monolithic CMOS will capture a small but growing share in low-cost 3G devices over the next five years. Nevertheless, the market for GaAs-based PAs will continue to grow in more demanding applications and in the form of complex modules for multiband smartphones, it concludes (see page 6). On page 7 Strategy Analytics also notes that, although the GaAs device market slowed in second-half 2011 after record revenues in 2010, annual growth was still equal to the historic rate (6%).

After last issue reporting Q4/2011 revenues down year-on-year by 19% for RFMD and 17% for Skyworks, this issue we report TriQuint down 10% (page 10) and Anadigics down 39% (page 12). However, a return to growth is broadly expected in second-half 2011.

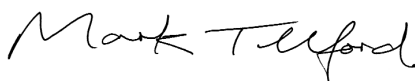
Also going through a pause, the LED industry has a glut of capacity, with 150 MOCVD systems coming on-line in China alone during 2012, according to Digitimes (page 7). Correspondingly, MOCVD system maker Veeco's revenue fell 28% in Q4/2011 and is expected to fall a further 33% in Q1/2012 (to \$115–140m) — see page 32. However, Veeco's flexible cost structure allows breakeven on quarterly revenue of just \$100m, and revenue from services should grow even more rapidly in 2012 as over 400 reactors come 'off warranty'. Nevertheless, 2012 is still expected to be a "transition year" between the LED TV market and a much larger LED lighting market. Penetration of LEDs into lighting will grow from 6.6% in 2011 to 11.3% in 2012 then 25.8% in 2014, forecasts Digitimes, aided by economies of scale.

One hope is the growth of gallium nitride on the larger area of silicon substrates, leading to a \$25m investment by China's Kaistar Lighting in US LED maker Bridgelux's transition from 4" sapphire to 6" silicon (page 47). Meanwhile, in the UK, Plessey has just acquired Cambridge University GaN-on-Si LED technology spin-off CamGaN (page 46).

While LED efficiencies are continuously rising (with Cree's XT-E doubling the lm/W of its predecessor XP-E — see page 50), the same applies to solar technologies such as CPV (with Sempris raising module efficiency to 33.9%). Such progress has won cell supplier Solar Junction a £10.5m investment from epiwafer maker IQE (pages 66–67) which, like many firms, is aiming to diversifying its technology into potentially high-growth 'adjacent' markets.

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(e.g. GaAs, InP and SiGe wafers, chips and modules for microelectronic and optoelectronic devices such as RFICs, lasers and LEDs in wireless and optical communications, etc).

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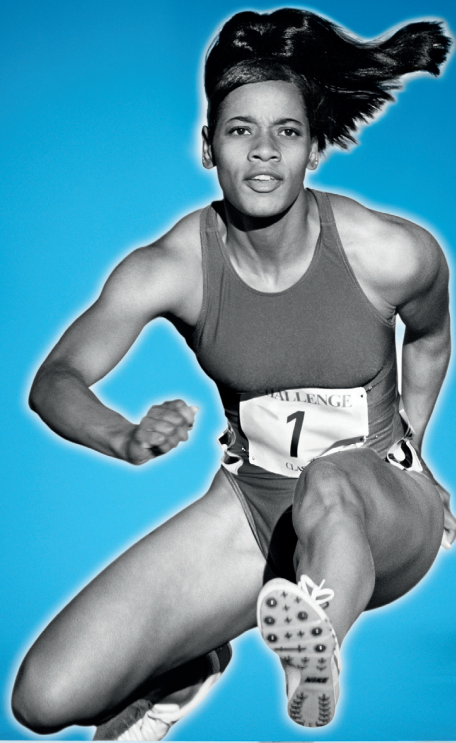
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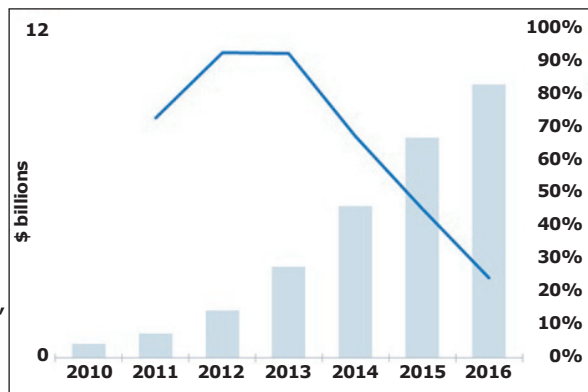
LED lighting power supply market to reach \$10bn in 2016

Driven by legislation and rising costs of electricity, the rapid uptake of LED lighting is forecast to result in a potential global market of 4 billion power supply units by 2016, worth \$10bn, according to the report 'Opportunities for Power Components in LED Lighting' from IMS Research.

"Demand for LED lighting solutions is increasing rapidly for all applications from low-power residential retrofit LED lamps and bulbs to high-power commercial and industrial LED luminaires for applications such as street lighting," comments co-author and senior market analyst Ryan Sanderson.

The report also found that the traditional lamp and luminaire market is well established. Manufacturers are faced with new challenges when it comes to powering LED lamps and luminaires and often require significant power electronics expertise, opening up opportunities for power supply manufacturers. The requirements to power new LED lighting products varies widely, depending on design factors including power rating, the number of LEDs or LED strings and the environment in which the solution will be placed. "These design requirements, coupled with the lack of clear standards for LED lighting, means that LED lamp and luminaire manufacturers need considerable power electronics expertise, either via employing specialists or from a merchant power supply manufacturer," says Sanderson.

The report found that LED lighting would become a unique opportunity, despite the fact that general lighting has always been a relatively small and low-growth market for the power supply industry. How-



Market for power supplies in LED lighting (\$bn).

ever, competition in lighting is already fierce, and some of the largest manufacturers of LED lamps and luminaires are positioning themselves to cope with these challenges internally.

"Some of the largest manufacturers of LED lamps and luminaires already have the capability to design and manufacture power circuitry in-house, either via subsidiaries or through the acquisition of power supply manufacturers... Philips Advance is a prime example," says co-author and market analyst Jonathon Eykyn. This means that a portion of the total power supply opportunity is absorbed by these vertically integrated companies and becomes 'captive'. "Designing and manufacturing the power solution in-house, however, only really makes sense in high-volume, low-cost markets and where the design is simple; for example, LED retrofit lamps," adds Eykyn. "In medium- and high-power applications, design becomes more complex and it often makes more financial sense to outsource the power supply design to a merchant vendor."

As a result, the report forecasts that more than 50% of the market in 2016 will be controlled by merchant power supply manufacturers.

www.imsresearch.com

IN BRIEF

Cellular PA market to grow from \$3.3bn in 2011 to \$4bn in 2016; CMOS to gain market share in low-cost 3G

Driven by the growth of cellular terminal shipments to an estimated 2.3 billion units, the cellular power amplifier (PA) market grew 19%, to more than \$3.3bn in 2011, according to the report 'Cellular PA Forecast 2012' from the Strategy Analytics RF & Wireless Components (RWC) service, which covers the market for PAs and PA-front-end modules in dollars and units through 2016.

"Grey market (illegal, or shanzhai) handsets grew, as did smartphones, cellular-enabled notebooks, netbooks, tablets, USB dongles and M2M devices," says Christopher Taylor, director, Strategy Analytics RF & Wireless Components. "The average number of bands and modes supported by cellular devices also grew, which slightly increased the average number of PAs per cellular device 2011. Strategy Analytics expects the non-handset segments of this market to contribute more than 40% of the demand in 2016," he adds.

"Gallium arsenide (GaAs)-based PAs make up about 95% of the market, however W-CDMA PAs fabricated in monolithic CMOS will capture a small but growing share in low-cost 3G devices over the next five years," forecasts Eric Higham, director of the Strategy Analytics GaAs and Compound Semiconductor market research service. "Even so, the market for GaAs-based PAs will continue to grow in more demanding applications and in the form of complex modules for multiband smartphones," he concludes.

www.strategyanalytics.com

HB-LED market to grow 13.4% from 2011's \$8.9bn to \$10.1bn in 2012

Penetration of lighting market to rise from 6.6% to 11.3%

After growing 7.9% year-on-year to about \$8.9bn in 2011, the global high-brightness (HB) LED market output value will grow 13.4% to \$10.1bn in 2012, forecasts Digitimes Research. However, demand for metal-organic chemical vapor deposition (MOCVD) systems will shrink to 200 units, it adds.

The combined share of HB-LEDs in the Japan, South Korea and Taiwan markets will reach 61.3% in 2012, Digitimes Research predicts. In particular, China will grow by 30% in 2012 due to the large amount of MOCVD equipment ordered previously, with about 150 units coming online in 2012. China mainly focuses on low- and medium-power LED products, the firm notes.

For backlighting of large-size panels, LEDs will reach a penetration of

34.1%, higher than other applications (such as lighting, with 16.7%), predicts Digitimes Research.

By 2014, the penetration of LED backlighting in large-size panels and lighting will be 28.7% and 33.4% respectively, it adds.

The sweet-spot prices for LED light bulbs to replace traditional 60W

The combined share of HB-LEDs in the Japan, South Korea and Taiwan markets will reach 61.3% in 2012.

China will grow by 30% in 2012 due to the large amount of MOCVD equipment ordered previously

light bulbs are \$25/unit in Japan, \$15/unit in Europe and North America, and \$7/unit in emerging markets, says Digitimes Research. The LED light bulb penetration rate is expected to be 5.4% (comprising about 1.05 billion units) in 2012.

The penetration of LED lighting in the entire lighting market was only 6.6% in 2011, reckons the firm. However, governments have been announcing policies and measures to increase LED lighting market share (e.g. to 50% in Japan, 30% in South Korea, and 20% in China in 2015). Globally, the penetration of LED lighting will reach 11.3% in 2012 and 25.8% in 2014, forecasts Digitimes Research. Output value will reach \$16.5bn in 2012 and \$41.9bn in 2014, it concludes.

www.digitimes.com

GaAs device revenue grows 6% in 2011, returning to historical averages

Growth rate to continue to flatten in 2012

After a banner year in 2010 (hitting record revenue of nearly \$5bn) followed by a fast start to 2011, the gallium arsenide (GaAs) device revenue growth rate slowed, maintaining the historical average of 6% for full-year 2011, according to a report from the Strategy Analytics GaAs and Compound Semiconductor Technologies Service (GaAs).

The Insight report '2011 GaAs Device Revenue Falts after Strong Start' explores GaAs device revenue growth trends in handsets and smartphones, as well as revenue performance of leading substrate and device makers, such as IQE, VPEC, Kopin, RFMD, Skyworks, TriQuint Semiconductor, Avago Technologies and WIN Semiconductors. While growth drivers

are still present, the rates are likely to continue to flatten in 2012, forecasts Strategy Analytics.

"Tremendous growth in the smartphone segment of the handset market in 2010, and the early part of 2011, had propelled the overall GaAs market to record levels of revenue which are now slowing," notes Eric Higham, director of the Strategy Analytics GaAs and Compound Semiconductor Technologies Service. "However, increasing GaAs content in hand-

Growth in the smartphone segment... had propelled the overall GaAs market to record levels of revenue which are now slowing

sets and the sheer volume of the handset market should still power GaAs growth," he adds.

"There were revenue declines in the second half of 2011 at GaAs substrate manufacturers," says Asif Anwar, director, Strategy Analytics Strategic Technologies Practice. "Strategy Analytics will continue to monitor these trends throughout 2012, in order to see their effect on the GaAs supply chain."

The insight summarizes revenue performance of a representative set of GaAs device manufacturers for 2010 and 2011. It also discusses trends and drivers for the overall GaAs device industry and forecasts trouble spots and directions to be monitored through 2012.

www.strategyanalytics.com

RFMD launches quad-band GSM/GPRS Tx modules with UMTS transmit/receive ports

RF Micro Devices says that its new RF3235 and RF3237 quad-band GSM/GPRS Class 12-compliant transmit modules, paired with one or more discrete 3G power amplifiers (PAs) such as those from the RF722x or RF724x series, enable what is claimed to be best-in-class performance at the lowest total solution cost for 3G entry platforms.

The new modules include four (RF3237) to six (RF3235) high-linearity UMTS transmit/receive (TRx) ports that also serve as GSM Rx ports and are pin-to-pin compatible. Both build on RFMD's PowerStar integrated power control technology, SOI (silicon-on-insulator) switch technology, and integrated transmit filtering.

The devices are designed for use as the final portion of the transmitter section in a GSM850/EGSM900/DCS1800/PCS1900/UMTS handset and eliminate the need for a PA-to-antenna switch module-matching network. 50Ω matched input and output ports require no external matching components (with no external DC blocking needed on TRx ports).

TRx insertion loss is 0.6db (low band) and 0.8dB (high band), boosting 3G efficiency and improving Rx sensitivity. Efficiency at the rated output power (P_{OUT}) is 43% (GSM850/EGSM900) and 36% (DCS1800/PCS1900) at a supply voltage (V_{BATT}) of 3.5V. Isolation is >35dB for most port combinations.

Applications include single- through quad-band UMTS handsets and connected devices including TDSCDMA and CDMA, GSM850/EGSM900/DCS1800/PCS1900 products, 3V multi-mode mobile applications, and GPRS Class 12 compliant devices.

Pricing begins at \$2.70 for the RF3235 and \$2.47 for the RF3237, each in 100-unit quantities.

www.rfmd.com

Compound Semiconductor Group head Van Buskirk retires

RF Micro Devices Inc of Greensboro, NC, USA, has announced the retirement of Bob Van Buskirk, corporate VP of its Compound Semiconductor Group (CSG).

Van Buskirk has been a member of RFMD's executive staff since 2007. He joined RFMD with the acquisition in November 2007 of Sirenza Microdevices Inc (a supplier of RF components for communications applications), where he had been president & CEO. He led the integration of Sirenza and was instrumental in the formation of CSG and RFMD's Multi-Market Products Group (MPG).



"I am looking forward to transitioning to a new phase of my career where I will look to serve on boards of technology-oriented companies," says Van Buskirk.

"Bob has been a key contributor in the overall management of the company, in setting the strategic direction of the company, and in communicating this direction to customers and shareholders," says president & CEO Bob Bruggeworth.

Transmit/receive front-end modules for 433–470MHz & 470–510MHz AMI/AMR

RFMD has launched two new transmit/receive front-end modules (FEMs) in 5.5mm x 5.0mm, 28-pin packages for advanced metering infrastructure (AMI) and automatic meter reading (AMR) applications.

The RF6504 is for 433–470MHz AMI/AMR systems (433MHz/450MHz to 470MHz ISM-band applications). The Tx port provides a power amplifier (PA) with nominal output power of 30dBm and gain of 15dB. The Rx pass-through port is on a separate path. Both are combined with a single antenna port and SP2T switch.

The RF6514 for 470–510MHz

AMR systems (i.e. 490MHz ISM-band applications) contains separate ports for the Rx and Tx paths. Its PA produces nominal output power of 30dBm.

For both devices, features include a separate 50Ω Tx/Rx transceiver interface and Rx insertion loss of 1dB. Applications include wireless automated metering, wireless alarm systems, portable battery-powered equipment, smart energy, and single-chip RF front-end modules.

Pricing begins at \$2.04 each for the RF6504 and \$1.73 each for the RF6514, in 750-piece quantities.

RFMD launches 1W linear high-power amplifier

RFMD has launched the RF5652 high-power amplifier, which addresses IEEE 802.11b/g/n WiFi (2.4–2.5GHz) for customer premises equipment (CPE) applications, as well as supporting IEEE 802.16e WiMAX (2.5–2.7GHz) CPE applications.

Applications also include picocells and femtocells, spread-spectrum and microwave multipoint distribu-

tion systems (MMDS), and LTE.

The new module integrates a three-stage linear power amplifier with 30dBm (1W) linear power at PA output (with <3% EVM at 5V), along with a power detector, in a 5mm x 5mm QFN package. Gain is 34dB.

Pricing begins at \$6.15 each for 100-unit quantities.

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TriQuint's quarterly revenue rises more-than-expected 5%

Growth expected for second-half 2012

RF front-end component maker and foundry services provider TriQuint Semiconductor Inc of Hillsboro, OR, USA has reported revenue growth of 2% from 2010's \$878.7m to a record \$896.1m in 2011 (the sixth consecutive year of growth).

Declines of 4% in Networks and 9% in Defense & Aerospace were offset by Mobile Devices revenue rising 6% (including 20% growth for 3G/4G). "We believe overall handset units grew about 9%, with much faster growth in smartphone," says president & CEO Ralph Quinsey.

"In 2011, we expanded our capacity to serve our customers' rising demand," says Quinsey. "We were able to grow important submarkets such as 3G and optical, while also expanding our overall capacity footprint," he adds. "Growing requests from our high-volume customers is assurance of supply and, with our dual-site capability for GaAs now in place [in Oregon and now Texas], we can assure our customers a flexible and continuous supply of product independent of localized disruptions."

For fourth-quarter 2011, revenue was \$227m, down 10% on \$253.4m a year ago but up 5% on Q3's \$216m (and above the guidance of \$215–225m). Taiwan's Foxconn Technology Group comprised 41% of total revenue (making 35% for full-year 2011). By end market, the split was: Mobile Devices 71%; Networks 19%; and Defense & Aerospace 10%.

● Mobile Devices revenue was \$162m, down 12.8% on \$185.9m a year ago but up 7% on Q3's \$151.5m. In particular, year-on-year growth for 3G/4G (from 69% of Mobile Devices revenue to 80%) was offset by a drop in revenue for 2G from \$23.8m (13% of Mobile Devices revenue) to \$7.4m (just 4%), due mainly to declines in legacy CDMA and GSM revenue streams. "We intentionally moved away from these submarkets during the period our capacity was limited," notes Quinsey.

● Networks revenue of \$43.3m was flat on Q3's \$43.6m and down 8% on \$47.3m a year ago. Macroeconomic weakness during the year led operators to spend cautiously on infrastructure equipment, resulting in lackluster demand (especially in base-stations, e.g. Radio Access revenue was flat year-on-year and down 15% on Q3. Nevertheless, although down 5% on \$22.6m a year ago, Transport revenue of \$21.5m was up 7% on Q3's \$20.1m, with strong growth in optical. Likewise, although down 27% on \$10.1m a year ago, Emerging Markets revenue of \$7.4m was up 14% on Q3's \$6.6m.

● Defense & Aerospace revenue of \$21.7m was up 4% on Q3's \$20.8m and up 7% on \$20.2m a year ago. During 2011, the firm completed the bulk of supply to the B-2 bomber and F-22 projects and began to ramp up new programs like the F-35 Joint Strike Fighter and EQ-36 radar.

On a non-GAAP basis, gross margin was 31%, down from Q3's 36.3% and below the forecast 32–34%. This was driven by a less favorable product mix and lower factory utilization (just 69%) as the firm completed long plant capacity additions and reduced inventory (by \$8m). Full-year margin was 37.2%, down from 41% in 2010.

Smartphones represent about 30% of the market. I expect them to pass 50% in the next few years as they push into the mid and low end of the market

Operating expenses were \$56.9m, down \$1.8m on \$58.7m last quarter, due to litigation expenses (related to antitrust and IP claims against Avago Technologies) falling from \$4.1m to \$2.3m. However, operating expenses for full-year 2011 (including litigation expenses of \$19.2m) were \$244.4m, up from \$221m in 2010.

Net income was \$13.3m, down on \$19m in Q3 and \$42.8m a year ago, but at the high end of guidance. Net income for 2011 was \$87.3m, down from \$137.7m in 2010.

During the quarter, total cash and investments rose by \$15.1m, from \$147.2m to \$162.3m. Cash flow from operations was partially offset by capital expenditure of \$32.5m. Full-year CapEx was \$192.4m, as TriQuint expanded total capacity by about 40% across its GaAs and SAW/BAW filter lines. In late Q4, qualification was completed on the new 6" GaAs line at the fab in Richardson, TX (a copy-exact of the firm's Oregon 6" GaAs facility but on a smaller scale). "The investments we've made in increased capacity will allow us to participate in a strong market growth we anticipate over the next few years," says chief financial officer Steven J. Buhaly. "We expect lower capital expenditures in 2012 [by roughly half], and our spending will be largely focused on new capabilities." Depreciation expense rose to about \$17m in Q4 and will rise to about \$21m in Q1/2012 as a result of placing the new 6" line in service.

For Q1/2012, TriQuint expects revenue of \$210–220m and gross margin of 30–31% (with improved product mix largely offsetting \$5m in new costs from the Texas line). Operating expenses are expected to grow to about \$62m, due in part to \$4.5m of litigation expense.

"We have recently re-engaged in the GSM market with our next-generation high-performance low-cost QUANTUM Tx Module," says Quinsey. "However, we believe our Mobile Devices total addressable market [TAM] will continue to grow with increased smartphone adoption and increase our content as multiple bands of 3G and 4G [LTE] are added to devices," he adds.

"Smartphones currently represent about 30% of the market. I expect them to pass 50% in the next few

► years as they push into the mid- and low-end of the market,” says Quinsey. “This growth is compounded with increased RF content to support the number of frequency bands required in 3G and LTE. There are over 30 frequency bands defined in the standard, and each band drives expanded content. Handsets have gone from dual-band voice capability to now include four or five 3G bands and two or three LTE bands plus WiFi. This has significantly expanded the RF dollar content from about \$1 to, in some cases, over \$10,” he notes.

“Customers must balance size, flexibility and cost for their next-generation 3G and 4G applications,” continues Quinsey. “TriQuint supplies all of the critical products for this market, including RF amplifiers, SAW and BAW filters, switches and WiFi solutions for smartphones. Customers thus continue to see TriQuint as the complete RF solutions innovator instead of simply a

point supplier of discrete power amplifiers or filters,” he claims.

Regarding Networks business, Quinsey notes: “We have been very successful with our modulator driver amplifiers supporting the optical market. Based on design wins to date, I anticipate an expanding customer base in 2012”. He adds: “In addition to our success for the 40G product family, I expect more equipment providers will begin offering a 100G solution by the end of 2012. TriQuint is well positioned to enjoy growth at this next generation of communications technology.”

“This surge in network traffic, rapid adoption of smart mobile device, and expanding RF content, are solid and favorable trends for TriQuint,” says Quinsey. “We have made the investments and capacities we prepared to serve this exciting market... We see solid prospects for growth in the second half of the year.”

Regarding Defense & Aerospace business, new programs like the

Joint Strike Fighter and EQ-36 ground-based radar system should result in a return to modest growth in 2012 and beyond, believes TriQuint. Also, the firm has begun shipping production volumes of GaN products into a 3-year radar program valued at \$25m, and has GaN-based products in production supporting its first communications application with the defense industry. “We remained closely involved in a broad portfolio of contracted R&D programs sponsored predominantly by DARPA, the Air Force Research Lab and the Office of Naval Research,” says Quinsey. “In 2011, these contracts totaled about \$15m in revenue and were primarily focused on the development and manufacturing of GaN technologies for future DoD programs,” he adds. Contract-based revenue is expected to increase in 2012 with additional GaN-related research programs.

www.triquint.com

TriQuint's foundry supports Sarda's market entry

TriQuint's Foundry Services division is supporting fabless power semiconductor start-up Sarda Technologies Inc of Durham, NC, USA to bring to market a new line of high-efficiency DC-DC converter switches. Sarda plans to offer cost-saving solutions for increasing efficiency and reducing component size in smartphones, mobile PCs and similar applications.

“Sarda Technologies is a good example of the innovative commercial and defense start-ups our Foundry Services division supports,” says James L. Klein, TriQuint's VP & general manager for Defense Products and Foundry Services. “Sarda is developing an impressive family of power semiconductors for high-volume applications,” he adds. “We offer a complete support system that enables a company's first-to-market strategies including best-in-class modeling, program management and applications engineering teams.”

Market demand for highly efficient DC-DC switches for power converters is significant, says TriQuint. According to the Darnell Group's December 2011 report ‘Worldwide DC-DC Converter IC Forecasts: Applications, Amperages and Emerging Designs’, the market is projected to rise at a compound annual growth rate (CAGR) of 9.7% from nearly 20 billion units in 2011 to just under 32 billion in 2016; revenue should grow to \$4.3bn.

Power switching process technology currently used in DC-DC converters is not highly efficient, notes TriQuint. The switch is seen as an increasingly critical consumer electronics design element, since power consumption dramatically impacts end-user product experiences. The higher efficiency, reduced size and cost effectiveness of compound semiconductor-based technologies can be a definitive marketplace advantage, the firm adds.

“Sustained growth built on delivering improved DC-DC converters depends on innovative solutions,” comments Darnell Group's president Jeff Shepard. “Sarda is a good example of a high-tech company striving to deliver products that aim to meet these emerging requirements,” he adds. “TriQuint's ability to deliver proven, high-volume foundry services and its direct experience manufacturing products for smartphones and mobile PCs can enable Sarda's market plans and growth,” Shepard believes.

“TriQuint's foundry business enables Sarda to quickly and cost-effectively develop a power semiconductor product line,” says Sarda's CEO & co-founder Bob Conner. “Sarda employs TriQuint's proven high-volume manufacturing processes to bring the performance advantages of compound semiconductors to cost-sensitive power electronics applications.”

<http://sardatech.com>

Anadigics' Q4 sales down 2% as broadband constraints offset wireless growth

...but Q1 wireless revenue to fall by 15%

For full-year 2011, GaAs-based broadband wireless and wireline communications component maker Anadigics Inc of Warren, NJ, USA has reported revenue of \$152.8m, down 29.5% on 2010's \$216.7m. Most recently, fourth-quarter net sales were \$36.5m, down 39.4% on \$60.2m a year ago. However, this was down just 2% on \$37.3m in Q3/2011, despite the challenges in the global economy. The greater-than-10% customers were Samsung, ZTE, RIM (Research in Motion) and Huawei.

"Wireless business grew sequentially for the second consecutive quarter," says president & CEO Ron Michels. Wireless revenue rose 7.3% from Q3's \$27.9m to \$29.9m, driven by continued design-win success at the firm's top three wireless customers Samsung, Huawei and ZTE. In particular, in November Anadigics announced that it was supplying power amplifiers to Samsung for its Galaxy S 4G and Galaxy SII X smartphones. The firm also expanded its family of 4G power amplifiers.

The wireless revenue growth was offset by a decline in broadband business. Compared with Q3's 75:25 split, the revenue split was 82% wireless and just 18% broadband. Broadband revenue was \$6.6m, down 29.7% due partly to Q3's seasonally strong \$9.4m, as business was restrained by the economy, lower home building and partly impacted by slight constraints from the Thailand flood in October. Most affected was set-top box revenue, down from \$2.3m to \$1.8m.

Due mainly to a less favorable revenue mix and factory utilization of just 50%, gross margin has fallen from 20% in Q3 to 16.5%.

Operating expenses rose slightly from Q3's \$15.5m to \$15.7m. However, the increase was "in the

right place", says VP & chief financial officer Terry Gallagher: R&D spending rose by \$600,000 (6%) to \$10m, as the firm continues to introduce new product offerings. Meanwhile, selling, general & administration (SG&A) expenses were cut by \$300,000 (5.2%) to \$5.7m, consistent with the firm's focus on limiting expenses while funding mission-critical efforts. "We recently took action that serves to further reduce our annual SG&A cost structure by roughly \$1m," says Gallagher.

On a non-GAAP basis, compared with a profit of \$4.9m a year ago, net loss has risen from \$7.8m in Q3 to \$9.5m in Q4. Full-year net loss was \$31.7m, compared with a profit of \$7.7m in 2010.

Depreciation expense was \$4.4m, resulting in a pro forma EBITDA loss of \$5.3m. Capital spending was \$1.6m. Hence, during Q4, cash, cash equivalents and short- and long-term marketable securities fell from \$100.6m to \$93.6m.

"We continued to make notable progress on new product development," says Michels. In February Anadigics expanded its portfolio of small-cell wireless infrastructure

power amplifiers, launched multi-mode-multiband power amplifiers (MMPAs), and unveiled its new power amplifier duplexer (PAD) family. "We have received strong customer interest in our expanding

Broadband revenue was down 29.7% ...impacted by slight constraints from the Thailand flood in October

portfolio of PADs, multimode-multiband PAs, and penta-band PAs for 3G/4G applications," Michels notes.

"Our new circuit architecture for dual-band PAs gives us a strong competitive advantage that will enable us to

increase our 3G/4G market penetration," he believes. Also in Q1/2012, Anadigics announced that it is shipping production volumes of its HELP3E power amplifiers for the new Galaxy Nexus smartphone of Samsung Electronics.

"We are acutely focused on execution in 2012," says Gallagher.

"In commenting on the first quarter, we expect revenues to reflect the high end of seasonal softness [with wireless revenue down 15%] in addition to a decline in revenue from products sold to our former top customer [Research in Motion] reaching end of life," he adds. RIM revenues have lasted longer than anticipated, says Gallagher, but the firm is not expected to be a major customer in 2012.

"As we look beyond the seasonal first quarter, our new products serving an expanded addressable market will position us for growth in second half of 2012 and beyond," reckons Michels. Assuming a return to a revenue split of 75/25 between wireless and broadband, Anadigics expects cash flow break-even for quarterly revenue of about \$50m.

www.anadigics.com



Anadigics' new ALT6181 multimode multiband power amplifier.

Anadigics adds small-cell wireless infrastructure PAs for E-UTRA Band 7 WCDMA/LTE equipment

Anadigics Inc of Warren, NJ, USA has expanded its family of small-cell infrastructure power amplifiers (PAs) to support E-UTRA Band 7 WCDMA and LTE applications by launching the AWB7128 and AWB7228 PAs.

Anadigics says that its family of small-cell infrastructure PAs delivers a combination of high output power, efficiency, and linearity, optimized for the rapidly growing class of small-cell base stations that includes picocells, enterprise-class femtocells, and high-performance customer premises equipment (CPE).

"The continual increase in consumer demand for wireless data is fueling the rapid deployment of small-cell wireless infrastructure devices, such as picocells and femtocells," says Glenn Eswein, director of product marketing for broadband RF products. "Anadigics' small-cell power amplifier family delivers the highest output power, power-added efficiency, and linearity in its class, enabling manufacturers to develop compact,



aesthetic, high-throughput devices that offer service providers an economical path to expand broadband network coverage," he claims.

"Working closely with device manufacturers, we are expanding this family to help bring the same performance and design flexibility to additional frequency bands."

The AWB7128 and AWB7228 are optimized for WCDMA, HSPA, and LTE small-cell base-stations operat-

ing in the 2620–2690MHz frequency band. The AWB7128 provides +24.5dBm linear output power (optimized for $\frac{1}{4}W$ applications), while the AWB7228 delivers +27dBm linear output power (optimized for $\frac{1}{2}W$ applications). The PAs use Anadigics' exclusive InGaP-Plus technology to achieve what is claimed to be best-in-class power-added efficiency (PAE = 15% for the AWB7128 and 14% for the AWB7228) and linearity ($-47dBc$ ACPR @ $\pm 10MHz$ offset; 10MHz channel bandwidth) at these output power levels, enabling small-cell wireless infrastructure solutions that are more thermally efficient, consume less power, and provide greater range.

In a compact 7mm x 7mm x 1.3mm surface-mount package, integration includes RF matching optimized for output power, efficiency, and linearity in a 50 Ω system

Engineering samples of the AWB7128 and AWB7228 are available now for qualified programs.

www.anadigics.com

MMPAs for quad-band GSM/EDGE and dual-band WCDMA/LTE

Anadigics has made available engineering samples of the ALT6181 multimode multiband power amplifier (MMPA), which uses the firm's third generation High-Efficiency-at-Low-Power (HELP3E) technology to provide what is claimed to be industry-leading efficiency in a single module solution for quad-band GSM/EDGE and dual-band WCDMA/LTE mobile applications. The combination of performance and integration helps to extend battery life and reduce RF space requirements in handsets, smartphones, tablets, netbooks, and notebooks, it is claimed.

"Mobile devices continue to evolve in both form and function, creating performance and size constraint challenges on the RF

front-end," notes John van Saders, senior VP of RF products. "Our new multimode multiband power amplifiers extends our high-performance RF integration," he adds. "By delivering a converged solution with industry-leading performance, we are able to provide manufacturers with greater design flexibility to enable the next-generation of mobile devices."

Anadigics' MMPAs are optimized for performance under LTE, WCDMA and CDMA signal modulations for bands 1, 5, 6, 18, 19 and 26. Efficiency, current consumption and linearity specifications have been enhanced for all modulations, while ensuring that critical harmonic, noise and intermodulation performance results in better phone-level

performance. The MMPA solution uses Anadigics' exclusive InGaP-Plus technology and HELP architecture to achieve optimal efficiency across low-range and mid-range output power levels, without the use of a DC-DC converter. When paired with a DC-DC converter, the MMPA can deliver additional performance benefits, the firm claims.

The compact 5mm x 7.5mm MMPA features an integrated voltage regulator and separate single-ended RF chains. The inclusion of high-directivity couplers also ensures optimum system performance. GSM performance is characterized by high efficiencies at all power levels, while EDGE performance meets all stringent modulation mask requirements under all conditions.

IN BRIEF

Mitsubishi Electric develops six-band PA in conventionally sized package for automatic band switching and seamless roaming

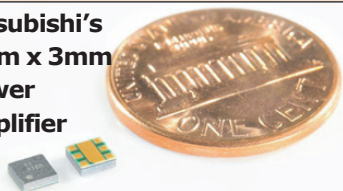
Tokyo-based Mitsubishi Electric Corp has developed a power amplifier with broadband circuitry that is compatible with six 3GPP-compliant frequency bands between 1.7GHz and 2.0GHz, enabling automatic band switching and seamless international roaming with a single mobile device.

Through using the Quantance qBoost ultra-fast, low-noise, envelope tracking power supply, the unit's power-added efficiency (PAE) rating of 40% is claimed to be one of the highest for a multi-band power amplifier, and its package is among the world's smallest (at 3mm x 3mm x 1mm), which will lead to mobile devices offering longer battery life and reduced size.

Mitsubishi Electric says that its six-band power amplifier addresses several key demands in wireless communication. The increase in wireless traffic due to proliferating smartphones requires mobile devices increasingly to locate and switch to available frequencies when other bands are overloaded. Automatic band switching is also necessary for international roaming. In addition, the use of multiple amplifiers — each dedicated to a certain frequency band — forces mobile devices to devote more space to additional circuitry.

www.MitsubishiElectric.com

**Mitsubishi's
3mm x 3mm
power
amplifier**



Skyworks ramps GPS/GNSS receive-only front-end for Samsung

Skyworks Solutions Inc of Woburn, MA, USA (which manufactures high-reliability analog and mixed-signal semiconductors), is ramping global positioning system (GPS) and global navigation satellite system (GNSS) solutions for smart-phone maker Samsung Electronics Co Ltd. The firm's newest devices, which integrate a low-noise amplifier with filtering designed specifically for GPS/GNSS receiver applications, are claimed to be the smallest solutions on the market requiring no external components, allowing manufacturers an easy 'plug and play' option.

"Navigation is becoming one of the fastest-growing consumer features for smart phones and tablets," notes Liam K. Griffin, executive VP & general manager of high performance analog at Skyworks. "By leveraging core capabilities, Skyworks is delivering innovative solutions that help drive better performance and reduce complexity for our customers, while at the same time capturing additional RF content in high-growth markets," he adds.

Global adoption of smart phones continues to be robust, and is

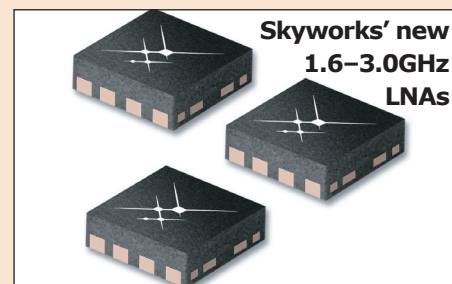
quickly being followed by a growing tablet adoption cycle. According to Oppenheimer & Co Inc, worldwide shipments of smart phones are predicted to reach 1 billion by 2015, up from about 400 million units at the end of 2011. In addition, tablets are expected to surpass 125 million units by 2015, up from roughly 50 million for the end of December 2011. Embedded GPS/GNSS functionality is expected to be an integral part of these devices.

The SKY65702-11 is a receive-only front-end solution with an integrated low-noise amplifier and filtering designed for GPS and global navigation satellite system receiver applications. The device provides high linearity, high gain, a high 1dB input compression point, and what is claimed to be a superior noise figure. The integrated GPS and GNSS filter provides low in-band insertion loss and good out-of-band rejection performance for the cellular/LTE, personal communication service and wireless local-area network (WLAN) frequency bands. The SKY65702-11 comes in an ultra-small 2.5mm x 2.0mm low-cost package.

Skyworks launches GaAs LNAs for 1.6–3.0GHz receiver applications

Skyworks Solutions has introduced three low-noise and high-linearity LNAs for 1.6–3.0GHz receiver applications.

The SKY67002-396LF (1.6–2.1GHz high-linearity LNA), SKY67003-396LF (2.0–3.0GHz high-linearity LNA) and SKY67102-396LF (2.0–3.0GHz ultra-low-noise LNA) are single-stage GaAs pHEMT low-noise amplifiers (LNAs) that offer ultra-low noise figure, high linearity and what is claimed to be excellent return loss in a small QFN package. On-die active bias design ensures



consistent performance and enables unconditional stability.

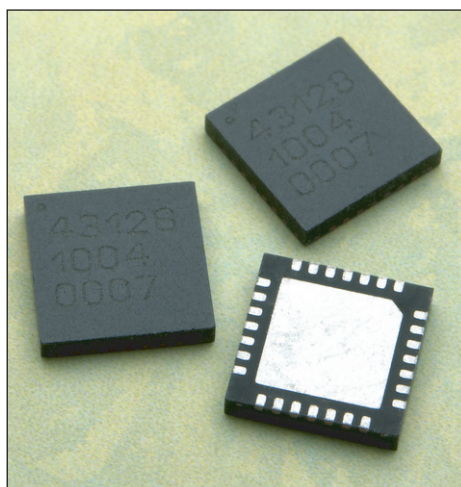
The LNAs are designed for wireless infrastructure OEMs that require high-performance, cost-effective solutions.

www.skyworksin.com

Avago launches high-gain linear power amplifier for 700–800MHz 4G LTE cellular infrastructure equipment

Avago Technologies has launched a high-gain (33.4dB), high-linearity power amplifier for high-data-rate applications in 700–800MHz cellular infrastructure equipment. The MGA-43128 provides what is claimed to be superior signal transmission quality with low power consumption for LTE AP, CPE, and picocell equipment, and can also serve as a base-station driver amplifier.

Designed for superior signal quality while transmitting at high data rates, the MGA-43128 features low distortion and high power-added efficiency (22% PAE at linear Pout for 750MHz), which help to reduce power consumption. RF input is fully matched, while the output includes integrated pre-match circuitry for matching and application simplicity. An integrated bypass switch controlled attenuator provides up to 18.0dB attenuation (using a single CMOS-compatible switch pin), and the device also has a temperature-compensated output power detector on-chip.



Avago's MGA-43128 power amplifier module for 700–800MHz 4G LTE cellular infrastructure equipment

The MGA-43128's very linear output power is achieved by using a proprietary 0.25 μ m GaAs enhancement-mode pHEMT process, which allows single 5V supply operation and usable performance down to 3.3V.

With high-linearity performance of 29.1dBm linear Pout at 2.5% error

vector magnitude (EVM), the 700MHz MGA-43128 joins Avago's 29dBm linear power amplifier family, following the launch in March 2010 of the MGA-43228 and MGA-43328 power amplifiers (which cover 2300–2500MHz and 2500–2700MHz, respectively). All devices in the series have a common package footprint to further simplify design.

The MGA-43128 is offered in a miniature 5.0mm x 5.0mm x 0.85mm surface-mount, 28-lead QFN package and operates over a temperature range of -40°C to $+85^{\circ}\text{C}$. The package is lead free and halogen free, and has a moisture sensitivity rating of MSL-2a to permit a floor-life of four weeks out of the bag.

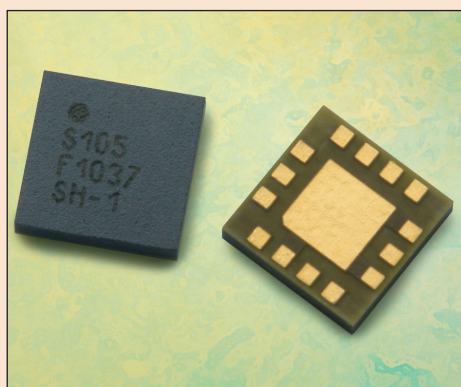
Samples and production quantities are available now through Avago's direct sales channel and worldwide distribution partners. An evaluation board is also available.

www.avagotech.com

High-efficiency front-end module for WiFi 5GHz access points

Avago Technologies has launched the AFEM-S105 highly efficient front-end module for WiFi access points, integrating a power amplifier, directional coupler and SPDT antenna switch in a small-footprint 3.2mm by 3.2mm by 0.6mm package. The power amplifier is optimized for IEEE 802.11 a/n WiFi modulation, helping the module to streamline the design of mobile and fixed wireless data applications in the 5.15-5.85GHz frequency range.

Integrating multiple high-performance technologies to reduce PCB board footprint and simplify design, the module leverages the firm's proprietary 0.25 μ m GaAs enhancement-mode pHEMT process technology to achieve robust RF performance across



Avago's new AFEM-S105 front-end module for WiFi access points.

voltage and temperature levels, as well as low current consumption. It exhibits flat gain of 28dB and good match (with all RF ports matched to 50 ohms for simplified design) while providing linear power efficiency to meet stringent

802.11a/n mask conditions.

Additional features of the AFEM-S105 include high Tx-Rx switch isolation, and stability under all loads or conditions. The module also meets FCC 15.205 emission requirements at 15dBm.

"Designers are under tremendous pressure to integrate WiFi connectivity to bring new products to market first," says James Wilson, director of marketing for wireless products. "Our easy-to-use AFEM-S105 front-end module provides a highly integrated, compact solution that can be quickly designed in to WiFi access points and portable WiFi applications," he adds.

The AFEM-S105 front-end module is priced at \$2 each in 10,000 piece quantities.

New form of hafnium oxide boosts dielectric constant

A novel material developed by researchers at the University of Cambridge is opening up new possibilities for next-generation electronic and optoelectronic devices, and paving the way for further component miniaturization.

Developed by Dr Andrew Flewitt's research team in the Department of Engineering's Electronic Devices & Materials Group, the new form of hafnium oxide provides higher dielectric constant compared with existing forms of hafnium oxide, which is already a key material in the electronics industry.

Normally, metal oxides are produced on substrates by sputtering (ejecting some atoms of an electrode through bombardment by heavy positive ions). However, one of the problems when attempting to make high-quality electronic materials through sputtering is the difficulty in precisely controlling the energetics of the deposition process, and hence the material properties such as defect density.

To enable greater control of the material properties, Flewitt's team began using HiTUS (High Target Utilisation Sputtering) deposition technology to promote plasma sputtering. Hafnium oxide was one of the first materials they looked at.

Hafnium oxide is an electrical insulator that is used in optical coatings, capacitors and transistors, among other applications. In particular, many firms are using it to replace silicon dioxide in transistors, due to its high dielectric constant (ratio of electric displacement in a medium to the intensity of the electric field producing it). The higher the dielectric constant of a material, the higher its capacitance (ability to store an electric charge).

Hafnium oxide forms in different crystalline and polycrystalline structures: monoclinic, cubic and orthorhombic. However, an amorphous form is preferable to polycrystalline forms due to the absence of grain boundaries (the point at which two crystals in a polycrystalline material meet). Grain boundaries act as conduction paths through thin films of the material. They not only reduce the resistivity, but lead to non-uniformity in conductivity over a large area, which itself leads to spatial non-uniformity in device performance. However, until now amorphous hafnium oxide has had a relatively low dielectric constant of about 20. The form of hafnium oxide developed by Flewitt has a dielectric constant higher than 30.

"Most people thought that all amorphous hafnium oxide had to exist in the monoclinic-like phase," says Flewitt. "What we've shown is that it can exist and does exist in a cubic-like phase," he adds. "This is similar to amorphous carbon, where you can get diamond-like properties out of amorphous carbon material."

Amorphous dielectrics are more homogenous than other forms, allowing improved uniformity from one device to another, and the absence of grain boundaries results in not only higher effective resistivity but also less optical scatter.

The material is produced using a room-temperature, high-deposition-rate process, making it particularly suitable for plastic electronics and high-volume semiconductor manufacturing. The absence of grain boundaries also makes the material ideal for optical coatings and more efficient solar cells, it is reckoned.

Cambridge Enterprise Ltd, the university's commercialization group, is currently seeking commercial partners for collaborative development and licensing of the new material.

www.g.eng.cam.ac.uk/edm
www.enterprise.cam.ac.uk

Hittite's margins trimmed as revenue falls 11.6% in Q4

For full-year 2011, Hittite Microwave Corp of Chelmsford, MA, USA (which designs and supplies analog, digital and mixed-signal RF, microwave and millimeter-wave ICs, modules and subsystems as well as instrumentation) has reported revenue was \$264.1m, up 8.1% on 2010's \$244.3m.

However, for fourth-quarter 2011, revenue was just \$60.2m, down 8.2% on \$65.6m a year ago and 11.6% on \$68.1m last quarter. Of total revenue, 46% (\$27.7m) came from customers in the USA (versus \$30.3m, or 44.4%, in Q3) and 54% (\$32.5m) came from

outside the USA (versus \$37.8m, or 55.6%, in Q3).

Gross margin has fallen from 74.5% (both a year ago and last quarter) to 74%. Operating income was \$24.6m (an operating margin of 40.9% of revenue), down from \$33.3m (48.8% operating margin) last quarter and \$32.2m (49.1% operating margin) a year ago.

Net income was \$21.2m, down on \$22.4m last quarter but up on \$20.9m a year ago (and above the expected \$15.2–16.5m). However, Q4 included a \$5.5m tax benefit due to the resolution of a tax audit. Net income for the year was

\$84.7m, up from 2010's \$77m. During the fourth quarter, total cash and cash equivalents rose by \$2.5m, to \$353.7m.

Net bookings for 2011 were \$256.9m, up slightly from 2010's \$254.9m. Order backlog at the end of December was \$67.4m (down from \$74.5m at the end of 2010).

For first-quarter 2012, Hittite expects revenue to grow to \$61–63m (though still down year-on-year from Q1/2011's \$67.2m). Net income should be \$15.5–16.3m (roughly level on Q4, after excluding that quarter's \$5.5m tax benefit).

www.hittite.com

M/A-COM Tech launches products for networks and aerospace & defense applications

M/A-COM Technology Solutions Inc of Lowell, MA, USA has launched seven new products covering networks and aerospace & defense applications.

For CATV/broadband, the MAAM-010263 completes M/A-COM Tech's family of default-on broadband active splitters designed for multi-tuner set-top boxes, home gateways and customer premises equipment (CPE) applications. Featuring a default-on loop-through path, the MAAM-010263 allows for access to the cable signal even when the CPE box is powered down.

The device is a highly linear 6-way active splitter with low distortion and low noise figure. Designed for operation from 50 to 1100MHz, the amplifier is packaged in a RoHS compliant 4mm 24-lead PQFN. The 6-way Splitter is fabricated on M/A-COM Tech's established E/D pHEMT process which delivers, low distortion, low noise figure and highly repeatable performance.

Also released is the MAAM-010333, an optical node RF amplifier operating at 50–1000MHz. The integrated TIA, VVA, RF amplifier provides high gain, low equivalent input noise (EIN), and low distortion amplification for optical node applications. Fabricated on M/A-COM Tech's GaAs pHEMT technology, the amplifier is packaged in a 4mm 24-lead PQFN, and operates between

–8dBm to +2dBm of optical input power. With a single +5V bias and 27dB gain control range, the MAAM-010333 is a highly integrated, low-cost solution for optical node applications, says M/A-COM Tech.

For cellular infrastructure, the MAAM-000523 is a 6-bit, 0.5dB digital attenuator for 50Ω systems, operating in the 0.7–6GHz frequency range. The attenuator is suitable for when high accuracy, low power consumption and low intermodulation products are required.

The MAAM-000523 includes an integrated TTL/CMOS-compatible driver, and offers parallel and serial control with a power-up state function. Packaged in a lead-free 4mm 24-lead PQFN, it has small relative phase variation per bit, and achieves an insertion loss of 1.6dB at 2GHz. The attenuator features a typical input return loss of 18dB up to 6GHz.

M/A-COM Tech has also launched two new additions to its family of switches for cellular infrastructure applications. Operating at 0.01–4.0GHz and packaged in an industry-standard 4mm 24-lead PQFN, the MASW-010350 is a high-isolation single-pole four-throw (SP4T) switch, while the MASW-010351 is a high-isolation single-pole five-throw (SP5T) switch.

With a symmetric circuit design using M/A-COM Tech's GaAs pHEMT

technology and an integrated CMOS decoder, both switches maintain what is claimed to be an excellent combination of low insertion loss and high isolation for all states. The new switches are designed to lower the system complexity and reduce the bill of material (BoM) cost by replacing multiple single-pole double-throw (SPDT) switches. The switches are suitable for band switching in multi-channel and multi-mode base-station applications.

For aerospace & defense, the 8–12GHz MAPS-010146 and MAPS-010166 are X-band additions to M/A-COM Tech's family of digital phase shifters, facilitating easy implementation in communication antennas, phased array radars, weather radars, and EW (electronic warfare) receivers.

The MAPS-010146 is a 4-bit digital phase shifter that provides 360° phase shift range with a step size of 22.5°. Insertion loss is 6.5dB, with a low ±1.0dB attenuation variation and ±10.0° phase accuracy.

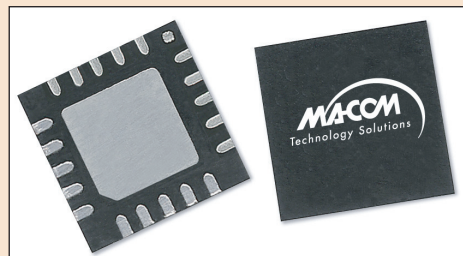
The MAPS-010166 is a 6-bit digital phase shifter that provides 360° phase shift range with a step size of 5.625°. Insertion loss is 6.5dB, with a low ±1.2dB attenuation variation and ±8.0° phase accuracy.

Both are housed in a 4mm 24-lead PQFN package, and are controlled with a single +5V serial or parallel control line.

High-linearity 1.2W GaAs PA launched for point-to-point applications

M/A-COM Tech has launched the MAAP-008924, a 3-stage, high-linearity 1.2W GaAs power amplifier (PA) for point-to-point radio applications (e.g. for 10, 11 and 13GHz point-to-point radio transceivers for cellular backhaul applications). Packaged in a 5mm, 20-lead PQFN, the amplifier is fully matched to 50Ω on both the input and output.

Operating in the 10–13.3GHz frequency range, the MAAP-008924,



can be used as a power amplifier stage, or as a driver stage in high-power applications. Fabricated using M/A-COM Tech's high-linearity

MESFET process, the amplifier features 20dB gain and 44dBm OIP3.

"The MAAP-008924 provides a high output IP3 while maintaining low DC power consumption," says product manager Jack Redus. Quiescent current is 1000mA. Output power at 1dB compression (P1dB) is 31dBm. Input return loss is 12dB and the output return loss is 10dB.

www.macomtech.com

Peregrine ships billionth CMOS-on-sapphire RFIC

Peregrine Semiconductor Corp of San Diego, CA, USA, a fabless supplier of RFICs based on silicon-on-sapphire (SOS), has shipped its billionth CMOS-on-sapphire RFIC.

The milestone was achieved with a new SP8T (single-pole, eight-throw) RF switch, which is one of several new high-throw-count switches designed on the latest 'STeP5' version of its UltraCMOS process technology, which is used for many of the firm's latest RFICs, including the newest SP8T and SP10T RF switches and the most recent DuNE digitally tunable capacitors (DTCs) for RF impedance tuning. Peregrine says that the technology innovation associated with the STeP5 release has driven demand from cellular handset makers and global customers for UltraCMOS RFIC products to a record number of devices per week.

"UltraCMOS STeP5 process brings an unprecedented capability to our product design team," reckons chief marketing officer Rodd Novak. "It has enabled us to develop unique RF switches that achieve industry-leading results for combined linearity, insertion loss, isolation and power consumption, all monolithically integrated into the industry's smallest footprint," he claims. "STeP5 has also opened the door for future product categories for the

RF front-end," Novak adds. "With the support of our robust supply chain and manufacturing foundries, we have achieved the fastest production ramp in Peregrine history."

The 4G/LTE network has introduced significant challenges to the RF front-end (RFFE) of the cellular handset, including a fragmented RF spectrum, which causes co-existence issues between bands and other standards such as connectivity (GPS, Wi-Fi and Bluetooth), says Peregrine. The lack of global frequency alignment has resulted in 28 LTE bands being identified in the 3rd Generation Partnership Project (3GPP) mobile standards specification (3GPP TS 36.101 V10).

"One of the most difficult problems 4G and LTE handset designers face is the coexistence of multiple bands and the linearity needed to support operation without self-jamming," comments Allen Noguee, research director with market research firm In-Stat, covering the Wireless market segment. "The RF front-end is bearing most of the design burden for performance of the RF signal. In fact, LTE's spectral efficiency comes at the cost of increased linearity and power consumption," he adds. "Peregrine's new STeP5 UltraCMOS products appear to have hit the need right on the mark."

The firm's latest family of high-throw-count RF switches — which support 4G LTE RFFE linearity and insertion loss demands over all conditions — includes the PE426151, PE426152 and PE426153 SP10T devices, and the PE426821 and PE426851 SP8T devices with integrated MIPI, SPI or GPIO interface options:

● **PE426821 and PE426851 SP8T RF switches.** Insertion loss (0.35dB at 900MHz and 0.45dB at 1900MHz); linearity (2fo,3fo is -42dBm at 824MHz to 2.6GHz); IMD2/3 of -111dBm; isolation 37dB on all paths (900/1900MHz); and 4kV HBM ESD (ANT) and 2kV (all pins);

● **PE426151, PE426152 and PE426153 SP10T RF switches.** Insertion loss (0.4dB at 900MHz and 0.5dB at 1900MHz); linearity (2fo,3fo is -42dBm at 824MHz to 2.6GHz); IMD2/3 of -111dBm; isolation 38dB on all paths (900/1900MHz); and 4kV HBM ESD (ANT) and 2kV (all pins).

All the above devices operate up to a frequency of 3GHz and are offered in flip-chip known good die (KGD). The new STeP5 RF switches are now in high-volume production, and samples are available to qualified customers.

www.psemi.com

Peregrine sues RFMD and Motorola, alleging patent infringement

Peregrine has filed a complaint with the US International Trade Commission (ITC) and a lawsuit in the US District Court for the Central District of California against RF Micro Devices Inc and Motorola Mobility Inc.

The complaint claims that certain components and smartphones infringe patents relating to silicon-on-insulator (SOI) technology for RF ICs. It seeks an exclusion order preventing the import and sale of infringing products in the USA. The lawsuit also seeks damages and to enjoin RFMD and Motorola Mobility

from further infringement.

Peregrine's products are based on proprietary UltraCMOS process and design technologies and are the result of over 20 years of R&D activity and the investment of about \$200m, the firm claims.

Peregrine says that it has been awarded numerous US and foreign patents based on its work in developing and manufacturing products for the RF front-end, which can be produced using standard CMOS-based semiconductor manufacturing processes. The patented developments allow RF solutions

to be produced with a combination of high levels of monolithic integration and performance, small size and low power consumption, the firm claims. "We intend to vigorously protect our intellectual property and our resultant advancements in the field," says president & CEO Jim Cable.

In response, RFMD says that it has a strong intellectual property portfolio relating to RFICs and switching technology that it has developed over many years, and it intends to vigorously defend its position in the lawsuit.

Black Sand closes \$10m Series C funding round

Fabless semiconductor firm ramps volume production of CMOS power amplifiers for 3G phones, tablets, datacards

Fabless semiconductor firm Black Sand Technologies Inc of Austin, TX, USA, which was founded in 2005, has received \$10m in third-round (series C) funding, as it ramps volume production of its range of CMOS silicon power amplifiers for use in 3G phones, tablets and datacards. The latest funding round was led by existing investors Northbridge Venture Partners and Austin Ventures.

"The enthusiastic commitment of our shareholders, placing \$10m in cash on the balance sheet, is a powerful endorsement of our strategy and our growing success in the market," reckons CEO John Diehl. "We are already shipping in volume to multiple customers, and this additional investment will allow us to take the company to the next level — in terms of new products and an expansion of the sales and technical team," he adds.

Black Sand uses industry-standard CMOS semiconductor technology in the manufacture of key handset components that have traditionally required specialized process technologies. The firm says that its products can hence be made in the world's largest semiconductor foundries, improving quality, reliability and robustness, reducing costs, and giving customers supply assurance.

"The team at Black Sand has performed impressively over the last 24 months, not only successfully productizing the silicon power amplifier concept, but also achieving significant market traction," comments Basil Horangic, a partner at Northbridge.

"The market that Black Sand addresses certainly has a compelling need for its technology," reckons Clark Jernigan, venture partner at Austin Ventures. "Black Sand's products benefit consumers, handset makers and network operators."

The firm's BST34 series of power amplifiers is designed as a drop-in replacement for existing 3G gallium arsenide PAs, improving supply and lowering cost for handset manufacturers, it is claimed. The BST35 series also uses another key feature of CMOS process technology — the ability to integ-

rate more functionality on-chip. Black Sand claims that the overall result is a reduction in the incidence of dropped calls, an increase in real-world data rates, and reductions in network operators' capital expenditure requirements.

www.blacksand.com



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RFaxis granted four patents for single-chip single-die RF front-end IC technology

Fabless semiconductor firm RFaxis Inc of Irvine, CA, USA, which was founded in 2008 to design RF semiconductors and embedded antenna solutions for the wireless connectivity and cellular mobility markets, has been awarded four patents for its single-chip, single-die RF front-end integrated circuit (RFeIC) architecture. The firm says that these are the fundamental patents among its intellectual property (IP) portfolio, which consists of more than 30 patents that have been filed to-date.

The patents are 'Radio Frequency Transceiver Front End Circuit with Matching Circuit Voltage Divider', 'Multi Mode Radio Frequency Transceiver Front End Circuit', 'Multi Mode Radio Frequency Transceiver Front End Circuit with Inter-Stage Matching Circuit', and 'Multi Mode Radio Frequency Transceiver Front End Circuit with Inter-Stage Power Divider'.

"Our single-chip, single-die RFeIC architecture is process and materials agnostic, and can be implemented in all semiconductor technologies such as gallium arsenide-based HBT, indium phosphide-based HEMT, silicon-germanium-based BiCMOS or pure bulk CMOS [silicon]," says chief technology officer Dr Oleksandr Gorbachov.

"We developed and productized our first-generation RFeICs, including the RFX2401 for ZigBee and RFX2402 for WLAN, using BiCMOS

Our single-chip, single-die RFeIC architecture is process and materials agnostic, and can be implemented in all semiconductor technologies such as GaAs-based HBT, InP-based HEMT, SiGe-based BiCMOS or pure bulk CMOS

process in 2009. We have since successfully migrated these products to standard bulk CMOS process and are now shipping our second-generation, backwards-compatible products including RFX2401C and RFX2402C," he adds. "We are in the process of launching several new pure CMOS-based RFeICs that serve major wireless protocols including WLAN 802.11a/b/g/n/ac, Bluetooth, ZigBee/ISM, and markets such as smart meters, wireless audio/video and home automation, among others," Gorbachov continues.

"These four fundamental patents provide full protection for our main architecture," says RFaxis' chairman & CEO Mike Neshat.

"Our disruptive RFeIC technology is now fully patented," he adds. "We expect to have more patents granted in the coming weeks and months."

www.rfaxis.com

RFaxis celebrates 4-year anniversary by shipping 4 millionth RFeIC

RFaxis has celebrated two milestones: shipping 4 million units of its patented single-chip/single-die RF front-end integrated circuits (RFeIC) and its 4-year anniversary.

"RFaxis was incorporated in January 2008, amidst one of the most severe global business downturns in history... at a time when almost every company in the world was either downsizing or going out of business," says chairman & CEO Mike Neshat. "There were major economic doubts whether any startup could succeed, much less survive. Many experts in the RF field did not believe RFaxis could ever deliver a fully integrated single-chip/single-die RF front-end," he adds. "The shipment of our 4-millionth RFeIC, which is being used in many products and serving several markets — from Wi-Fi to smart meters to home automation

— is the best testimony of the tremendous value that RFaxis brings to the wireless ecosystem."

For its work in bringing innovations to the global wireless and RF community, RFaxis has received awards including the 2010 Electronic Engineering Times ACE

Wi-Fi-enabled devices are projected to reach 2.6 billion annual shipments by 2016, and 'Internet of Things' up to 50 billion connections gradually, becoming a natural part of consumer lifestyles and business operations

Award for 'Start-up of the Year', EE Times 'Silicon 60', the 2011 Red Herring Top 100 North America Award, and the TechAmerica 18th Annual OC High-Tech Innovation Award.

"With Wi-Fi-enabled devices projected to reach 2.6 billion annual shipments by 2016, and 'Internet of Things' with up to 50 billion connections gradually becoming a natural part of consumer lifestyles and business operations, we firmly believe RFaxis' pure CMOS RFeIC solutions are on solid path to becoming the next mainstream in RF," says Neshat. "Based on our existing design wins and customers' demand, we will be shipping in excess of 50 million RFeICs in 2012," he adds. "Our goal is to beat this number as we win more sockets."

Javelin claims first fully qualified CMOS power amplifier shipping in volume for 3G smartphones

Javelin Semiconductor Inc of Austin, TX, USA, which claims to have developed the first high-performance CMOS 3G power amplifier (PA), says that South Korea's Samsung Electronics Co Ltd has selected the JAV5501 Band I PA for its new Galaxy smartphones.

The initial Samsung phone model available with Javelin's PA is the Galaxy Ace Plus, a mid-range Android-based 3G smartphone. Following the widely popular Galaxy Ace, the Galaxy Ace Plus features a larger 3.65-inch display, faster 1GHz processor, 5 megapixel camera, Bluetooth and Wi-Fi.

"As a fully qualified 3G PA supplier [founded in 2007], Javelin has proven the performance, quality and reliability of our patented architecture," says president & CEO Brad Fluke. "We look forward to continue working closely with Samsung on next-generation smartphones."



Javelin's JAV5501 CMOS 3G power amplifier, selected by Samsung

Launched in February 2011, the JAV5501 is claimed to be the first CMOS 3G PA in volume production with a leading smartphone maker. Javelin's PAs use standard CMOS to implement a mixed-signal architecture. The firm claims that its PAs achieve excellent linearity and have the best noise performance of any 3G PA on the market, improving

overall smartphone performance by minimizing interference with wireless radios such as Bluetooth, Wi-Fi and GPS. Also, with low average power consumption, the PAs can extend overall smartphone battery life.

Javelin says that, with PAs fabricated in standard CMOS, it can offer supply assurance from the world's largest foundries as well as high levels of quality, reliability and robustness, compared to existing proprietary PA

process technologies. The firm offers a family of CMOS 3G PAs supporting multiple bands that are available in an industry-standard 3mm x 3mm package and are software compatible with all 3G baseband platforms.

www.javelinsemi.com

www.samsung.com

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Renesas launches second series of SiC power devices

Renesas Electronics has announced the availability of three new SiC power devices (the RJQ6020DPM, RJQ6021DPM and RJQ6022DPM), which incorporate multiple SiC diodes and power transistors in a single package to comprise a power converter circuit or switching circuit.

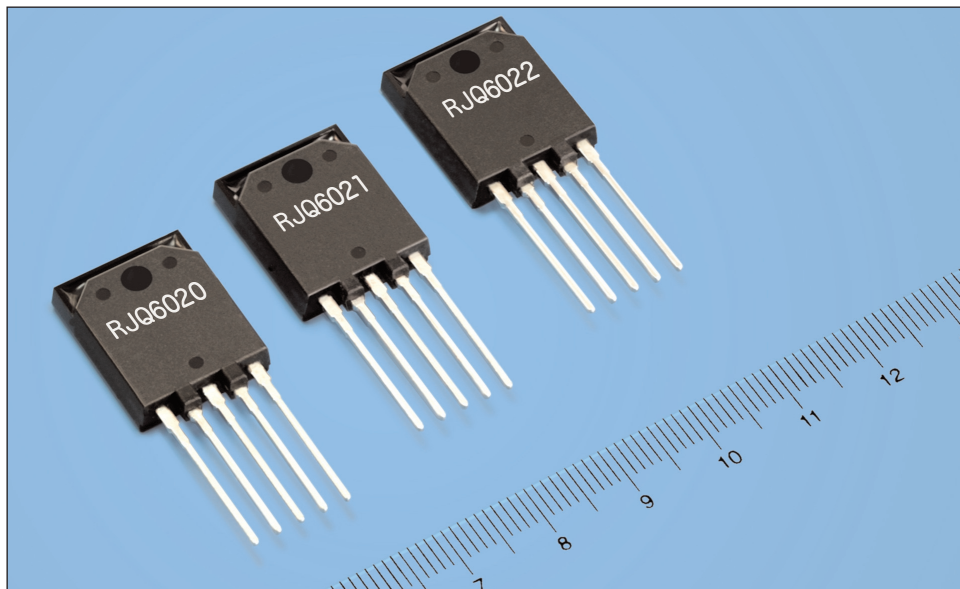
The new devices are the second series of power semiconductor products from Renesas to use SiC, following its new RJS6005TDPP Schottky barrier diode (SBD), launched earlier in January.

The latest, second series of SiC power devices implement a circuit (switching, power conversion, etc) in a single package by combining a SiC Schottky barrier diode and high-power silicon MOSFETs or IGBTs (insulating-gate bipolar transistors).

The new products have a voltage tolerance of 600V and use an SiC diode based on low-leakage SiC-SBD technology developed jointly by Renesas and Hitachi Ltd. They combine low loss and compactness and are available in a fully molded TO-3P package with a 5-pin configuration and pin assignments optimized for specific applications, making it easy to configure a circuit unit incorporating them, it is claimed.

Key features of the three new SiC power devices are as follows:

- The RJQ6020DPM device for critical-conduction mode PFC applications combines an SiC SBD and two high-voltage power MOSFETs (required in switching circuits for critical-conduction mode PFC in the power supplies of products such as air conditioners or flat-panel TVs). The reverse recovery time (t_{rr}) of the SiC-SBD is only 15ns, and the high-voltage power MOSFETs are highly efficient super-junction (SJ-MOS) transistors employing a deep-trench configuration to achieve a low on-resistance of 100m Ω . The RJQ6020DPM can also be combined with Renesas' R2A20112A/132 critical-conduction mode PFC-IC, making it easy to implement interleaved control.



Renesas' new RJQ6020DPM, RJQ6021DPM and RJQ6022DPM SiC devices.

- The RJQ6021DPM device for continuous-conduction mode PFC applications combines an SiC-SBD and two IGBTs (required for PFC in applications such as AC/DC rectifiers for communication equipment and PC servers). The ultra-thin-wafer IGBTs deliver a low on-voltage of 1.5V, suiting continuous-conduction mode PFC. The RJQ6021DPM can also be combined with the R2A20114A continuous-conduction mode PFC-IC, making it easy to implement interleaved control.

- The RJQ6022DPM device for inverter half-bridge circuits combines two SiC-SBDs and two IGBTs (required for half-bridge circuits in inverters for applications such as motor drive in air conditioners and industrial machinery). The ultra-thin-wafer IGBTs deliver a low on-voltage of 1.5V and short-circuit time (t_{sc}) of 6 μ s, suiting motor drive applications. A single RJQ6022DPM device is sufficient to implement a half-bridge circuit, while two can be used for a full-bridge configuration and three for a three-phase bridge configuration. In addition to simplifying the design of motor drive circuits, the RJQ6022DPM will be available as part of kit solutions with Renesas MCUs (microcontroller units) such as the RX600 Series.

With a focus on high-voltage power devices, the new series of SiC power devices was developed to provide total solutions comprising MCUs plus analog and power devices. The firm plans to roll out kit solutions combining the new SiC

The second series of SiC power devices implement a circuit (switching, power conversion, etc) in a single package by combining a SiC Schottky barrier diode and high-power silicon MOSFETs or IGBTs

products with MCUs, power control ICs, and other devices. Reference boards mounted with the new SiC power devices, PFC-ICs, RX600 Series MCUs etc are being planned to help customers with kit evaluation and product design.

Sampling of the new SiC power devices is scheduled to begin in February, priced at \$10 per unit. Mass production will start in May and is expected to reach a combined volume

of 300,000 units per month in April 2013.

www.renesas.com

SemiSouth launches 1200V normally-on SiC JFET with ultra-low switching losses

SemiSouth Laboratories Inc of Starkville, MS, USA (which designs and manufactures silicon carbide devices and electronics for high-power, high-efficiency, harsh-environment power management and conversion applications) has launched the SJD120R340, a normally-on SiC trench junction field-effect transistor (JFET) that, compared with silicon MOSFETs, enables higher switching speeds and substantially lower losses.

Rated at 1200V with a maximum on-state resistance of 340m Ω (typical RDS,on of 270m Ω), these new devices feature a positive temperature coefficient for ease of paralleling and extremely fast switching with no tail current at 150°C. Key applications include photovoltaic microinverters, SMPS (switched-mode power supplies) and UPS (uninterruptible power supplies),



SemiSouth's SJD120R340 JFET.

motor drives, and induction heating. "Because of the small die size and our compact device design, the new SJD120R340 normally-on SiC trench JFETs are very cost-effective," says director of sales Dieter Liesabeths.

Samples are available today. Volume production is set to begin in second-quarter 2012, with pricing below \$7 in quantities of 1000.

www.semisouth.com

Demonstration board showcasing SiC JFETs in cascode half-bridge configuration

SemiSouth Laboratories Inc of Starkville, MS, USA (which designs and manufactures silicon carbide devices and electronics for high-power, high-efficiency, harsh-environment power management and conversion applications) has announced a demonstration board showing the operation of its SiC junction field-effect transistors (JFETs) in a cascode half-bridge configuration.

Enabling a quick evaluation of the SJD120R085 JFET, the demo board platform is suitable for applications including boost, buck, inverter and PSU half-bridge power-stage designs. In the cascode configuration, the JFET is driven via a source-connected MOSFET, allowing existing, commercially available MOSFET driv-

ers to be used.

Normally-on SJD120R085 1200V power JFETs enable high-speed switching, are compatible with standard gate drive circuitry, and feature a positive temperature coefficient for ease of paralleling, says SemiSouth. The JFETs have a high saturation current (27A), low on-resistance per unit area (85m Ω max), and improved switching performance.

The demo board comes complete with Gerber files and a BOM to allow users to build their own circuits. "Our SiC JFETs have industry-leading performance," claims VP of sales & marketing Dieter Liesabeths, "and we are committed to supporting them with the best available design tools."

www.semisouth.com

IN BRIEF

SPICE model for Cree power MOSFET

Cree Inc of Durham, NC, USA has expanded its design-in support for what it claims is the industry's first commercially available SiC MOSFET power devices with a fully qualified SPICE model.

Using the new SPICE model, circuit designers can evaluate the benefits of its SiC Z-FET MOSFETs for achieving a higher level of efficiency than is possible with comparably rated conventional silicon power switching devices.

Since SiC MOSFETs have significantly different characteristics to silicon devices, they require a SiC-specific model for accurate circuit simulations, says Cree. Its behavior-based, temperature-dependent SPICE model is compatible with the LT spice simulation program and enables power electronics design engineers to reliably simulate the advanced switching performance of Cree's CMF10120D and CMF20120D Z-FETs in board-level circuit designs, the firm adds.

Cree claims its SiC MOSFETs can deliver switching frequencies up to 10 times higher than silicon IGBT-based solutions. Their higher switching frequencies can enable smaller magnetic and capacitive elements, shrinking the overall size, weight and cost of power electronics systems.

The SiC MOSFET SPICE model adds to Cree's suite of design-in support tools, technical documentation and reliability information to provide power electronics engineers with the design resources needed to implement SiC power devices into next-generation power systems.

The SiC MOSFET SPICE model is available for download. Users can also download published specifications and design guidelines as well as request samples.

www.cree.com/power/mosfet.asp

Cree launches packaged 1700V SiC Schottky diodes

Cree Inc of Durham, NC, USA has introduced a series of packaged diodes that deliver what is claimed to be the industry's highest blocking voltage available in silicon carbide (SiC) Schottky technology. The 1700V Z-Rec Schottky diodes virtually eliminate the reverse recovery losses suffered in silicon PiN diode alternatives, it is claimed, enabling ultra-efficient, smaller and lighter systems — all with improved reliability. The new packaged products extend the performance improvements and system cost savings enabled by Z-Rec technology at 1700V to lower-power applications designed with discrete components.

"Cree's 1700V silicon carbide Schottky diodes are ideal for high-efficiency power electronics systems," reckons Cengiz Balkas, Cree VP & general manager, Power and RF. "They provide all the proven benefits of Cree's Z-Rec SiC Schottky diodes — zero reverse recovery losses, temperature-independent



Cree's new 1700V Z-Rec SiC Schottky diode.

switching and higher-frequency operation," he adds.

While the 1700V bare die have been available for customers designing their own custom power modules, the new TO-247-2 packages allow customers to take advantage of SiC for lower-power 1700V designs, enable more design flexibility in choosing current levels, and support a faster time to market.

"The availability of 1700V SiC Schottky diodes provides a number

of advantages for design engineers in high-voltage power applications," says Balkas. "Silicon carbide diodes enable maximum power efficiency and better EMI performance. The switching-loss improvement allows for increased system frequencies that can reduce the size of magnetic and capacitive components," he adds. "Significant reductions in system size, weight and cost can be achieved. Moreover, the availability of 1700V SiC diodes can eliminate the need for stacking multiple lower-voltage silicon diodes, thereby cutting component count, improving thermal performance and increasing reliability," Balkas concludes.

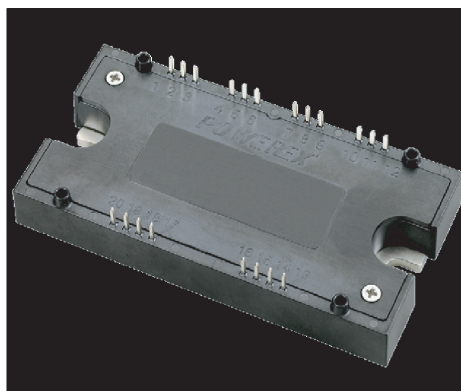
Designated the C3Dxx170H Series, the new SiC Schottky diodes are rated for 10A/1700V and 25A/1700V and are available in an industry-standard TO-247-2 package. Operating junction temperature is rated for -55°C to $+175^{\circ}\text{C}$.

www.cree.com/power/diodes.asp

Powerex launches low-profile split dual SiC MOSFET modules with multiple circuit topologies

Powerex Inc of Youngwood, PA, USA has launched two split dual silicon carbide (SiC) MOSFET modules (the QJD1210010 and the QJD1210011) designed for use in high-frequency power applications.

Created with a low profile and multiple circuit topologies (including independent, dual, in parallel, common collector, and common emitter), each module consists of two MOSFET SiC transistors, with each transistor having a reverse-connected Zero Recovery free-wheel SiC Schottky diode made by Cree Inc of Durham, NC. All components and interconnects are isolated from the heat-sinking baseplate, offering simplified system assembly and thermal management.



Powerex's low-profile split dual QJD1210010 SiC MOSFET module.

Rated at 100A/1200V, the new modules incorporate two individual switches, each of which features a junction temperature of 175°C , low internal inductance and capacitance, and what is claimed to be industry leading $R_{\text{DS(on)}}$. As well as

having high power density, this allows high-speed switching with low switching losses and low drive requirements. The isolated baseplates are copper on the QJD1210010 and (for extended thermal cycle life) AlSiC on the QJD1210011.

The modules can be used in high-frequency applications including: energy-saving power systems (such as fans, pumps and consumer appliances); high-frequency-type power systems (such as UPS, high-speed motor drives, induction heating, welding and robotics); and high-temperature power systems (such as power electronics in electric vehicle and aviation systems).

www.pwr.com

GaN nanowires show six-fold stronger 3D piezoelectric effect than bulk GaN

Although nanowires are often considered one-dimensional (being just 100nm in diameter), researchers at Northwestern University in Evanston, IL, USA have reported that individual gallium nitride (GaN) nanowires show strong piezoelectricity (charge generated by mechanical stress) in three dimensions (Nano Lett., 2012, 12 (2), pp 970).

While GaN is ubiquitous in optoelectronic elements such as blue lasers (i.e. blue-ray disc technology) and LEDs, more recently nanogenerators based on GaN nanowires have been demonstrated that are capable of converting mechanical energy (such as biomechanical motion) to electrical energy.

"Although nanowires are one-dimensional nanostructures, some properties — such as piezoelectricity (the linear form of electromechanical coupling) — are three-dimensional in nature," says Horacio Espinosa (the James N. and Nancy J. Farley professor in Manufacturing and Entrepreneurship at the McCormick School of Engineering and Applied Science). "We thought these nanowires should show piezoelectricity in 3D, and aimed at obtaining all the piezoelectric constants for individual nanowires, similar to the bulk material," he adds.

The findings revealed that individual GaN nanowires as small as 60nm show piezoelectric behavior

in 3D up to six times of their bulk counterpart. Since the generated charge scales linearly with piezoelectric constants, this implies that nanowires are up to six times more efficient in converting mechanical to electrical energy.

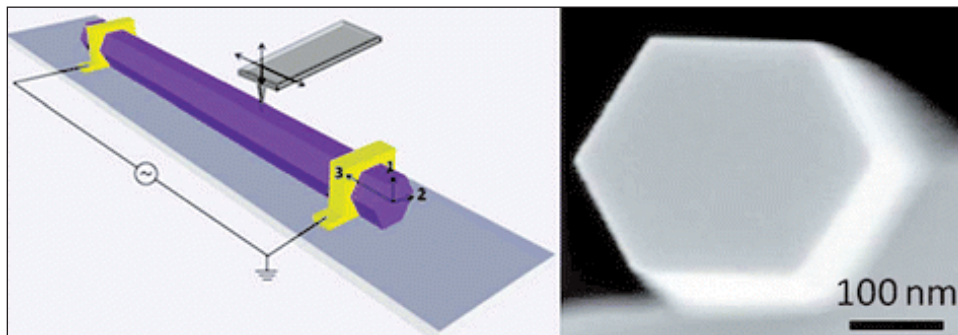
To obtain the measurements, researchers applied an electric field in different directions in a single nanowire and measured small displacements, often in the picometer range. The group devised a method based on scanning probe microscopy (SPM) leveraging the high-precision displacement-measurement capability of an atomic force microscope (AFM).

"The measurements were very challenging, since we needed to accurately measure displacements 100 times smaller than the size of the hydrogen atom," says postdoctoral fellow and lead author Majid Minary.

The researchers say that the results are especially interesting considering the recent demonstration of nanogenerators based on GaN nanowires that are capable of powering self-powered nanodevices.

In addition, they reckon that the method that they have developed is applicable to other piezoelectric nanowire materials as well as wires manufactured along different crystallographic orientations.

<http://pubs.acs.org/doi/abs/10.1021/nl204043y>
www.mccormick.northwestern.edu



As well as their direct bandgap, GaN nanowires exhibit piezoelectricity, making them attractive in energy-harvesting applications for self-powered devices.

IN BRIEF

AtlanTecRF launches X-band miniature amplifier with MIL-STD-883 screening as standard

RF & microwave equipment and component provider AtlanTecRF of Braintree, UK has launched the AGM-1005-15 miniature X-band amplifier, which can be used in either connectorized or drop-in configuration and which features high-reliability screening to MIL-STD-883 as standard.

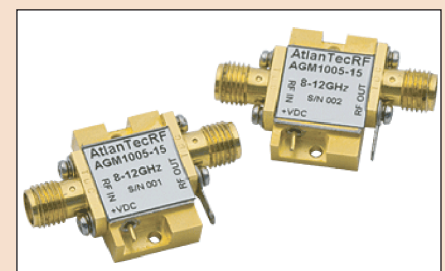
Covering the frequency range 8.0–12.0GHz, the amplifier uses thin-film and MMIC technology to provide what is claimed to be a versatile, economical and reliable gain module for microwave applications in communications, radar and defence equipment.

The AGM-1005-15 runs from a +15V DC supply to deliver more than 18dBm of linear power at a typical gain of 12dB and noise figure of 4dB at +25C. Gain flatness is ± 0.75 dB (maximum) over the band, and the input and output VSWRs are 2.0:1 maximum.

All units are tested over the temperature range from -55°C to $+85^{\circ}\text{C}$, and the MIL-STD-883 screening includes precap, stabilization bake, temperature cycling, burn-in, acceleration, vibration as well as gross and fine leak.

About the size of a small postage stamp, the amplifier enables high-density assembly and is also casacadeable for higher gain.

www.atlantecrf.com



AGM-1005-15 X-band amplifiers.

Transphorm unveils first qualified 600V GaN product

In what it says is its latest step to solve the growing problem of electrical energy waste in power conversion, at the Applied Power Electronics Conference (APEC) Transphorm Inc of Goleta, near Santa Barbara, CA, USA announced qualification of its first products, 600V power diodes based on its patented EZ-GaN technology, all in industry-standard TO-220 packages: TPS2010PK (6A), TPS2011PK (4A), and TPS2012PK (2A). The products are now qualified and available for sale to approved customers.

Transphorm claims its efficient, compact, easy-to-embed power conversion modules cut energy waste by 20% and can simplify the design and manufacturing of a variety of electrical systems and devices, including motor drives, power supplies and inverters for solar panels and electric vehicles. To demonstrate the performance of its technology, at APEC Transphorm showcased its EZ-GaN-based DC-to-DC Boost Converter running at more than 99% efficiency.

Transphorm emerged from stealth mode in early 2011. Backed by \$38m in funding from Google Ventures, Kleiner Perkins Caufield & Byers, Foundation Capital and Lux Capital, Transphorm was co-founded in 2007 by CEO Umesh Mishra, a professor of electrical & computer engineering at the University of California, Santa Barbara (UCSB), together with Primit Parikh as president.

"As predicted at APEC 2011, we are pleased to announce the availability of our first qualified products at APEC 2012 and showcase our technology to customers, partners and other stakeholders, as examples of our commitment to demonstrate that GaN devices for power are moving into mainstream adoption," says CEO Umesh Mishra.

"Our EZ-GaN solutions also impact broad applications such as motor drive systems, where our products provide 2-8% electromechanical efficiency gains," he adds.

Electric power waste during power conversion is equivalent to the daily output of 318 coal plants, and costs

the US economy \$40bn per year, it is reckoned. Transphorm claims to be the first firm to provide a qualified 600V GaN solution to inefficient power conversion. The GaN products are designed for optimum high-frequency switching. Transphorm says that its proprietary EZ-GaN platform can reduce power system size, increase energy density and deliver high efficiencies across the grid, from HVACs to hybrids, and from servers to solar panels.

"Our team lays the key first stake in the ground demonstrating that 600V GaN is not just a long-term promise, but today a superior product — an accomplishment made possible by working closely with our customer-partners who deliver the end products for power conversion," says Parikh. "For customers looking for a low-risk roadmap to the next generation of power conversion technology, Transphorm's EZ-GaN provides a cost-effective, customizable and easy-to-use solution ready for commercial scale."

www.transphormusa.com

Testing completed on Next Generation Jammer array transmitters using GaN-based power amplifiers

As part of the US Navy Next Generation Jammer (NGJ) program's technology maturation phase, a team led by defense contractor ITT Exelis of McLean, VA, USA has completed testing of critical components of array transmitter technology that incorporate GaN-based devices.

Observed by US Navy representatives, the testing demonstrated multiple critical technology elements, including digital beam-forming and mid-band and high-band power amplifiers (PAs). The demonstrations were accomplished in accordance with program objectives to achieve a high-technology readiness level deemed critical to reducing future technical risk to the Navy's Next Generation Jammer program.

The digital beam-forming technology demonstrated recent advances made in broad-band electronically steerable antenna arrays. The technology developed for the mid-band and high-band PA displayed the high technical maturity and performance of GaN semiconductors, as well as the packaging and cooling required for a future NGJ array transmitter, says ITT Exelis.

"Our receiver exciter expertise, coupled with these recent successes, enables a low-risk transition to an integrated operational system," says Bob Ferrante, VP & general manager of the airborne electronic attack business of ITT Exelis Electronic Systems in Clifton, NJ. "Our technology efforts are highly focused to ensure we address the

evolving NGJ requirements," he adds.

The Next Generation Jammer will help to ensure that US forces have complete dominance of the electronic spectrum, providing a comprehensive capability to disrupt and disable enemy communications and radars. Teamed with Boeing, Exelis leads one of four industry teams in competition to develop the final NGJ system.

Valued at more than \$2bn, the NGJ program will replace the existing inventory of aging ALQ-99 jamming pods on the Navy's newest airborne electronic attack aircraft, the Boeing EA-18G Growler. The NGJ pod will also be a stepping stone to electronic attack capability on other advanced platforms.

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First application-focused GaN transistors textbook

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA, which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) used in power management applications, has announced publication of a textbook designed to provide power system design engineers with basic technical and application-focused information on how to design more efficient power conversion systems using GaN-based transistors.

"This book will help designers to understand the exceptional benefits of GaN technology and the intricacies of working with GaN transistors in power conversion systems," comments Sam Davis, editor-in-chief of Power Electronics Technology magazine. "It will set the stage for a new era in power electronics applications that surpass everything that came before it," he adds.

EPC says that the practical guide provides guidance on the use of GaN transistors in widely used power electronics applications,

ranging from buck converters to Power over Ethernet. Also included are discussions on fundamental power engineering subjects such as: performance characteristics of GaN transistors, layout considerations for GaN circuits, paralleling GaN transistors and driver IC requirements for GaN transistors. The final chapters address GaN device reliability, their exceptional radiation-resistant characteristics as well as their future in power electronics.

"Gallium nitride transistors provide a long-awaited displacement technology for MOSFETs, and much has been learned over the past several years about how to apply this new technology," says CEO Dr Alex Lidow (co-author of the book). "In addition to increasing the efficiency of today's power conversion systems, GaN transistors open up new applications such as RF envelope tracking and wireless power transmission that are much needed to keep pace with the ever-expanding communications industry and

battery-operated products," he adds. "These new applications are enabled by the high-frequency switching capability combined with the high-voltage and high-power capabilities of gallium nitride FETs."

The four authors, Alex Lidow, Michael DeRooij, Johan Strydom and Yanping Ma, work for EPC, which claims to be the first firm to introduce enhancement-mode GaN transistors. Collectively they have over 90 years experience working in power transistor design and application. All four have doctorates in scientific disciplines and are already published authors. Lidow concentrates on transistor process design, Drs DeRooij and Strydom focus on power transistor applications, and Dr Ma provides expertise on quality assurance and reliability.

'GaN Transistors for Efficient Power Conversion' is available for \$39.95 via www.amazon.com, distributor DigiKey (www.digikey.com) and EPC's web-site.

www.epc-co.com

Texas Instruments extends family of GaN FET driver ICs with low-side gate driver

Dallas-based Texas Instruments Inc (TI) has introduced a low-side gate driver for use with MOSFETs and gallium nitride (GaN) power field-effect transistors (FETs) in high-density power converters.

The new LM5114 drives GaN FETs and MOSFETs in low-side applications, such as synchronous rectifiers and power factor converters. Together with the LM5113 (the industry's first 100V half-bridge GaN FET driver, launched in 2011), the family provides a complete isolated DC/DC conversion driver solution for high-power GaN FETs and MOSFETs used in high-performance telecom, networking and data-center applications.

The LM5114 drives both standard MOSFETs and GaN FETs by using independent sink and source out-

puts from a 5V supply voltage (for optimized rise and fall times enable higher efficiency). It features a high 7.6A peak turn-off current capability needed in high-power applications where larger or paralleled FETs are used. The 7.6A/1.3A peak sink/source driver current maximizes change-in-voltage over change-in-time (dV/dT) immunity. The increased pull-down strength also enables it to drive GaN FETs properly. The independent source and sink outputs eliminate the need for a diode in the driver path and allows tight control of the rise and fall times. A typical propagation delay of 12ns enables high switching frequency while maintaining improved efficiency. Matching delay time between inverting and non-inverting inputs reduces dead time losses.

Key features of the LM5114 low-side gate driver include: a 0.23Ω open-drain, pull-down, sink output (preventing unintended turn-on); up to 14V logic inputs, regardless of V_{CC} ; and an operating temperature range of -40°C to +125°C.

The LM5114 is available in volume. Offered in a 6-pin SOT-23 package and 6-pin LLP package with exposed pad, the suggested retail price is \$0.58 in 1000-unit quantities.

TI showcased its FET driver family (the LM5114, the LM5113 in a new micro SMD package, the pin-compatible 4A/8A UCC27511 low-side gate driver due for release in March, and other products that help unlock the benefits of GaN FET technology) at the Applied Power Electronics Conference (APEC) in Orlando, FL.

www.ti.com

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Ceres acquires Veeco's CIGS PV equipment assets

Partnerships sought to develop pilot- and production-scale tool-sets

Ceres Technologies Inc of Saugerties, NY, USA, which provides process equipment for the semiconductor and solar industries (as well as ultra-high-purity specialty gas and chemical handling products), has expanded further into the photovoltaic equipment manufacturing supply chain with its recent purchase of certain technology and product assets of the copper indium gallium diselenide (CIGS) system business formerly operated by epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA.

The CIGS product line adds to Ceres' growing portfolio of products and services in renewable energy, with production-ready CIGS deposition tool sets including machines for molybdenum back contact, CIGS absorber layer and transparent conductive oxide (TCO) layers. The current product offering allows

roll-to-roll deposition on stainless-steel substrates at 0.3m, 0.6m and 1.0m widths. In addition, a production-scale CIGS glass process tool is in development. As part of the technology purchase, Ceres has obtained the right to manufacture, support and further develop the CIGS equipment technology previously sold by Veeco.

"Ceres intends to selectively collaborate with PV equipment suppliers, CIGS cell and module manufacturers, and state and federal agencies with the intent of expanding production-worthy CIGS manufacturing tool sets to the PV market place," says president & CEO Kevin Brady. "Ceres is well positioned to facilitate near-term and future CIGS module production capacity growth," he reckons.

"Our business model fosters strategic partnership with our customers to develop and fulfill pilot-line and

production-scale requirements. Our CIGS equipment platforms, together with our full portfolio of gas and chemical handling products, provide our customers with a production-worthy supply of equipment infrastructure," Brady continues.

"Ceres Technologies' 'adaptive' (CIGS) platform architecture is designed to provide readily available process tool-sets to PV companies, allowing them to focus on development of their core IP by deploying it on a proven platform," says Frank Reilly, VP of the Ceres Technologies' Solar Group. "Cell and module manufacturing companies can also rely on Ceres' engineering and equipment manufacturing expertise to realize scaling of their unique development or pilot-line methods and recipes," he adds.

www.cerestechnologies.com

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AXT's revenue grows 9% in 2011, but falls 25% in Q4 ...but return to growth expected in Q1/2012

For full-year 2011, AXT Inc of Fremont, CA, USA, which makes gallium arsenide, indium phosphide and germanium substrate and raw materials, has reported revenue of \$104.1m, up 9% on 2010's \$95.5m. Gross margin rose from 38.2% to 43%, and net income rose from \$18.7m to \$20.3m.

"Despite near-term challenges, for 2011 as a whole, we posted the strongest fiscal year results in more than 10 years," says CEO Morris Young. "Across our business, we placed great emphasis on diversification of our customer base, with notable success in every product category," he adds. "We strengthened our sales presence and product specifications to enhance our participation in key geographic areas, such as China, Japan and Taiwan."

However, most recently, for fourth-quarter 2011, revenue was \$21.2m, down 25% on \$28.3m in

Q3 and 21% on \$26.9m a year ago. In particular, total GaAs substrate revenue was \$11.1m, down 41% on \$18.7m both in Q3 and a year ago. InP substrate revenue was \$724,000, less than half the \$1.5m in Q3 and down 34% on \$1.1m a year ago. Germanium (Ge) substrate revenue was \$3m, level on Q3 but down 13% on \$3.4m a year ago. Raw materials sales were \$6.4m, up 25% on \$5.1m in Q3 and almost double the \$3.5m a year ago.

After rising from 39.8% a year ago to 43.2% in Q3, gross margin has fallen to 36.9%. Although down from \$5m a year ago, operating expenses have risen slightly from \$4.2m in Q3 to \$4.5m.

"Throughout 2011, we carefully managed our expense levels and further improved our manufacturing and operating efficiency to keep pace with the pricing requirements of our customers and the

sizeable fluctuations in raw materials costs," notes Young. Nevertheless, net income was \$2.6m, down from \$4.9m a year ago and less than half the \$6.5m in Q3.

"We laid important groundwork to prepare our company for growth as we enter the next semiconductor cycle as well as increasing demand relating to a number of key secular trends that we play into," says Young. "Further, we took a critical, measured step to ensure that we have the appropriate level of capacity at the right time to meet market demand as it increases over the next several years," he adds.

"I am pleased by the way our team executed on its mission in 2011 and believe that we are well positioned for continued growth in 2012," concludes Young. For first-quarter 2012, AXT estimates revenue to either stabilize or grow, to \$21-24m.

www.axt.com

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Veeco's revenue falls 28% in Q4/2011 due to MOCVD declining 32% after China purchasing slowdown

Revenue to drop a further 33% from \$192m in Q4 to \$115–140m in Q1

Epitaxial deposition and process equipment maker Veeco Instruments of Plainview, NY, USA has reported full-year 2011 revenue of a record \$979m, just under the \$1bn target set at the beginning of the year and up 5% on \$931m in 2010.

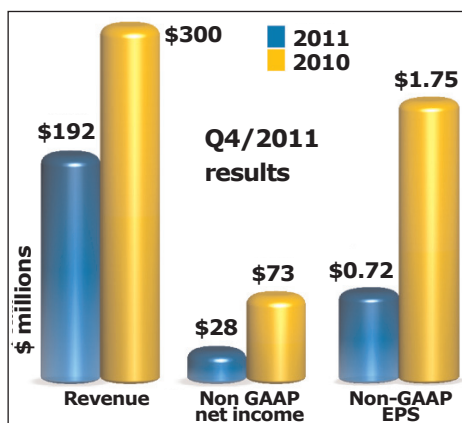
"We gained market share in top-tier LED customers around the world and, according to IMS Research, MaxBright was the top selling MOCVD tool for 2011 [reaching well over 50% market share in Q3]," says CEO John R. Peeler. "The LED customer base in China expanded much more rapidly than anyone expected it would," he adds.

Gross margin was 48% (up from 47.6%) and non-GAAP net income was \$206m (up on \$203m).

However, fourth-quarter 2011 revenue was just \$191.7m. Although this was down 36% on the record \$299.8m a year ago due to discontinuation of the CIGS (copper indium gallium diselenide) Solar Systems business at the start of Q3 and divesting the Metrology business to Bruker Corp in October 2010, it was also down 28% on Q3/2011's \$268m.

Of total Q4 revenue, 17% came from Data Storage revenue of \$31.6m, down on \$34.1m in Q3 (13% of revenue). The other 83% comprised LED & Solar revenue of \$160m, down 32% on Q3's \$234m (87% of revenue). This included metal-organic chemical vapor deposition (MOCVD) revenue of \$150m, down 32% on \$220m in Q3 due to a general slowdown in system purchases, particularly in China. "While not a new phenomenon, we experienced tool shipment rescheduling by several Chinese customers as they continue to manage through facility readiness and funding issues," says chief financial officer David D. Glass.

On a non-GAAP basis, gross margin was 43.7% (below the 44–45% guidance), negatively impacted by



lower volumes and higher supply-chain cost.

Operating expenses were \$48m, down from \$50m last quarter as spending controls were instituted in response to the weakening business outlook. Also, bonus and profit-sharing expenses were lower as the firm did not meet its targets set at the beginning of year. Veeco also took a \$2.6m restructuring charge (\$1.3m in asset write-offs and \$1.3m in staff termination and other costs).

Adjusted EBITDA (earnings before interest, tax, depreciation and amortization) has fallen from \$113.7m a year ago to \$39.4m. This included \$5.2m for Data Storage (down from \$12.5m a year ago) and \$34m for LED & Solar (less than a third of the \$107.6m a year ago). Net income was \$28.1m, down from \$53.3m last quarter and \$73.5m a year ago. Nevertheless, strong operating cash generation of \$57m helped to boost cash and short-term investments from \$449m to \$492m.

Order bookings were \$143m, down 51% on \$295m a year ago but rebounding by 8% from \$133m last quarter. Of total bookings, 53% came from Data Storage orders of a record \$76m (up 258% on \$21m, just 16% of total orders, in Q3). This included orders from key hard-drive customers to expand or rebuild manufacturing capacity lost during the Thailand flooding in October. Unusually, bookings were higher in

Data Storage than in LED & Solar. As LED business conditions continued to deteriorate, LED and Solar bookings have fallen from \$253m a year ago and by 40% from \$112m (84% of total orders) in Q3 to \$67m (just 47% of orders), the lowest since second-quarter 2009.

LED & Solar bookings included MOCVD orders down 43% from \$103m in Q3 to \$59m as customers delay capacity expansions until tool utilization levels increase. Veeco continued to book a mix of both MaxBright and single-chambered K465i MOCVD tools, with China remaining the largest proportion of orders by region (about 80%). Veeco has several MOCVD system orders for emerging applications such as power electronics and CPV solar. Also, molecular beam epitaxy (MBE) system orders were \$8m, down only slightly from \$9m in Q3..

After adjusting by about \$7m for a Chinese MOCVD order cancellation, total quarter-end order backlog was \$333m (including \$205m for MOCVD).

For Q1/2012, Veeco expects revenue to fall 33% to \$115–140m. Despite the decline in volumes, gross margin should be stable at 43–45% due to mix improvements. Operating spending will be \$46–49m, yielding adjusted EBITDA of \$7–18m and net income of \$5.2–13.2m.

Customers are reporting that LED backlighting demand remains weak, and factory utilization levels in Taiwan and Korea are just 50–70%. "We don't see signs of near-term improvement in the LED environment, and the current overcapacity situation could mean that MOCVD orders remain at these depressed levels for multiple quarters," says Peeler. "With the dialing back of the natural variable components in our cost structure as well as reducing discretionary cost, we're able to achieve quarterly breakeven EBITDA performance and mid-40% ➤

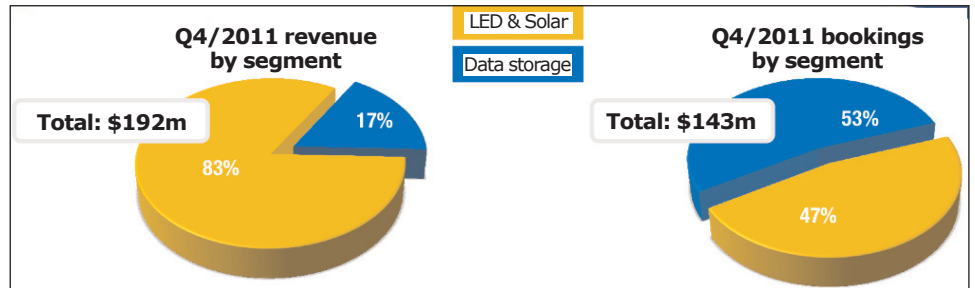
► gross margins on about \$100m of quarterly revenue," he notes.

"While consumer electronics has been the dominant end market for LED technology over the past decade, and for which most MOCVD capacity was installed, these applications are expected to reach saturation in the next few years [with LED penetration into TVs rising from 40% in 2011 to 60–70% in 2012]. Conversely, the LED general lighting market is in its infancy," notes Peeler. "The widely anticipated pause in China investment is clearly here, and in Taiwan top customers are planting investments at home and in conjunction with their China joint venture partners, and yet those projects are proceeding at a slow pace," he adds. Korea is still 'quiet'.

"It's difficult to pinpoint the duration or the depth of the current investment pause, which explains the wide band of MOCVD estimates," Peeler says. "Wall Street's low estimate for 2012 demand is 200 tools, and the high number is over 500. 2013 forecasts have an even wider range: 260 on the low end to over 700 on the high end. We think that the actual numbers will come in well above the low-end forecast and likely below the high-end forecast," he adds.

"We continue to see evidence that LED lighting prices are dropping and getting closer to mainstream adoption levels. Samsung and LG both have 40W-equivalent bulbs on the market at about \$12 a unit and have or will soon have 60W-bulb-equivalent priced in the mid teens," continues Peeler.

"In China there is speculation about additional LED incentives [in the government's 12th 5-year plan] and the government continues to expand its LED street-light programs, and in Taiwan there are plans to replace over 250,000 halogen street lights in 2012, and then in Japan and Korea they also have very aggressive LED lighting programs underway," says Peeler (e.g. Korea's '20–60' plan, targeting 60% penetration by 2020). "With LEDs less than 5% of the lighting market,



the future potential for this market is enormous... recovery will be driven by LED lighting investments."

Tier-1 lighting and chip companies are positioning themselves for growth in the LED market. Philips is to set up an LED lighting plant in Chengdu, China. Taiwan's Epistar has formed a strategic alliance with China-based Yankon Lighting (Asia's largest CFL bulb maker). Korea's Samsung EC is merging with Samsung LED to accelerate its LED lighting business. Japan's Panasonic aims to grow LEDs to over 50% of its lighting revenue by 2016.

"We believe that 2012 will be a transition year between the LED TV investment phase over the last three years, which helped to fuel a \$4bn LED market, and the much larger LED lighting market, forecasted to be over \$13bn from 2013 to 2015," says Peeler. "Demand for MOCVD tools will reaccelerate, driving demand for thousands of additional next-generation reactors to make lower-cost, higher-efficiency, brighter LEDs for lighting applications. While estimates vary, LEDs are expected to represent more than 25% of the global lighting market by 2015 and the majority of the market by 2020," he adds.

"We remain focused on driving next-generation product development to secure our MOCVD technology leadership position for the lighting wave," Peeler says. "With nearly \$500m in cash at the end of 2011, virtually no debt and leading market share in all our core tech-

nologies, we can invest through this downturn and emerge even stronger when the market returns," he believes. "We plan to maintain a high level of R&D investment."

In the meantime during the LED market pause, a 'cushion' is provided by the collective three-year compound annual growth rate (CAGR) of 25% for Data Storage and MBE revenues. These markets have different customers and capital investment cycles as well as different geographic exposure (with under 10% of their revenues coming from the main MOCVD market regions of China, Korea and Taiwan), providing consistency through the MOCVD investment cycles. With nearly \$130m in backlog at the start of this year, these businesses are expected to show similar strong growth in 2012.

In addition, the Services business grew over 40% to nearly \$100m in 2011, and in 2012 over 400 MOCVD reactors will come 'off warranty' (leading to expected sales of extended warranty plans plus spare parts, consumables, and upgrades that drive tool performance).

For full-year 2012, Veeco forecasts revenue to fall to \$500–600m. Capital expenditure should be just \$40m. "It's likely that this CapEx will be heavily weighted toward the first half of the year as we finish up the build-out of our new Korea site and continue to invest in our New Jersey R&D facilities," says Glass.

"With the work that has been done over the past three years to outsource our manufacturing and utilize variable costs where possible, we will maintain a reasonable level of profitability and generate cash through this temporary pause in the LED market," Peeler concludes.

www.veeco.com

IN BRIEF

SemiLEDs qualifies Veeco K465i MOCVD system for high-volume LED production

Epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA says that its TurboDisc K465i gallium nitride (GaN) metal-organic chemical vapor deposition (MOCVD) system has recently been qualified by SemiLEDs Corp of Hsinchu Science Park, Taiwan for the high-volume production of high-brightness LEDs.

SemiLEDs makes LED chips and components primarily for general lighting applications, including street lights and commercial, industrial and residential lighting. The firm sells blue, green and ultraviolet (UV) LED chips under the MvpLED (metal vertical photon LED) brand.

"In addition to their proven MOCVD technology, Veeco's commitment to providing best-in-class LED manufacturing equipment, as well as enhanced local support with their technology center in Hsinchu, makes the selection of Veeco as our vendor a logical choice," comments SemiLEDs' president and chief operating officer Chuong A. Tran Ph.D.

"Our TurboDisc K465i platform consistently offers excellent productivity while keeping production costs low," says William J. Miller Ph.D., Veeco's executive VP, Process Equipment. "Our Taiwan Technology Center will help the SemiLEDs Taiwan team learn best practices to maximize the value of their new system and grow as a leader in the energy-efficient lighting market," he adds.

www.semileds.com
www.veeco.com

Veeco's K465i MOCVD system chosen for GaN-on-Si development by both Epistar and LG Siltron

Veeco says that its TurboDisc K465i GaN MOCVD system has been selected by Taiwan's largest LED chipmaker Epistar Corp as the development tool for light-emitting diodes grown on silicon substrates.

"We are excited about the potential of GaN-on-Si technology as we move to larger wafer sizes," says Epistar's president M. J. Jou Ph.D. "We appreciate the strong support from Veeco, and look forward to this collaboration," he adds.

The K465i provides low cost-of-ownership and production worthiness for Epistar's GaN-on-Si LED development, says William J. Miller, Veeco's executive VP, Process Equipment. "Large-diameter Si wafers offer tremendous promise as a low-cost alternative to sapphire for volume production of lower-cost LEDs."

Veeco's TurboDisc K465i GaN MOCVD system has also been selected by South Korean electronics materials manufacturer LG Siltron as its first system for the production of GaN-on-Si epitaxial wafers for both power electronics and LED devices.

As traditional silicon-based power

transistors approach their limits, materials such as GaN are gaining popularity to speed energy conversion at lower costs, says Veeco. A wide range of industries, including many in 'green-tech' such as wind, solar, smart grid and hybrid electric vehicles, are driving demand for energy-efficient GaN-based power electronics.

The K465i offers "unparalleled throughput advantages, and its TurboDisc technology provides superior uniformity and low particle count, which is critical for producing GaN-on-Si wafers," comments Dr Hee Bog Kang, general manager of LG Siltron R&D. "We appreciate the strong support we have received from Veeco, and look forward to this and future collaborations," he adds.

Miller looks forward to supporting LG Siltron as they ramp production. "The market for GaN-on-Si power devices continues to grow, and the K465i offers many advantages, such as improved device performance, lower manufacturing costs and increased productivity," he adds.

www.epistar.com.tw
www.lgsiltron.co.kr

NTU Singapore orders Black Magic system for high-frequency electronics CNT project

Aixtron says that Singapore's Nanyang Technological University (NTU) has bought an Aixtron 2" Black Magic PECVD reactor.

The turnkey system has been installed and commissioned by the local Aixtron service and support team in the Nanoelectronics Laboratory of NTU's School of Electrical and Electronic Engineering, and will be used for the preparation of carbon nanotubes (CNT) and graphene for high-frequency electronic devices.

"Our new project involves the R&D of new types of materials for high-frequency electronics," says professor Beng Kang Tay. "We plan to

develop new interconnect and similar technologies for these devices using structures based on CNT, graphene and other carbon materials. These unique functional materials have great promise for the manufacture of RF electronic devices for advanced communications and networks," he adds.

"As our work primarily focuses on the development of latest applications and devices, we needed a system that is flexible, reliable and ergonomic, whilst providing simultaneously highest-quality reproducible thin films," continues Tay.

www.ntu.edu.sg

Aixtron allies with Minsheng Financial Leasing in China

MoU signed to cooperate on joint marketing of leasing options for MOCVD equipment

Minsheng Financial Leasing Co Ltd (MSFL), China's main non-banking financial institution, and deposition equipment maker Aixtron SE of Herzogenrath, Germany have announced a strategic alliance for joint marketing of leasing options in China.

The new agreement defines a strategic cooperation to promote the distribution of Aixtron's metal-organic chemical vapor deposition (MOCVD) equipment to customers across China with the aid of MSFL's financial services. Feng Wang, president of MSFL's Finance Leases strategic business unit, and Aixtron's chief financial officer Wolfgang Breme signed the memorandum of understanding (MoU) at MSFL's headquarters in Beijing.

"This exciting strategic cooperation will enable LED manufacturers to draw upon the most appropriate financing opportunities for the acquisition of key enabling MOCVD equipment," comments MSFL's CFO Rong Wang. "Due to temporary restrictions in China in the availability of financing, this news is expected to be received very positively," she adds. LED technology has been defined as one of the key industries (energy conservation/environmental protection, new materials) in China's 12th 5-year plan.

"The leasing of MOCVD equipment in China is a relatively new concept, and we are confident that this initiative will be widely appreciated by LED manufacturers," says Breme. "This cooperation, with one of Asia's largest and fastest growing leasing companies, is significant for us because it enhances our customers' financial flexibility," he adds.

MSFL was established in April 2008 and was one of the first five leasing companies approved by the China Banking Regulatory Commis-

sion (CBRC). It is co-sponsored by China Minsheng Banking Corporation Ltd (81.25%) and Tianjin Port Free Trade Zone Investment Co Ltd (18.75%) with total registered capital of CNY3.2bn. MSFL provides financial leasing products and services to domestic and foreign large and SME enterprises.

"Aixtron's role and commitment to China is to deliver the essential key enabling technology that the emerging LED lighting market

In 2011, China was the biggest regional buyer of MOCVD equipment, accounting for 58% of all global shipments.

Our joint goal with Minsheng is to facilitate the most appropriate financial instruments to support Chinese manufacturers

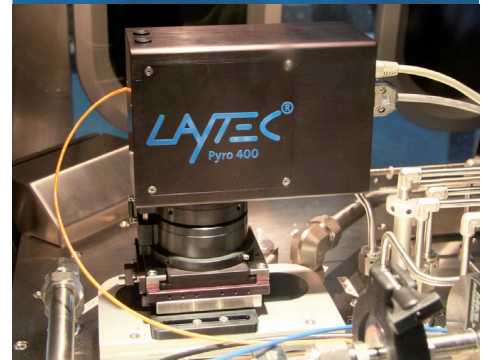
needs, taking full advantage of Aixtron's technology and embedded expertise," says Aixtron's president & CEO Paul Hyland. "Our joint goal with Minsheng is to facilitate the most appropriate financial instruments to support Chinese manufacturers as they strive to become global players," he adds. According to internal market research analysis from GBRA/MBL last November, China's LED market showed annual growth of 45% in 2010 and is expected to grow in output value from CNY120bn in 2010 to CNY500bn during the 12th 5-year plan, representing total growth of 317%. These projections reflect the fact, that in 2011, China was the biggest regional buyer of MOCVD equipment, accounting for 58% of all global shipments.

www.aixtron.com

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IN BRIEF

Soitec completes acquisition of Altatech

Soitec of Bernin, France, which makes engineered substrates including silicon-on-insulator (SOI) wafers (as well as III-V epiwafers through its Picogiga International division), has completed its acquisition (announced on 23 December) of all the outstanding shares composing the capital of privately held Altatech Semiconductor S.A. of Montbonnot Saint Martin, near Grenoble, France.

Formed in 2004 by a group of semiconductor professionals based on expertise in high-tech semiconductor production systems, Altatech currently develops technologies and equipment for new applications in emerging markets. Specifically, it makes wafer inspection and analysis, liquid-vaporization chemical vapor deposition (CVD) and nanoprinting equipment.

The final purchase price was 15m Euros. The acquisition was financed partly in cash and partly using Soitec stock, purchased by BNP Paribas Exane on the market under the share buy-back program approved by the shareholders during the combined ordinary and extraordinary meetings on 24 June 2011. Selling shareholders are bound by certain holding requirements for the portion of the purchase price to be paid in Soitec stock.

Soitec says that the acquisition will ensure strategic access to the specific equipment needed to deliver its light-emitting diode (LED) strategy as well as supporting the manufacturing ramp up of its new Plug&Sun stand-alone mini solar tracker system.

www.soitec.com

www.altatech-sc.com

OIPT's systems chosen for Lancaster Quantum Technology Centre

As part of its strategy for the development of physical sciences, the UK's Lancaster University is populating part of its new Lancaster Quantum Technology Centre (LQTC) with plasma systems made by UK-based Oxford Instruments.

Oxford Instruments Plasma Technology (OIPT) says that its proven PlasmaPro NGP80 and PlasmaPro System100 ICP Etch systems were chosen for their flexibility and suitability to enable the many applications that the multi-user LQTC aims to run in its cleanrooms, plus an extensive process library of over 6000 recipes together with customer support, service and training packages.

"These new Oxford Instruments etch tools will enable us to run dry plasma etching and nano-patterning on a range of semiconductors including narrow-gap antimonides and dilute nitrides for mid-infrared light sources and detectors," says professor Tony Krier, head of Lan-

caster's Semiconductor Physics & Nanostructures Research Group. "They will also be used for development of novel solar cells, quantum dot memories, nano-electronic structures, and much more," he adds.

"The new cleanroom facility provides a focus for industrial and academic researchers with interests in fabricating nanoscale structures to enable them to investigate quantum phenomena," Krier continues. "We chose Oxford Instruments because of the excellent technical specification and well founded reputation of the processing tools, backed up by expert specialist support," he comments.

"Oxford Instruments was founded as a result of the pull-through of science into the marketplace, and we are delighted to be part of this significant development in UK scientific research capabilities," notes Mark Vosloo, sales & customer support director at OIPT.

www.physics.lancs.ac.uk/qtc

OIPT receives ISO14001 certification

OIPT's headquarters in Bristol, UK has received accreditation to the international environmental management standard ISO14001.

"Accreditation from our certification body, Det Norske Veritas (DNV), means that we have achieved an important business objective," says general manager Dan Ayres. "The certification provides us with a platform for improved environmental management. It demonstrates to customers, shareholders and investors our commitment to achieving high environmental standards, and it will assist in supporting our continued growth," he adds.

"In addition to the formal business requirements of the certification, we have put in place an extensive awareness-raising program to encourage our employees to participate, and car share, recy-

cle waste and to rationalize the use of other resources," Ayres continues. "We actively encourage everyone in the business to participate and continuously improve our performance."

OIPT says that its accreditation recognizes its determination to manage the ecological impact of its business through tangible measures and a dedication to exceed the expectations of its customers and the community at large.

OIPT is part of the Oxford Instruments Group. Recently, the first league table of company performance under the UK Government's Department of Energy and Climate Change 'Carbon Reduction Commitment (CRC) Energy Efficiency Scheme' was published, with Oxford Instruments finishing in the top 7% of companies.

www.oxford-instruments.com

SEMI-GAS offers semi-automatic gas cabinets to reduce cost for low-flow applications

SEMI-GAS Systems, a division of Applied Energy Systems Inc of Malvern, PA, USA and a manufacturer of ultra-high-purity gas handling and distribution systems, is offering a variety of semi-automatic Centurion gas cabinets that safely store, handle and deliver hazardous, ultra-high-purity process gases.

The semi-automatic gas cabinets, which feature manual purging capabilities, save gas equipment costs in applications requiring low flow rates or when cylinder change-out is infrequent, such as in R&D programs or in university and government laboratory environments.

The units, designed to conform to Semi S2 and the International Fire Code, feature GigaGuard emergency shutdown system (ESS) controllers that monitor up to 11 optically isolated inputs, all of which are customizable by appli-



SEMI-GAS Systems Centurion gas cabinet.

cation. System conditions, including flow, pressure and exhaust, are continuously monitored for alarms. The system will automatically shut down by interrupting the gas flow when undesirable system conditions are met to ensure safety. Remote control boxes for system status and remote shut-down are also available.

The Centurion gas cabinet line is

available in one-, two- and three-cylinder standard configurations, as well as custom multi-cylinder and wall-mount system solutions for more complex and specific gas delivery applications. Additional mechanical, electrical and enclosure design features are also available.

Each gas cabinet enclosure is constructed of welded 11 gauge steel and features a UL-approved fire sprinkler and a corrosion-proof non-skid floor mat. The units feature a self-closing, self-latching door as well as a ¼"-thick safety glass window with a polycarbonate face shield. Cylinder brackets are made of heavy cast aluminum.

The one-cylinder semi-automatic system measures 83" tall x 15" wide by 23" deep; the two cylinder system is 86" tall x 25" wide x 23" deep; the three-cylinder system is 86" tall x 40" wide x 23" deep.

www.appliedenergysystems.com

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EV Group launches second-generation EVG620HBL mask alignment system for LED making

At the Strategies in Light 2012 conference in Santa Clara, CA, USA (7–9 February), EV Group (EVG) of St Florian, Austria, a supplier of wafer bonding and lithography equipment for the MEMS (micro-electro-mechanical system), nanotechnology and semiconductor markets, has launched the EVG620HBL Gen II — its second-generation fully automated mask alignment system for volume manufacturing of high-brightness light-emitting diodes (HB-LEDs).

Introduced a year after the launch of the first-generation EVG620HBL (at last February's Strategies in Light 2011 event), the Gen II delivers a tool platform tailored to address HB-LED customer-specific needs and the ongoing demand of total cost-of-ownership reduction. It also optimizes tool footprint in the fab — delivering 55% higher wafer output for every square meter of cleanroom space compared to competing offerings, it is claimed.

"The HB-LED market is dynamic and fast changing, and our customers constantly need innovative solutions to ensure their output and capital investments are being maximized," says business development manager Dr Thomas Uhrmann. "The EVG620HBL Gen II is a great example of how EVG quickly responds to its customers' needs by leveraging its expertise in HB-LED manufacturing to deliver an effective solution," he adds. "Having already built a proven platform that is now a de-facto industry standard with our first-generation mask alignment tool, we expect the EVG620HBL Gen II will further widen the economical gap over competitive offerings.", EVG's bonders and mask aligners are currently being deployed by four of the top five major HB-LED makers, it is reckoned.

Escalating demands for cost reductions and yield enhancements



Second-gen EVG620HBL mask alignment system for LED making.

require that equipment providers re-think what they offer in terms of total cost of ownership, EVG says. This is particularly true with mask alignment for lithography where maximizing yield is critical to fulfilling the long-term growth potential of LED technology, it adds. Accordingly, the EVG620HBL Gen II is outfitted with new features aimed at satisfying the specific demands of high-volume manufacturing (HVM) customers:

- enhanced microscope supporting automated mask pattern search, further

Escalating demands for cost reductions and yield enhancements require that equipment providers re-think what they offer in terms of total cost of ownership. This is particularly true with mask alignment for lithography

reducing mask setup and change time (both of which are critical to enabling continuous device production in HVM environments);

- updated robotic handling layout with wafer mapping capability (supporting the demand for wafer traceability);

- improved alignment capability (line alignment), which leverages the grids that mark single LEDs for orientation instead of requiring alignment marks that take up valuable space on the wafer; and
- reduced system footprint, which optimizes total cost of ownership for operation and increases the wafer per footprint index.

Together, these key enhancements to the EVG620HBL Gen II enable a 20% reduction in cost-per-processed wafer compared to competing offerings, the firm reckons.

Built on EVG's field-proven mask aligner platform, the EVG620HBL series features a high-intensity ultraviolet (UV) light source and an optional filter fan unit to maximize yield and enable what is claimed to be the industry's highest wafer throughput of up to 165 six-inch wafers per hour (up to 220 wafers per hour in first print mode).

Another key feature is the availability of special recipe-controlled microscopes whose illumination spectrum can be varied and optimized to ensure the best pattern contrast with various wafer and layer materials, including substrate materials such as sapphire, silicon carbide (SiC), aluminum nitride (AlN), metal and ceramic. The EVG620HBL series processes 2- to 6-inch wafers.

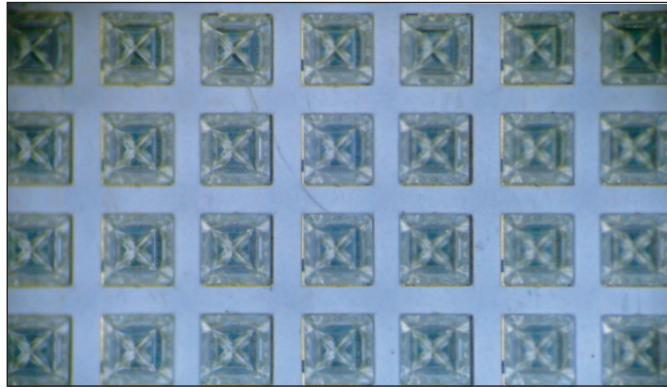
- Also at the Strategies in Light conference, EVG's Dr Thomas Uhrmann gave a presentation on 'High Throughput Lithography and Metal Wafer Bonding: Two Enabling Technologies for Future High-Brightness LEDs'.

www.EVGroup.com

Palomar develops wire-bond-free direct attach for LEDs

Microelectronics and optoelectronic packaging system maker Palomar Technologies Inc of Carlsbad, CA, USA (a former subsidiary of Hughes Aircraft) has launched a precision eutectic process development for direct-attach LEDs.

"Direct-attach LEDs are the next generation of solid-state LED emitters that deliver superior value for consumer products and markets that include TV backlighting, camera flash and a variety of general illumination needs," says Donald Beck, general manager of Palomar Technologies Assembly Services. "Assembly Services is supporting more than 390 700 μ m LEDs that are attached with an Au/Sn solder to a single 50mm metal core carrier. Palomar Technologies' Pulsed Heat System is a major contributor to this development, allowing our precision die attach systems o con-



Direct-attach LEDs via eutectic Au/Sn to a single 50mm metal core carrier.

trol LED exposure much more effectively than most other processes," he adds. "The bond-pad-down design of direct-attach LEDs eliminates the need for wire bonds, yet improves the thermal management."

Palomar exhibited at Strategies in Light 2012 in Santa Clara, CA

(7–9 February), where Julie Adams, director of worldwide Assembly Services Sales, was on site assisting in discussions about Palomar's LED packaging capabilities, including direct-attach LED eutectic bonding.

Also on 7–9 February, Palomar exhibited as a premier sponsor at IMAPS'

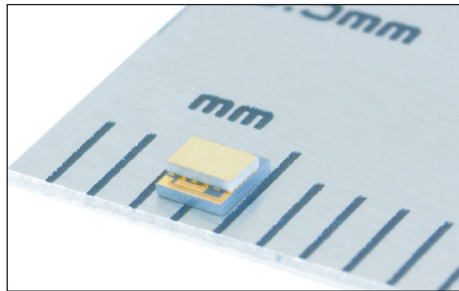
2012 Advanced Technology Workshop and Tabletop Exhibition on RF and Microwave Packaging in San Diego, CA,, where Western Americas sales manager Bradley Benton also presented an overview of Palomar's solutions and RF automated packaging processes.

www.palomartechnologies.com

Nextreme's thin-film thermoelectric surpasses 60°C temperature differential of bulk thermoelectric

Nextreme Thermal Solutions of Durham, NC, USA, which designs and manufactures microscale thin-film thermal management and power generation modules and sub-systems, says that its thin-film thermoelectric technology has achieved a 60.1°C temperature difference between its cold and hot sides at an ambient temperature of 24.7°C, bringing it on par with the performance of bulk thermoelectric technology.

The 60°C temperature milestone (ΔT_{max}) reflects the ability of the thermoelectric device to pump heat efficiently. Nextreme says that this new level of performance translates to improved cooling efficiency, lower input power requirements, and greater opportunities for solving thermal issues in electronics, photonics, automotive, avionics, and high-speed PCR (polymerase chain reaction) applications.



Nextreme's thin-film thermoelectric thermal management technology, showing its small size.

The electronic industry's continued trend to smaller form factors, greater circuit density, and highly integrated packaging has translated into significant thermal problems for electronics-related manufacturers, Nextreme says.

The firm reckons that, as a result of the latest technology achievement, it can now bring its thermal management solutions to additional markets that require not only the existing advantages of its products,

but also the performance provided by the new capability.

"Our thin-film technology has now achieved the performance level of standard bulk thermoelectrics," claims VP of engineering Dave Koester. "Achieving a 60°C ΔT at room temperature raises the bar for improved efficiencies and lower operating costs for our customers while opening up new markets for Nextreme," he adds.

The improved performance is the result of new materials development at Nextreme and the use of interconnect and contact technology developed at the Center for Solid State Energetics at RTI International research institute of Research Triangle Park, NC.

Nextreme says that it will be introducing new products with the higher level of cooling performance during 2012.

www.nextreme.com

www.rti.org

GT to provide 6" cores for Silian's sapphire substrate production

GT Advanced Technologies' subsidiary GT Crystal Systems has entered into a purchase agreement with Chongqing Silian Optoelectronics Science & Technology Co Ltd (Silian) to supply 500,000 TIE (2-inch equivalent) of 6"-diameter c-plane sapphire cores, which Silian will use to make sapphire substrates for high-brightness LED making.

"We are pleased to announce this important agreement for large diameter sapphire cores and to continue our long and successful relationship with Silian," says Cheryl Diuguid, GT's VP & general manager of its Sapphire Equipment and Materials Group. "Silian has an outstanding reputation for providing high-quality substrates to some of the most advanced LED producers in the industry. This contract further validates that sapphire material produced in our ASF [Advanced Sapphire Furnace] is well suited for use in the LED supply chain," she adds.

"ASF-grown sapphire has helped Silian and our customers to achieve the high yields necessary for the maturing LED industry," says Silian's chief operating officer & general manager David Reid. "Consistency and quality of ASF-grown sapphire has served our business well and we look forward to continued collaboration with GT Crystal Systems."

GT says its ability to produce LED-grade sapphire at diameters of 6" and larger is helping to accelerate the transition to next-generation MOCVD production tools capable of handling larger-diameter wafers. Larger substrates allow more efficient MOCVD production processes than existing tools processing 2" and 4" wafers. The larger cores will be produced from boules grown in GT's ASF sapphire growth furnaces installed in its newly expanded sapphire manufacturing facility in Salem, MA. This is the same technology that has been sold commercially to GT's ASF equipment customers.

www.gtat.com

Rubicon's largest customer agrees new \$20m contract for 2012 ...but price cut on existing contract lowers Q4/2011 revenue to \$19-20m

Rubicon Technology Inc of Bensenville, IL, USA, which makes monocrystalline sapphire substrates and products for the LED, RFIC, semiconductor and optical industries, has entered into a new contract with its largest customer for large-diameter (6") sapphire wafers worth \$20m, representing a baseline level of shipments to be made from June through December. The previous contract expired at the end of December.

"As other LED chip manufacturers make the transition to large-diameter substrates in pursuit of greater efficiency, Rubicon — the world's largest, most experienced and most reliable provider of large-diameter sapphire wafers—stands to benefit greatly," reckons president & CEO Raja Parvez. "However, with LED chip capacity presently not fully utilized, the inflection point in demand for large-diameter sapphire wafers for LEDs is still some months in the future."

In light of current market conditions and in the interest of further establishing a long-term relationship with the customer, Rubicon granted adjustments to fourth-quarter 2011 price and volume requirements under the expiring 6" contract (previously, on 8 November, management had indicated that this was likely). Consequently, Rubicon's revenue for fourth-quarter 2011, was \$19-20m, slightly below its previous guidance of \$20-23m.

Rubicon also says that, as an accommodation to certain key customers of its small-diameter sapphire ingots (cores), it wrote off \$1.8m of accounts receivable in Q4.

"The fourth quarter of 2011 was a period of limited demand for sapphire substrates resulting from the accumulation of excess inventory in the LED supply chain," says Parvez. "This temporary decline in channel

demand in turn resulted in sapphire prices falling sharply in the second half of 2011. Out of consideration for our important customer relationships, we made certain concessions that we deemed to be in the best long-term interest of our company," he adds.

Near-term demand from the LED market continues to be limited, as inventory adjusts throughout the supply chain, but orders for 2" and 4" cores have begun to recover somewhat in the first quarter of 2012, and demand for large-diameter wafers for the silicon-on-sapphire (SoS) RFIC market is growing,

Near-term demand from the LED market continues to be limited, as inventory adjusts throughout the supply chain

Rubicon says. "As the channel inventory situation improves, and as LED technology further penetrates both the backlighting market and the general

lighting market, we expect significant strengthening of the market for sapphire substrates later this year," Parvez continues.

"We remain optimistic on the long-term outlook for the LED market and Rubicon's positioning to capitalize on the opportunity," Parvez comments. "To date, Rubicon has shipped more than 230,000 6" sapphire wafers to the LED manufacturing and RFIC industries," he notes. "This has provided us with the experience and scale to drive process and cost efficiencies throughout our system while maintaining our industry-leading quality and service. Cost and quality leadership are instrumental to the acceleration of LED adoption in the marketplace."

www.rubicon-es2.com

GT's sapphire furnaces counteract dip in polysilicon equipment revenue

Installation and acceptance completed on "significant number" of sapphire furnaces

For its fiscal third-quarter 2012 (to end-December 2011), GT Advanced Technologies Inc of Merrimack, NH, USA (a provider of polysilicon production technology as well as sapphire and silicon crystalline growth systems and materials for the solar, LED and other specialty markets) has reported revenue of \$153m, down 30% on \$217.7m last quarter and down 42% on \$262.9m a year ago.

Revenue by business segment was \$87.4m in polysilicon (down from \$98m) and \$34.4m in photovoltaic (down from \$111.2m) but \$31.2m in sapphire (up from \$8.5m), which included revenue for ASF (Advanced Sapphire Furnace) equipment as well as sapphire materials.

Gross margin has fallen further, from 46.4% a year ago and 43.7% last quarter to 43.1%, while operating margin has fallen from 36.1% a year ago and 24.7% last quarter to 20.7%. Net income was \$15.3m, down from \$36.9m last quarter and \$63.6m a year ago.

"We performed at the top end of our guidance for revenue and above our gross profit and earnings per share guidance, sustaining our track record of meeting or exceeding expectations," notes president & CEO Tom Gutierrez.

During the quarter, cash, cash equivalents and restricted cash fell from \$494m (including \$10.2m of restricted cash and \$90.9m of borrowing) to \$303.1m (including \$96.2m of restricted cash and zero debt), reflecting the use of \$75m for the accelerated share repurchase initiated during the quarter plus \$90.9m to pay down the firm's remaining debt facility.

Compared with just \$65.4m last quarter, new orders totalled \$228.9m (\$218.1m in polysilicon, \$0.9m in PV and \$10m in sapphire). Also, \$27.2m of adjustments to

backlog yielded net orders of \$201.7m. Order backlog has hence risen from \$2.1bn to \$2.2bn (\$1.1bn polysilicon, \$212.1m PV and \$908.2m sapphire) including \$431.1m of deferred revenue.

"In our sapphire business, we completed installation, received acceptance and recorded revenue on a significant number of sapphire furnaces," Gutierrez notes. "We continue to believe that our ASF solution offers the most viable path to low-cost, high-quality sapphire production," he adds.

"We continue to have one of the strongest balance sheets in the industry. This enables us to continue to invest strategically in new product technology and initiatives to further diversify the company and add new growth opportunities," Gutierrez concludes.

On 31 January, the firm and certain subsidiaries entered into a senior secured credit agreement with Bank of America N.A., RBS Citizens and certain other lenders. The credit agreement consists of a term loan facility of \$75m and a revolving credit facility of \$175m, both with a final maturity date of end-January 2016.

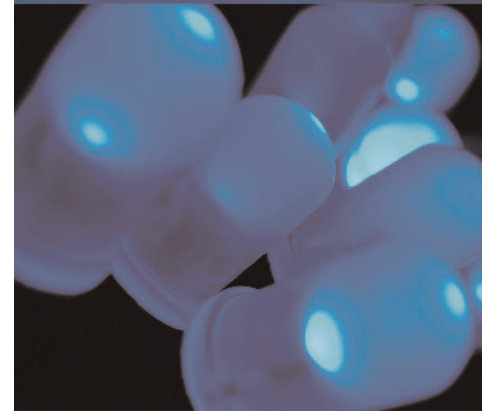
For fiscal 2012 (to end-March), GT Advanced Technologies still expects revenue of \$950m to \$1.05bn and gross margin of 43-45%, but the firm now expects fully diluted earnings per share of \$1.45-1.60 rather than \$1.45-1.65.

GT anticipates entering fiscal 2013 (beginning 1 April 2012) with a total backlog of more than \$1.7bn. For the fiscal year, the firm expects revenue to show modest growth over fiscal 2012, gross margin to remain stable, R&D spending to continue to increase, and EPS (earnings per share) to expand.

www.gtat.com

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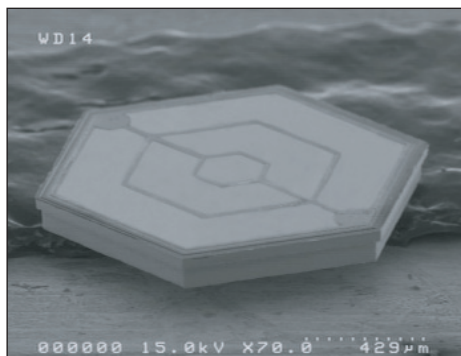
Verticle enters mass production of hexagonal LED chip

Verticle Inc of Dublin, CA, USA has announced mass production of its Honeycomb hexagonal-shaped LED chip, which has been developed with the firm's patented copper (Cu) substrate and chemical chip separation technology for optimized light extraction efficiency.

The vertically structured InGaN-based LED chip features benefits including higher light extraction and more uniform beam profile than conventional square or rectangular LED chips based on sapphire or silicon substrate, says reckons CEO Dr Mike (M.C.) Yoo.

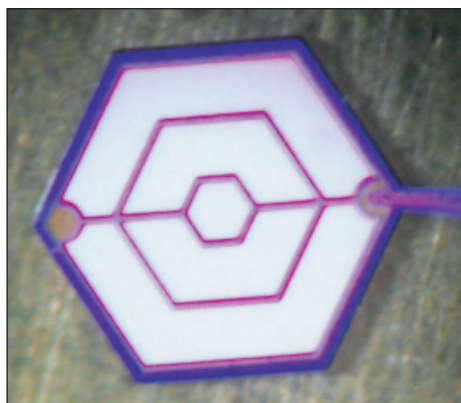
The firm says that, although there have been many attempts to fabricate various shapes of LED chip with conventional laser scribing or dicing, only a few (like diamond- or triangle-shaped LED chips) have been fabricated at the R&D level, and not at the production level. Chemical chip separation technology invented by Verticle makes the chip separation step much easier and quicker than conventional chip separation techniques, the firm claims, making it easier to fabricate any shape of chip (even circular).

Honeycomb also delivers an improvement in diode performance, compared with square or rectangular-type LEDs, it is claimed. Since the



Scanning electron micrograph of Verticle's hexagonal LED chip.

optical efficiency of an LED chip depends on the effective current density in the active region and the hexagonal architecture allows better control of current spreading, Honeycomb can operate at high currents, achieving higher brightness.



Photograph showing light emission.

A conventional square or rectangular LED chip has a distorted beam profile when it is packaged typically with a circular lens. However, a hexagonal-shaped LED chip (that is closer in shape to a circular chip) generates a much less distorted beam profile and hence a very small dark spot. This allows higher lumen output than a conventional square or rectangular chip with similar electro-optical properties after packaging with a circular lens. A Honeycomb chip can also use the same flat form package as square or rectangular chips, so no additional cost or system improvement is required, it is claimed.

Furthermore, due to its Cu substrate, Honeycomb has an excellent thermal and electrical conductivity, says the firm, which is crucial for both long life and good thermal behavior of the diode. The LED's main optical power range is 370–420mW at a drive current of 350mA with a forward voltage range of 3.1–3.4V.

The mass-production-level Honeycomb chip was introduced and available for sale at the LED China 2012 exhibition in Guangzhou (20–23 February).

www.verticleinc.com
www.ledchina-gz.com

SemiLEDs achieves 40% external quantum efficiency for ultraviolet LED chips

LED chip and component maker SemiLEDs Corp of Hsinchu Science Park, Taiwan says that its ultraviolet (UV) LED chips are now capable of emitting radiation at a wavelength of 390–420nm with 40% external quantum efficiencies (EQE) at a drive current of 350mA (up to 500mW output power, typical 3.3V forward voltage).

"Our patented structure and metal alloy substrate allow us to produce and supply to the industrial curing market UV LEDs that are capable of operating at high current with high

output power density," says chief operating officer & president Dr Chuong Tran. "We are proud to be able to advance the UV LED technology for the curing industry and to provide cost-effective solutions to our customers thanks to our proprietary MvpLED technology," he adds.

Founded in 2005, SemiLEDs' manufactures proprietary blue, green and ultraviolet (UV) LED chips under the MvpLED (metal vertical photon LED) brand for sale mainly to chip-packaging cus-

tomers, or to distributors who sell to packagers. It also packages chips into LED components for sale to distributors and end-customers in selected markets (mainly for general lighting applications, including street lights and commercial, industrial and residential lighting).

SemiLEDs UV LED products are available for sampling and order in wavelengths of 365–420nm, in chip sizes of 1.07mm x 1.07mm and 0.3mm x 0.3mm.

www.semileds.com

Nitride Solutions finalizes Series A round at \$2.5m

Commercialization of AlN substrates targets sampling this quarter

Nitride Solutions Inc of Wichita, KS, USA, which is developing substrates for LEDs, lasers and power electronics, has closed its Series A financing round (which was oversubscribed) at \$2.5m. After already participating in the round last June, Nebraska Angels and Aurora UV Inc of Santa Barbara, CA (which makes ultraviolet LEDs for applications including air and water purification) have again joined lead investor Midwest Venture Alliance (MVA) in completing the round.

Founded in 2009, Nitride Solutions' leadership has 30-plus years of experience in advanced materials businesses (both start-ups and Fortune 500 companies) and a total of 25 years in nitride crystal development. The firm maintains strong ties to Kansas State University in Manhattan, KS, with key employees and advisors hailing from the

university, as well as University of California Santa Barbara (UCSB).

The firm is now finishing commercialization of a high-volume manufacturing technology that aims to deliver high-volume, low-cost aluminum nitride (AlN) substrates. With projected defect rates 10 times lower than substrates currently on the market, the substrates will improve the performance, efficiency and cost of existing LED, laser and electronic products, while also making deep ultraviolet (UV) devices, the firm reckons. The result should be improved white lighting for consumer and industrial uses, more efficient power systems in hybrid vehicles, sharper color on

flat-screen TVs, and better air and water purifiers. The firm will use the Series A funding to perfect its technology and begin sampling in first-quarter 2012.

"We are excited about the potential for this technology, and the strong demand for the Series A financing is a demonstration of our confidence in the company's ability to execute on its business plan and deliver this revolutionary technology to market," says Nebraska Angels' president Bart Dillashaw.

"Fund raising in this economy is difficult," notes Trish Brasted, managing member, MVA Capital Group. "All of us at the Midwest Venture Alliance are very excited to see the support from the regional investment community, as demonstrated by the oversubscribed Series A offering."

www.nitridesolutions.com

The firm will use the Series A funding to perfect its technology and begin sampling in first-quarter 2012



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Soraa introduces 'LED 2.0' GaN-on-GaN technology

New LED MR16 lamp rivals traditional 50W halogen

Soraa Inc of Fremont, CA, USA, which is developing solid-state lighting technology built on 'GaN on GaN' (gallium nitride on gallium nitride) substrates, has launched its flagship product, the Soraa LED MR16 lamp.

The new product is claimed to be the first LED lamp to provide performance superior to a traditional halogen MR16, and the first to provide halogen-equivalent brightness without requiring a mechanical fan, as well as payback within months rather than years. Based on its GaN on GaN technology, the firm describes the Soraa LED MR16 lamp as representing an 'LED 2.0' stage in lighting technology.

Founded in 2008 by University of California Santa Barbara (UCSB) professors Shuji Nakamura, Steve DenBaars and James Speck, Soraa is backed by over \$100m in funding from Khosla Ventures, New Enterprise Associates (NEA), and NGEN Partners. As well as its lighting products design lab, the firm has what it reckons is the world's first commercial GaN on GaN light-chip fabrication plant.

Soraa's proprietary GaN on GaN technology yields what is claimed to be the highest-performance LED MR16 lamp on the market. Its GaN crystal is reckoned to be up to 1000 times purer than GaN on sapphire or GaN on silicon carbide (SiC) substrates (the existing platforms for LED lighting technologies).



Soraa's new LED MR16 lamp.

"Our technological foundation enables Soraa products to emit more light per LED material and handle more electric current per area than competitors, providing the highest-quality light that makes for a perfect, more energy-efficient replacement for traditional halogen lamps," claims CEO Eric Kim, who has experience in technology and brand development leadership as an executive at both Intel and Samsung.

The flagship Soraa LED MR16 lamp, available first to commercial customers, is priced to achieve payback in less than one year. The firm chose the MR16 format because it has been the most difficult LED lamp to do correctly, given its small size and intense, high-quality brightness requirements. Soraa's GaN on GaN MR16 is reckoned to be the first LED to rival the traditional 50W halogen. Its perfect crystal structure delivers

a bright, highly focused, controlled beam with the ability to produce a high color rendering index (CRI) and center beam candle-power to match a standard halogen lamp. Soraa's efficient thermal design also delivers halogen-equivalent performance without requiring a mechanical fan. The lamp's single-source LED design provides crisp object definition with solo shadow, uniform color and a what is claimed to be a perfect beam pattern. Additionally, it features optimized electrical design for compatibility with all common transformers and dimmers, both indoors and outdoors.

"I've been searching for a long time for a quality LED to replace an MR16 halogen," says US-based lighting designer Randall Whitehead.

"Soraa's lamp is a quantum leap over what is currently on the market, offering brighter light, dimmability, long lamp life, as well as dramatically improved energy efficiency," he comments. Soraa's lamp is the first LED MR16 he has found that outperforms halogen lamps, he adds.

"Lighting affects the way we see the world, and good light can make anything more compelling," says co-founder Shuji Nakamura. "At Soraa, we are proud to create efficient lighting products that do not compromise on performance, offer the highest quality available and greatly reduce energy waste."

www.soraa.com

Toyoda Gosei files patent lawsuits against Forepi

Toyoda Gosei Co Ltd has filed a patent infringement lawsuit in Taoyuan District Court against LED chip maker Formosa Epitaxy Inc (Forepi) of Taoyuan County, Taiwan. The lawsuit alleges infringement of two of Toyoda Gosei's Taiwanese patents regarding GaN-based LED chips and seeks an injunction against multiple Forepi LED products.

It has also filed a lawsuit in the US

District Court, Northern District of California alleging infringement of seven US patents, seeking damages and an injunction against multiple Forepi LED products.

Toyoda Gosei says that, as a result of its R&D, it has obtained numerous LED-related IP rights worldwide.

"We have respected others' and our own intellectual property rights in Japan and other countries, and

have made our best efforts to further develop the market," it says. "Particularly in Taiwan, we have not only manufactured and sold our products and procured parts, but we have also established cooperative relationships with our partner firms with regards to manufacturing."

www.forepi.com.tw

www.toyoda-gosei.com

Seoul Semiconductor launches AC-powered Acrich2 linear module for ballast-free fluorescent replacement

At the Strategies in Light 2012 conference in Santa Clara, CA, USA (7–9 February), South Korean LED maker Seoul Semiconductor Co Ltd has released another AC-powered LED solution in its second-generation Acrich2 family (following the launch of the initial Acrich2 product last October). The Acrich2 Linear Module exhibits efficacies, light output levels and power factors comparable to DC LED solutions, it is claimed, while eliminating the AC to DC power supply.

Compared with existing linear modules driven by direct current, the main feature of the Acrich2 Linear Module is the removal of the AC/DC converter and consequently the optimized form factor. This type of solution increases reliability by removing many of the components that cause early lifetime failure of other fluorescent replacement solutions, the firm claims. The design also provides more flexibility and space to work inside the fixture since the large ballast (power supply) does not have to be accommodated.

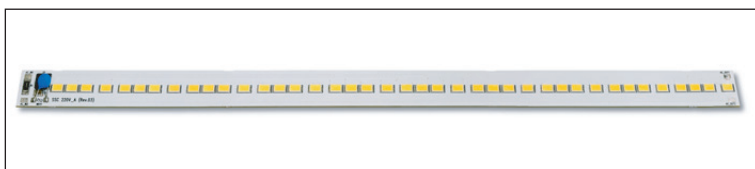
AC solutions of the past have required a sacrifice in power line performance such as power factor and total harmonic distortion (THD), says Seoul Semiconductor. The firm claims that Acrich2 solves this issue and provides power factor increases to 97%, power efficiencies up to 90% and THD approaching 10%. In addition, the Acrich2 Linear Module will be available with LM-80 and UL testing data.

"Armed with optimized and simplistic system design, the Acrich2 Linear Module is a state-of-the-art product that outperforms existing non-environmentally friendly fluorescent lamps and direct current LED fluorescent lamps," claims Seoul Semiconductor vice president Sunghun Bae. "With the doubly long life-span and lower carbon dioxide emission, customers will be able to actualize eco-friendly lighting while paying lower electricity bills," he adds.

The module comes in 220V, 120V and 100V variants. Starting this month, samples are available from the local sales force, manufacturer representatives, and distributors.

Earlier this year, the firm announced a family of similar Acrich2 modules targeted at the replacement lamp market that allows easy bulb design of A19, PAR, MR16 and other form factors.

www.seoulsemicon.com/en



Seoul Semiconductor's Acrich2 Linear Module



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Plessey Semiconductor acquires University of Cambridge GaN-on-silicon HB-LED spin-off CamGaN

Plessey Lighting targets 80% cut in cost

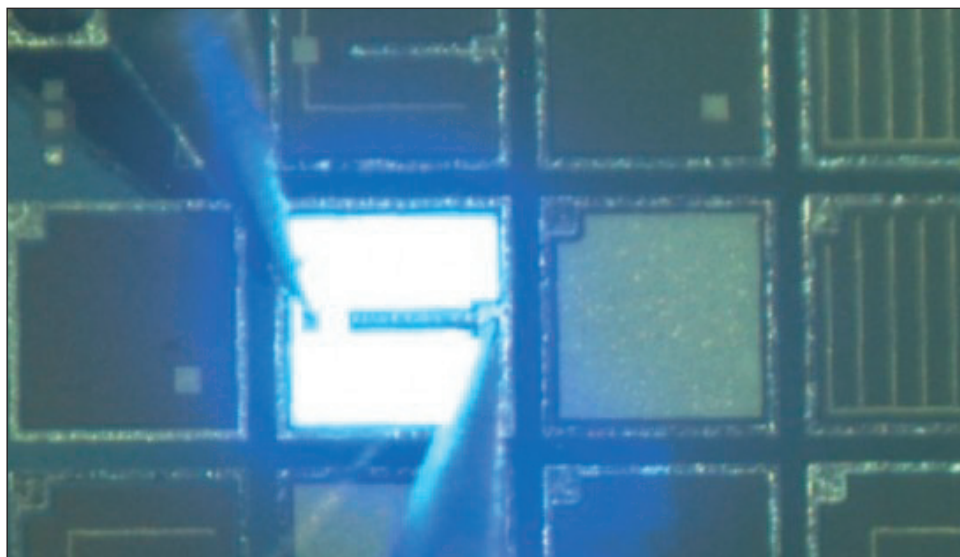
Plessey Semiconductors Ltd has acquired CamGaN Ltd, a University of Cambridge spin-off formed in 2010 to commercialize proprietary technology for growing gallium nitride (GaN)-based high-brightness (HB) LEDs on large-area silicon substrates.

The acquisition will enable Plessey to exploit synergies with its 6" silicon processing facility in Plymouth, UK to produce HB-LEDs based on CamGaN's proprietary 6" GaN-on-Si technology. The new technique will be commercialized by a new arm of Plessey called Plessey Lighting, which will initially make LEDs on silicon for external manufacturers, but in time hopes to develop its own light bulbs in-house.

The technology was co-invented by professor Sir Colin Humphreys CBE, director of research at the University of Cambridge's Department of Materials Science and Metallurgy (and director of the Cambridge Centre for Gallium Nitride). It is based on over 10 years of basic and applied research on GaN involving \$16m in funding (including funding from the UK's Engineering and Physical Sciences Research Council).

"If we had stopped at the research stage, our work would probably have been picked up and commercialized overseas," says Humphreys. "This way, we can create more jobs in a low-employment part of the country and potentially turn Britain into a major centre for better, greener lighting," he adds. "Plessey is committed to exploiting GaN-on-Si technology in the UK," Humphreys comments.

"Not only could his research result in a highly marketable, low-carbon alternative to the everyday light bulb, but he has worked closely with industry to ensure that the commercialization process also happens in the UK," comments David Willetts (the UK Government's Minister for Universities and Science)



An LED emitting light on a 6-inch silicon wafer.

on Humphreys' work.

The technology enables the growth of thin HB-LED structures on standard, readily available, silicon substrates. Whereas existing silicon carbide (SiC) and sapphire substrates are expensive and difficult to scale up, GaN-on-Si offers cost reductions of about 80% for LEDs due to the advantages

of using a proven semiconductor process, e.g. by reducing scrap rates, minimizing batch process time, and enabling the use of automated semiconductor processing equipment. These cost reductions can be achieved while

enabling luminous efficiency in excess of 150 lumens per watt — a combination that should allow Plessey to offer the most cost-

The technology enables the growth of thin HB-LED structures on standard, readily available, silicon substrates. GaN-on-Si offers cost reductions of about 80% for LEDs due to the advantages of using a proven semiconductor process

effective solutions in the HB-LED industry, the firm reckons.

"To date, the biggest technological challenge preventing the commercialization of HB LEDs grown on large-area silicon substrates has been the large lattice mismatch between GaN and silicon," says Plessey's chief engineer Dr John Ellis. The thermal expansion rate of GaN is very different to that of silicon. So, when the two substances cool down from the growth temperature of 1000°C, the material tends to crack. Humphreys' team introduced layers to the process that put the GaN in a state of compression before it heats up. "This compression balances the tension when it cools down, which allows the material to relax," says Humphreys. "As a result, we can grow LED structures which are totally crack-free."

The process can grow LEDs on 6" silicon. Each wafer costs about £20 (cheaper than 2" sapphire wafers) and ten times more LEDs can be grown on a 6" wafer. Combined with the intrinsic cost savings of using Plessey's existing automated 6" processing equipment, the new technology can put the resultant HB-LED lighting products at the forefront of the industry, says Ellis. ➤

► “We’ve got higher efficiency for growing gallium nitride on silicon than anyone else we know,” believes Humphreys. “LED light bulbs currently cost as much as £40, but we expect to be able to reduce that cost by a factor of five by growing on silicon,” he adds. “Mass manufacturing may reduce the cost further.”

Plessey’s first samples of a blue LED are characterized by peak emission at a wavelength of 460nm, but the technology also extends to other emission wavelengths such as cyan and green. Being able to achieve such high brightness at the blue end of the spectrum enables phosphors to be used to produce white light with a balanced spectrum of light emission that is better for the eye, Plessey notes. The firm plans that by late fourth-quarter 2012 it will have reached white output efficacy of 150 lumens/watt (comparable to state-of-the-art conventional LEDs based on sapphire or SiC).

“HB-LED lighting represents the future of domestic, architectural, medical and automotive lighting,” says Plessey’s managing director Michael LeGoff. “Achieving the goals of high efficiency and brightness is key to the rapid deployment of energy-saving solid-state lighting.”

Because tungsten filament light bulbs lose much of their energy as heat, just 5% of the energy they consume is used as light. Fluorescent tubes are 20–25% efficient. LEDs are currently about 30% efficient and Humphreys hopes to raise that to 60%. In the UK alone, the researchers estimate that the nationwide use of LEDs would save 15% of the electricity generated by power stations, resulting in a similar reduction in CO₂ emissions. Also, a US Department of Energy report in 2010 estimated that savings of \$20bn per year would result if LED light bulbs became widespread in the USA. Researchers estimate that a worldwide switch to LEDs would enable the closure of 560 power

plants and result in annual CO₂ savings equivalent to the output of all the cars on the planet. LEDs are also being designed to give off a more natural quality of light (better for people’s health).

Plessey’s broader work in electronics also means it aims to develop LED-based ‘smart lighting’ products (incorporating existing sensing and control technologies including its EPIC sensor), enabling intelligent energy management, remote control, controlled dimming and automated response to ambient daylight conditions.

“The plans for its commercial development within Plessey have tremendous potential,” Humphreys reckons. “The opportunities to develop affordable smart-lighting products for domestic, medical, automotive and other applications provide a real opportunity to have a positive impact on people’s lives.”

www.plesseysemiconductors.com

<http://camgan.com>

www.gan.msm.cam.ac.uk

Bridgelux gains \$25m from China’s Kaistar

Funding to speed GaN-on-Si LED chip and packaging technology development for lighting applications

LED chip and lighting array maker Bridgelux Inc of Livermore, CA, USA (which claims to be the only vertically integrated manufacturer of LED solid-state light sources specifically for the lighting industry) says that China’s Kaistar Lighting (Xiamen) Co Ltd — a joint venture between Kaifa and Taiwan’s Epistar — has agreed to invest \$25m in the firm.

After originally focusing on designing and making its power LED chips - based on ITO/InGaN (indium tin oxide/indium gallium nitride) on 4-inch sapphire substrates - Bridgelux launched its first LED array product line in January 2009, followed in March 2010 by the ‘plug-and-play’ Helieon Sustainable Light Module (jointly developed with Molex Inc of Lisle,

IL, USA) for industrial and commercial building owners. In May 2011, Bridgelux launched the third generation of its LED Arrays.

Last October, Bridgelux closed \$15m in financing, raised specifically to accelerate research, development, and scaling of its GaN-on-Si LED chip technologies (which are targeted for commercialization in 2013), driving a transition from 4-inch sapphire to 8-inch silicon substrates. Previously, in early August, Bridgelux raised \$60m in a Series E financing round led by Los Angeles-based Craton Equity Partners, taking total venture capital raised to about \$180m. Total funding is now over \$220m since Bridgelux was founded in 2002.

Bridgelux says it will use the latest

equity investment to further accelerate research, development, and production of LED chip and packaging technology for general illumination applications.

“The market for solid-state lighting is expected to grow from \$3bn in 2011 to more than \$25bn in 2015,” says CEO Bill Watkins. “This investment marks the beginning of our cooperation with Kaistar to lead the transition to solid-state lighting,” he adds. “Kaistar’s cost-competitive manufacturing capabilities combined with Bridgelux’s high-performance packaging solutions will continue to drive down the cost of solid-state technology for general lighting, helping to more rapidly expand the market for LEDs.”

www.bridgelux.com

www.kaistar.cn

Lumileds launches LUXEON K arrays for retrofit and downlight LED lighting

LED maker Philips Lumileds of San Jose, CA, USA has launched the LUXEON K, an illumination-grade array for downlights and retrofit bulbs that, it is claimed, allows solutions to come to market more quickly and at a price that will drive market adoption.

LUXEON K arrays provide thousands of lumens of light output (with a typical flux of 620–4455lm at a drive current of 700mA). They will be available in early second-quarter 2012 in three different correlated color temperatures (CCTs) of 2700K, 3000K and 4000K, with a typical color rendering index (CRI) of 85 (and a guaranteed minimum of 80) and with five configurations of 4–24 emitters per array. Luminous efficacy is more than 100 lumens/Watt at 350mA, a junction temperature of T_j 85°C, and a CCT of 3000K.



Lumileds' LUXEON K LED arrays for downlight and retrofit bulb solutions.

"LUXEON K extends our portfolio of illumination-grade LEDs engineered to optimize end-user satisfaction of specific applications,"

says Rahul Bammi, VP marketing. "For downlights and retrofit bulbs, LUXEON K provides a unique approach that delivers the highest, most consistent quality of light in an easy-to-implement array," he claims. "Our hot testing

and specification at 85°C, and freedom from color, flux and V_f binning, makes LUXEON K the simplest of LEDs to specify and use," he adds.

Lumileds launches LUXEON H LED for space-constrained bulbs

LED maker Philips Lumileds of San Jose, CA, USA has launched its LUXEON H next-generation high-voltage LED. With significant performance enhancements, LUXEON H enables a broad range of retrofit bulbs and space-constrained applications (such as GU10 and candelabra bulbs) while providing the light output, efficacy, and quality of light required to meet ENERGY STAR specifications.

The LUXEON H has correlated color temperatures (CCT) of 2700K and 3000K, with a minimum color rendering index of 80. Each part is hot tested and specified at a junction temperature (T_j) of 85°C, and delivers 'Freedom From Binning' (with no flux bins and no V_f bins; single 3-step MacAdam Ellipse color space and color over angle specified at a low 0.02 du ν).

Typical luminous efficacy is 90lm/W at 40mA, 100V, and T_j =



Lumileds' new LUXEON H, for the development of compact LED lighting like GU10s and candelabra bulbs.

85°C. Typical flux is 320–660 lumens at 20–90mA and 100V or 200V. The 100V/200V package rated for 4–8W.

"For the first time there is a practical solution for GU10 and other small-form-factor bulbs," says

Rahul Bammi, VP marketing. "Compared to other high-voltage or AC LEDs, LUXEON H delivers more light, better light, and better efficacy in a more cost-effective package with proven LUXEON reliability," he claims.

Compact and dimmable drivers are already available and LUXEON H is being designed into bulbs as a single LED solution that offers advantages over the multi-source designs previously required, it is claimed. The ease of solderless assembly reduces fixture manufacturing costs. Complementary components including drivers, optics and clamps will be available through Future Lighting Solutions. High-volume release of LUXEON H will be in March.

The new LUXEON LED was exhibited at the Strategies in Light 2012 conference in Santa Clara, CA, USA (7–9 February).

www.philipslumileds.com



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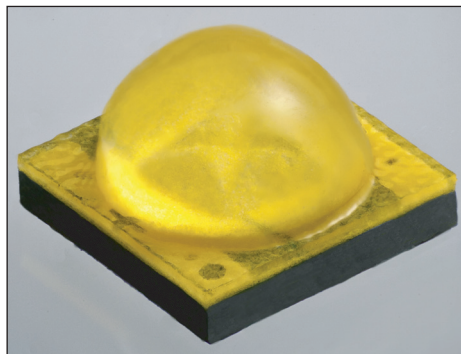
Cree's XLamp XT-E white LED doubles lm/W of XP-E

Cree Inc of Durham, NC, USA has launched the XLamp XT-E white LED, which is claimed to deliver twice the lumens-per-dollar of other LEDs and feature the highest performance and efficacy in the industry.

Based on a new silicon carbide (SiC) technology platform, the XT-E — as well as the XB-D (launched in mid-January) — represent what is claimed to be a transformation in LED price-performance.

The new platform addresses the largest obstacle to mass LED lighting adoption — initial cost — and enables LED lighting systems to replace their inefficient ancestors, Cree adds.

"The XLamp XT-E LED has exceeded our expectations," comments Fritz Morgan, chief product officer of Digital Lumens Inc. "We are committed to building the most energy-efficient industrial lighting systems and the XT-E LED enables us to do just that with high lumens per watt," he adds. "The result is an



Cree's new XLamp XT-E white LED.

intelligent LED-based lighting system that is driving widespread adoption of LEDs in industrial facilities, with compelling performance and end-user payback."

The XT-E delivers luminous flux of up to 148lm and luminous efficacy of 148lm/W in cool white (6000K) or up to 114lm and 114lm/W in warm white (3000K), both at a drive current of 350mA and a junction temperature of 85°C. At 25°C, the XT-E delivers up to 162lm/W in cool white. This more than doubles the lumens per watt of the XLamp

XP-E LED family, allowing use for almost all lighting applications.

Also, by leveraging the popular 3.45mm x 3.45mm XP footprint, users can easily incorporate the XT-E in existing XP LED designs to shorten the LED fixture design cycle and improve customer time-to-market.

Since the XT-E white LED is a successor to the XP-E high-efficiency LED, the application for ENERGY STAR qualification requires only 3000 hours of XT-E LED LM-80 data, instead of the normal 6000 hours.

"With the XB-D LED, Cree changed the game and introduced a better price-performance curve," claims Mike Watson, Cree's senior director marketing, LED components. "Now, with the XT-E LED, Cree continues to break barriers and extend its leadership on this new trajectory, delivering products that accelerate LED adoption."

Samples are available immediately and production volumes are available with standard lead times.

Cree debuts 230V LMH2 LED modules for Europe and Asia markets

To support growing global demand, Cree says that its LMH2 module (launched last November) is now available in a 230V version for lighting manufacturers based in Europe and Asia. The LMH2 is designed to speed time-to-market and is claimed to be the only LED module delivering 80lm/W system efficacy combined with a color rendering index (CRI) greater than 90.

"Cree modules let us quickly and easily create high-performance lighting solutions for our customers," comments Miroslav Masar, SSL director at OMS s.r.o. of Dojc, Slovakia. "The LMH2 delivers the perfect combination of efficacy, color consistency and cost management," he adds.

The compact, two-piece module gives lighting manufacturers the flexibility needed for rapid LED luminaire design and development,

Cree says. The LMH2 incorporates Cree TrueWhite LED technology for what is claimed to be unrivaled efficacy and CRI, featuring primary optics for superior color uniformity. LMH2 also features primary thermal management — potentially eliminating the need for costly secondary thermal management systems. Optimized for more than downlights and spots, the LMH2 is designed for many lighting applications, including wall sconces, pendant lights, ceiling fans and many other common luminaires in commercial, retail, museums, residential, hospitality and restaurant environments, says Cree.

"The LMH2 is designed with the needs of the 230V European and Asian lighting markets in mind," says Mike Watson, Cree's senior director marketing, LED components. "One of the major barriers

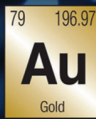
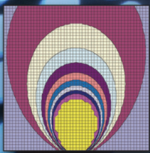
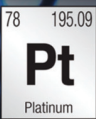
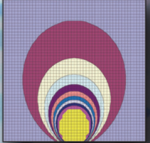
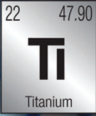
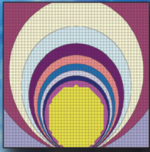
to LED lighting adoption and design remains upfront cost. The new Cree LMH2 modules can reduce initial luminaire cost and accelerate time-to-market for OEMs," he claims.

The LMH2 is available with a CRI of 90 at 850 and 1250 lumens and in color temperatures of 2700K, 3000K, 3500K and 4000K. Designed for 50,000 hours of operation and dimmable to 5%, the LMH2 comes with Cree's new five-year warranty. It is also UL-recognized and complies with multiple international regulatory and safety standards. Luminaire makers seeking ENERGY STAR qualification will have access to specification and performance data, including LM-80 reports, which can speed regulatory approvals.

www.cree.com/modules

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IN BRIEF

QD Laser achieves ISO 9001:2008 certification

QD Laser Inc of Kawasaki, Japan says that on 25 January it achieved certification to the international quality management standard ISO 9001:2008.

QD Laser was founded in 2006 based on more than 10 years of research on quantum-dot-based optoelectronic devices by Fujitsu Laboratories Ltd and the University of Tokyo. The firm has since developed and marketed commercial products including quantum-dot lasers.

The firm already makes 1270–1310nm FP (Fabry–Perot) and distributed feedback (DFB) quantum-dot lasers for fiber-optic communications applications, 1000–1120nm DFB lasers for material processing and sensing, and 600nm high-power lasers with a monitor photodiode. The firm also sells 1300nm quantum-dot epiwafers.

Most recently, at the SPIE Photonics West 2012 event in San Francisco in late January, QD Laser said that — together with the University of Tokyo, its Institute for Nano Quantum Information Electronics, and Fujitsu Laboratories Ltd— it has developed compact laser modules that emit at wavelengths of 561nm (yellow-green) and 594nm (orange) with high-speed modulation capability, as well as a high-power 532nm-wavelength compact green laser module that has both high-efficiency and high-speed modulation capability.

QD Laser says that, by running and continuously improving the certificated quality management system, it aims to provide higher-quality semiconductor laser solutions.

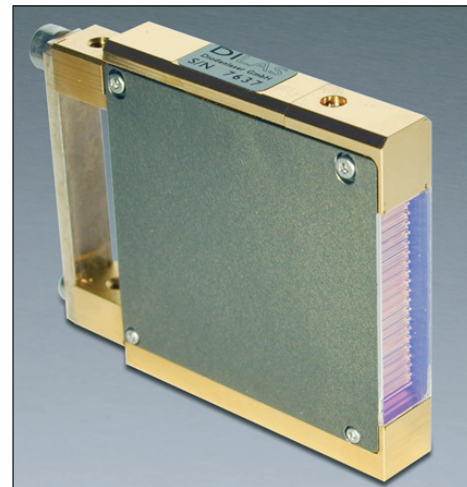
www.qdlaser.com

DILAS launches high-power laser bars on micro-channel coolers for diode-pumped alkali laser pump wavelengths

High-power diode laser maker DILAS of Mainz, Germany has continued the expansion of its wavelength range by extending its portfolio to water-cooled laser diodes for alkali laser pumping at 766, 780 and 852nm, on micro-channel heat sinks at continuous-wave power levels of 40, 60 and 100W, respectively.

The laser bar geometry is based on the popular industry standard of 1cm bar width, with 19 emitters on a 500µm pitch with fill factor options of 20% and 30%. Typical power conversion efficiency is in the range of 56% at rated power for all three wavelengths, as measured at 20°C.

Suited to R&D, defense and other diode-pumped alkali laser (DPAL) applications, the diodes are assembled in water-cooled stacks to scale power up to kiloWatt levels, according to customer requirements.



DILAS' water-cooled vertical diode laser stack for DPAL applications.

Diode laser stack arrays can also be offered with volume Bragg gratings (with standard or low-reflectivity coatings) and with both optical axes collimated.

www.DILAS.com

Laser diode firm Power Technology adds Europe sales office

Power Technology Inc (PTI) of Alexander, AR, USA, which was founded in 1969 and designs, manufactures and distributes laser diode products, has established a European sales office to improve its service to customers in Germany and throughout Europe. The office will be headed by Tony Pope and Damon Cookman, who founded UK-based Photonic Products Ltd in 1995 (now ProPhotonix Ltd) and have more than 30 years experience in the photonics industry collectively as well as in-depth knowledge of the German and European markets.

"By opening an office to serve our customers in Germany and the rest of Europe, Power Technology will

improve customer service and provide full sales coverage," says PTI's VP of sales & engineering Walter Burgess. "Pope's and Cookman's experience in the photonics industry will be invaluable to developing close working relationships with new and existing OEM customers," he believes. "As founders of highly successful and innovative photonics companies, Tony and Damon bring a wealth of knowledge and relevant European experience."

PTI now has direct sales centers in three countries (USA, Canada and Germany) and serves the rest of the world through a network of distributors.

www.powertechnology.com

www.prophotonix.com

Thorlabs completes new headquarters

Photonic product maker Thorlabs Inc has completed its new three-story, 120,000ft² headquarters facility, at 56 Sparta Avenue in Newton, NJ, USA. Subsequent construction phases are planned for the next 7–10 years and will ultimately expand space to include about 300,000ft². The new site will serve as the central hub for Thorlabs' sales, service, R&D and manufacturing operations.

The new facility is built on a 5.6-acre former brownfield site that had been vacant and in need of environmental remediation since 1993. The location, in Newton's downtown area, had been earmarked by the town for redevelopment.

Still privately held by founder & CEO Alex Cable, Thorlabs says that it has consistently experienced double-digit growth since its founding in 1989. The firm has expanded geographically over the years to include 12 sales, manufacturing and R&D offices in eight countries. During that same time, the need for more space also led it to expand its footprint in Sussex County, NJ, eventually purchasing 87,800ft² of space, spread out over five different locations. Thorlabs now employs about 700 people (350 in Sussex County, with others in the UK, Germany, France, Sweden, Japan, and China). It manufactures 95% of its product offerings (70% domestically, 25% internationally), which now number over 15,000.

In addition to optomechanics, optics, fiber optics, optical detector, motion control equipment and vibration isolation system products as well as system-level solutions such as optical coherence tomography (OCT), confocal and multiphoton imaging systems, Thorlabs also makes laser diodes and tunable lasers plus superluminescent diode (SLD) light sources, in particular after its acquisition of optoelectronic component and subsystem maker Covega Corp of Jessup, MD, USA (now Thorlabs Quantum Electronics, TQE) in 2009.

The additional space supports Thorlabs' continued growth and aim to bring products to market quickly, says Cable. Thorlabs intends to expand its machine shop at its 40,000ft² facility 2 miles away from the new site in Andover Township. Currently, the same equipment is shared for prototyping and production. "By expanding

our machine shop's footprint, we will be able to allocate specific resources and equipment to the creation of prototypes," adds Cable. "In addition, the expansion will support faster turnarounds on special customer requests for small modifications to our stocked products."

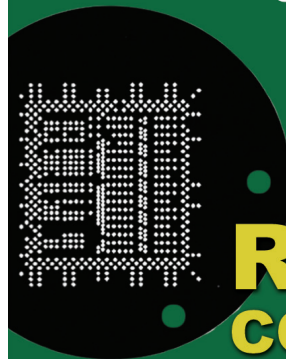
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Opnext's revenue falls 38% due to Thailand flooding

Capacity to return to pre-flood levels by end March

For its fiscal third-quarter 2012 (to end-December 2011), optical module and component maker Opnext Inc of Fremont, NJ, USA has reported revenue of \$53.1m, down 38.3% on \$86m last quarter and down 45.3% on \$97.1m a year ago. However, this is due mainly to the loss of production capacity at primary contract manufacturer Fabrinet in Thailand (where most 10G products are assembled and tested) following the flooding there in October.

Cisco Systems Inc and Hitachi Ltd each represented 10% or more of total revenue (43% combined). The Americas represented 46% of total revenue (down from 54% last quarter), Europe 17% (up from 13%), Japan 26% (up from 11%), and the rest of Asia 11% (down from 21%).

Revenue from industrial & commercial products was \$6.7m, down 25.5% on \$9m last quarter, due mainly to the inventory built up at Japanese industrial laser customers following the earthquake last March. "We anticipate that it will take about two quarters for this demand to recover," says chief financial officer & senior VP Bob Nobile.

Revenue from 40Gbps-and-above products was \$20.2m, down 37% on \$32.1m last quarter, as demand for 40Gbps and 100Gbps client-side modules fell (due to the timing of service provider deployments of next-generation systems) and demand for 40G line-side modules fell modestly (as the shift by China OEMs from externally purchased modules to internally produced modules continued).

Due to the disruption caused by the flooding in Thailand, revenue from 10Gbps-and-below products was \$26.2m, down 42% on \$44.9m last quarter and 57.6% on \$61.8m a year ago.

"During the quarter [in December], we started limited assembly and testing of our 10G modules at

our facilities in Japan [Totsuka] and California," says chairman & CEO Harry Bosco. "About \$2m of revenue came from products produced at Totsuka and Fremont that were previously assembled at Fabrinet, and about \$14m came from shipments by Fabrinet or inventory on hand prior to the flood," he adds.

On a non-GAAP basis, gross margin has fallen from 21.9% last quarter to 7.1%, due mainly to the lower revenue and a \$2.1m (or 4 percentage point) inventory charge from a customer discontinuing use of a 10Gbps product as they transitioned to their next-generation technology. "We have been awarded future 10G opportunities to compensate us for those losses," notes Nobile.

Excluding \$21.7m of fixed asset impairment and damaged inventory charges resulting mainly from the Thailand flood, adjusted earnings before interest, taxes, depreciation and amortization (EBITDA) has deteriorated to negative \$16m, compared to +\$0.1m last quarter and +\$1.1m a year ago.

Compared with \$2m a year ago and \$1.9m last quarter, cash used in operations was cut to \$1.4m. Opnext also used \$1.4m for capital expenditure (down from CapEx of \$2.2m last quarter) and \$2.2m to fund capital lease obligations (down from \$2.4m). Hence, during the quarter, cash and cash equivalents fell from \$90.5m to \$85.2m.

"We plan to restart manufacturing in Thailand at Fabrinet's Pinehurst campus this month, with a return to pre-flood production capacity expected by 31 March," says Bosco. "We will bring up an additional contract manufacturer in the March timeframe to enable us to dual source the assembly of our high-volume modules. Even though we had minimal inventory of products formally assembled by Fabrinet on 1 January 2012, we expect sequential growth in our 10G-and-below products in the March quarter, as

production ramps at Fabrinet's Pinehurst facility and our new contract manufacturer in parallel while we are continuing production in Totsuka and Fremont," he adds.

"Future gross margins are expected to benefit from faster growth in 40G-and-above revenues and from new 10G product introductions," says Bosco. For example, Opnext plans to deliver working samples of its tunable XFP in the March quarter (with mass production by mid-2012). The LR4 module (the multi-wavelength 40G transceiver in a CFP package) began shipping last quarter, and the QSFP version is expected to start shipping to customers this quarter. "The QSFP application and data-centers, where power density and costs are key factors, are critical for success... We view all of these as significant growth opportunities," he adds. Opnext shipped 100G coherent modules to core customers for qualification in the December quarter, and expects to add several others this quarter. In addition, overall 40G-and-above demand began to improve at the end of December quarter and was strong in January.

Based on the 10G production recovery plan and the improvement to date in orders for 40G-and-above products, for fiscal fourth-quarter 2012 (to end-March) Opnext expects revenue to rebound to \$70-75m.

"In addition, we will continue to improve our cost structure through increased vertical integration and by closely watching our expenses," says Bosco. Opnext expects a 40% gross margin on incremental revenues, consistent with its pre-flood business model. Also, excluding direct flood-related costs, operating expenditure is expected to be consistent with the December quarter. Accordingly, the firm's pre-flood business model to achieve breakeven adjusted EBITDA on \$85m of revenues per quarter and breakeven non-GAAP operating

► profit on \$100m of revenue per quarter (at an exchange rate of 80 yen/\$) is still intact.

"Our temporary 10G module manufacturing in Totsuka and Fremont will be transferred back to our contract manufacturers in the June quarter," says Bosco. "To support our customers during the transition period, we have worked closely with them to prioritize the sequence of our production recovery to meet their critical needs. Based on customer feedback, we expect our 10G and below market share to return to pre-flood levels once production is fully recovered," he adds. "We are also well positioned with the broad portfolio family of products for 40G-and-above that now includes our 100G coherent modules," continues Bosco.

"Market data continues to point to high demand for more bandwidth, and our new product floor addresses the high-growth segments of the market," notes Bosco. "Based on industry analysts' forecasts, our primary addressable market is predicted to grow more than 20% through 2015, and the 40G-and-above portion is predicted to grow about 40% in the same timeframe."

www.opnext.com

Opnext appoints The Optoelectronics Company as laser diode distributor in Europe and North America

Optoelectronic component distributor and manufacturer The Optoelectronics Company Ltd of Henham, Bishops Stortford, UK has been selected as an authorized distributor in Europe and North America for Opnext's laser diode products.

The firm will offer the complete Opnext line-up of industrial laser diodes from 404nm through 852nm and output power ranges from 5mW to 500mW. All Opnext laser diodes are RoHS compliant.

One of the red laser diodes from Opnext for mobile pico projector applications is the HL63603TG laser diode, which has a visible wavelength of 638nm and an output power of 120mW. Available in a 3.8mm package with single transverse mode, it is suitable as the red light source of RGB laser pico projectors.

"We expect current global economic conditions to make the next 12-18 months challenging, but we are confident that there will



OE Company's directors Damon Cookman and Tony Pope.

remain a strong market throughout Europe and North America for innovative optoelectronic products," comments says managing director Tony Pope.

www.oe-company.com

ProPhotonix adds Opnext's HL65051DG single-mode 660nm laser

ProPhotonix Ltd of Salem, NH, USA, a designer and manufacturer of LED light engines and laser diode modules as well as a distributor of laser diodes, has added Opnext's HL65051DG (launched in mid-January) to the range of laser diodes that it offers. The new laser gives system designers and OEMs the highest-power single-mode laser on the market at this wavelength in a package that includes an integrated monitor photodiode.

With continuous wave output power up to 120mW at 660nm, the single-mode HL65051DG red laser diode is suited to applications including medical, sensing and LIDAR systems. Its monitor photodiode allows for continuous feed-

back in the system, ensuring constant optical power output from the laser. It is temperature rated from -10°C to +60°C, allowing operation in harsh environments. With low operating current and voltage of 175mA and 2.5V, respectively, the HL65051DG is easy to integrate into a range of systems, it is claimed.

"The ability to achieve high optical power with a stable output will allow us to address our customers increasingly demanding applications, such as low-level laser therapy and 3D imaging," says David McGuinness, ProPhotonix's Europe, Middle East and Africa (EMEA) sales director.

"ProPhotonix is a key partner in selling and supporting Opnext laser

diodes into strategic accounts," says Wolf-Rudiger Gaepel, Opnext's EMEA account manager. "This newest red laser diode opens up multiple opportunities across a range of applications."

Opnext offers laser diodes spanning wavelengths from 404nm to 852nm. The firm claims that its red and infrared laser diodes are proven to consume a low operating current, extending battery life while still maintaining the integrity of the laser diode power in applications such as gun sights, rangefinders, line-leveling construction systems, and biomedical applications.

www.prophotonix.com
www.opnext.com

Infinera's revenue rebounds 7.7% in Q4/2011 despite Thailand flooding

Unexpected year-end budget spending boosts recovery

Infinera Corp of Sunnyvale, CA, USA, a vertically integrated manufacturer of digital optical network systems incorporating its own indium phosphide-based photonic integrated circuits (PICs), has reported revenue of \$404.9m for 2011, down 11% on 2010's \$454.4m. In particular, fourth-quarter revenue was \$112m. This was down 4.4% on \$117.1m a year ago but up 7.7% on \$104m last quarter.

"We benefitted from unanticipated year-end budget spending by a number of customers and were able to execute to our disaster recovery process following the historic flooding in Thailand," says president & CEO Tom Fallon. On 22 October, flood waters infiltrated the facilities of Thailand-based contract manufacturer Fabrinet Co Ltd. At that time, Infinera estimated the potential negative impact to its December-quarter to be 5–15% of revenue.

"Our fourth-quarter revenue performance was higher than our expectations, and reflects contin-

ued solid demand from customers for Infinera's unique digital optical networks including cable, tier-1 and bandwidth wholesale service providers," says Fallon.

The top five customers included two cable companies (one in excess of 10% of total revenue) and — for the second consecutive quarter — a tier-1 customer. Also during the quarter, Infinera achieved its first 40G revenue, addressing demand from key customers. Infinera also added five new customers (making a total of 16 during 2011 and 98 overall, including 36 network customers to date who have purchased multiple products across multiple applications).

On a non-GAAP basis (excluding non-cash stock-based compensation expenses and restructuring and other related costs), gross margin was 42%, down on 51% a year ago but up slightly from 41% last quarter. This took gross margin for the year to 43%, down from 2010's 47%.

Compared with net income of \$7.6m a year ago, net loss has been cut from \$9.2m last quarter to \$6.7m. Full-year net loss was \$31.7m, compared with net income of \$22.4m in 2010.

Development of the DTN-X multi-terabit packet-optical transport (P-OTN) network platform (launched last September) remains on track, with trials in Q1, expected volume production starting in Q2, and initial revenue recognition expected for second-half 2012. Four lab trials with tier-1 carriers have been scheduled in Q1/2012, and the firm is in the process of preparing for the production ramp.

"Customer interest in our new DTN-X since its launch has been very strong," says Fallon. "We believe this interest is in recognition of the unique advantage that Infinera's integrated platform brings to market — the only platform offering integrated DWDM and OTN switching functionality without compromise," he claims.

Infinera adds VP of global professional services

Infinera says that Todd Hanson has joined it as VP of global professional services. The firm says that Hanson has deep experience from serving in operations executive roles with cable and service provider companies.

Infinera's Global Professional Services division is growing rapidly to meet demand, with a team that supports customers with deployment, technical support, training, maintenance and consulting services such as network migrations from legacy equipment to PIC-based systems. The Global Professional Services team offers a range of options from walking customers through the critical responsibility of planning and building a



network to supporting and operating the network once it is live.

Having served in engineering and operations,

management and executive roles at Sprint, AT&T Canada, Qwest, Frontier, and Time Warner Cable, Hanson is familiar with Infinera's solutions and its technology and professional services.

"As a former Infinera customer on several occasions, I personally experienced Infinera's advanced solutions and services and quickly recognized the operational benefits in terms of simplicity and lower

overall life-cycle costs Infinera delivered to our network compared with others," says Hanson.

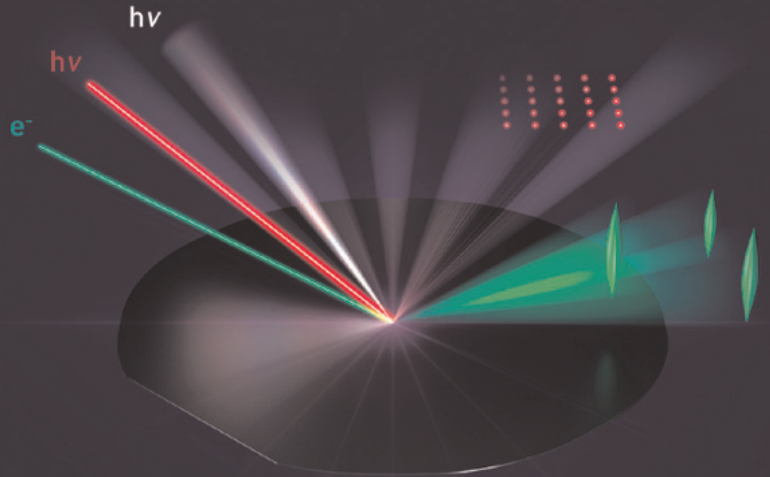
"Infinera has grown rapidly, expanding our worldwide footprint," says Lonny Orona, senior VP, customer services/product support. "Todd brings a wealth of operational experience from his leadership roles with world-class service providers that will serve our customers well," he adds.

Infinera serves 98 customers globally with equipment operating in 50 countries. The firm's product portfolio includes the DTN platform, ATN platform and the DTN-X platform featuring 500Gb/s FlexCoherent super-channels.

www.infinera.com



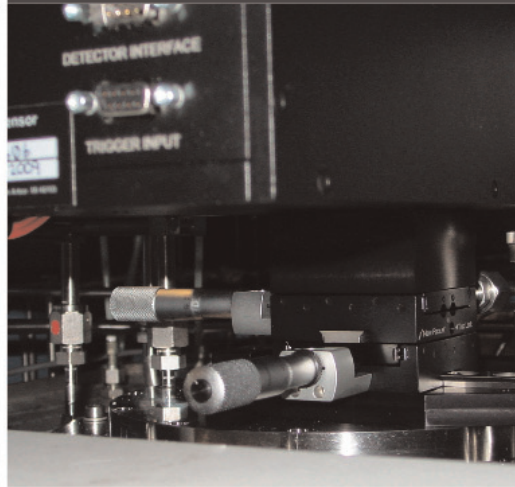
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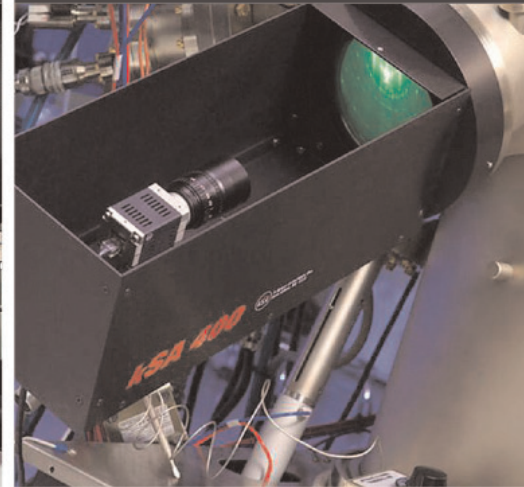
kSA BandiT Wafer Temperature



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Thin-Film Stress



kSA 400 Analytical RHEED



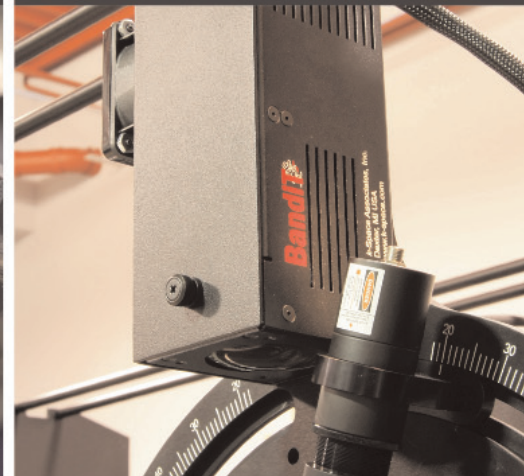
kSA MOS Ultra-Scan and
Thermal-Scan Stress Mapping



kSA Rate Rat Pro Thickness &
Deposition Rate



kSA BandiT PV Process Tuning



NeoPhotonics reports record revenue of \$57.2m in Q4

Return to profitability expected in 4–6 quarters

NeoPhotonics Corp of San Jose, CA, a vertically integrated designer and manufacturer of silica-on-silicon photonic integrated circuit (PIC)-based modules and subsystems for bandwidth-intensive, high-speed communications networks, has reported its ninth consecutive year of annual revenue growth, up 13% from 2010's \$177.7m to a record \$201m in 2011.

Expectations were also exceeded for gross margin. On a non-GAAP basis, gross margin was 25.7% (though down on 31.9% in 2010). Loss from continuing operations in 2011 was \$9.6m, compared to income of \$9m in 2010.

However, for fourth-quarter 2011, NeoPhotonics reported record revenue of \$57.2m, up 33% on \$42.8m in Q3 and up 14% on \$50.2m a year ago (and 14% above the top end of the projected range of \$45–50m).

The ten largest customers accounted for about 90% of total revenue. Revenue from largest customer Huawei Technologies of China grew 46% sequentially after a return to a more traditional order pattern, suggesting that (along with higher demand) Huawei was restocking its inventory after an unusually low third quarter. Huawei thus grew to 47% of total revenue, up from 44% in Q3. Ciena comprised 11% of revenue.

"We experienced strong demand in our 'Speed & Agility' and 'Access' product categories and [as a vertically integrated supplier] avoided adverse impacts from the floods in Thailand," says chairman, president & CEO Tim Jenks. "Instead of seeing an anticipated slowing with our customers due to their other suppliers being impacted by flooding in Thailand, we experienced an increase in demand from some customers seeking additional supply. This incrementally positive effect was more notable for 10G products and tunable laser products, both of which

are in our Speed and Agility product group," he adds. "In addition, we saw an increase in new customer engagements in the fourth quarter, particularly for our coherent PIC-based products," continues Jenks.

Q4 revenue also included \$5.8m attributable to Santur Corp of Fremont, CA (acquired on 12 October 2011), a designer and manufacturer of indium phosphide (InP)-based PIC products. "Revenue from Santur products was at the top end of our guidance projections [of \$5–6m], and we have seen an increase in new customer engagements for Santur products since the acquisition," says Jenks.

Founded in 2000, Santur commercialized PIC-based laser array and packaging technologies for communications networks.

Products are designed to provide reduced size, power consumption and cost for DWDM, coherent and client-side networking applications in 10G, 40G and 100G networks. Santur contributes almost exclusively to NeoPhotonics' 'Speed & Agility' product group.

In Q4, 'Speed & Agility' products comprised 52% of total revenue (up from 37% in Q3), 'Access' products comprised 31% (down from 34%), and 'Other Telecom' products (legacy products such as DWDM, Sonet and SDH) comprised 17% (down from 30%, due mainly to decreasing demand for transceivers used in legacy systems below 10Gbps).

Generally, 'Speed & Agility' products have higher-than-corporate-average gross margins and 'Access' products have lower gross margins. However, Santur's products overall

had lower gross margins than the NeoPhotonics product portfolio, so the margin differences for the three product groups have narrowed for the immediate term. On a non-GAAP basis, gross margin has fallen from 28.5% a year ago and 27.8% in Q3 to 23.5%. Nevertheless, despite the Santur acquisition and the effects of annual price negotiations completed during Q4, this was above the projected range of 19–21%.

Total operating expenses have risen from \$12.7m a year ago and \$16.1m in Q3 to \$35.1m (or \$22m, excluding a \$13.1m non-cash charge for impairment of goodwill). The increase was due mainly to the addition of Santur's operations (not yet offset by restructuring efforts, begun during the quarter).

Inclusive of the firm's 'delta' R&D investment begun in Q3 (spending \$1m per quarter for 4–6 quarters, in order to further leverage its PIC technology platform into next-generation network opportunities in switching and high-speed devices), the loss from continuing operations was \$6.4m, doubling from \$3.2m in Q3 and compared with income of \$1.8m a year ago.

During Q4, NeoPhotonics consumed \$2.2m of cash from operations and spent \$3.2m for capital expenditures. Total cash, cash equivalents and short-term investments fell from \$103m to \$86.4m, due mainly to paying the purchase price for Santur.

During Q4, NeoPhotonics initiated a plan to increase production capacity of narrow-linewidth tunable lasers (NLW-TLs), completing the first phase to double output. The firm believes that demand for these products has outstripped current industry supply capacity due to the rapid uptake of coherent optical technology, coupled with industry supply constraints attributable to the flooding in Thailand in October 2011. With orders received from seven new NLW-TL customers and

Demand for these products has outstripped current industry supply capacity due to the rapid uptake of coherent optical technology

► additional engagements underway, the firm is currently expanding production capacity further. "Due to the significant step up in customer qualifications, the existing strong relationships we have with these customers and our rapidly added capacity, we believe that our increasing share in this important marketplace can be a permanent shift, not a short-term supply opportunity," says Jenks.

For first-quarter 2012, NeoPhotonics expects results to reflect the typically seasonally lower first quarter against a more normalized demand pattern versus Q4/2011 revenue (which was atypically strong). Accordingly, it expects revenue of \$46–51m and gross margin of 20–22%.

NeoPhotonics says that, by combining Santur's InP PICs with its existing hybrid PICs, it can provide new products for 100G coherent systems that feature higher levels

of integration, higher performance and greater functionality. Santur also brings new growth opportunities, with tunable lasers for reconfigurable networks and 40G and 100G transceiver modules for client and cloud applications.

Various functions and systems of NeoPhotonics and Santur have been integrated, including ERP (enterprise resource planning).

Integration actions included reductions in staffing and the elimination of functional redundancies, systems and resources. The firm continues to pursue con-

These changes will make us leaner, while also being more flexible and more scalable in response to technology changes ... We could return to profitability in 4–6 quarters

solidation of its Silicon Valley facilities. Consolidation of operating functions, from sales and R&D to operations and finance, has resulted in lower combined total operating expenses and a smaller overall footprint. Total operating costs should be cut by \$1–1.5m per quarter. "These changes will make us leaner, while also being more flexible and more scalable in response to technology changes and customer needs," believes Jenks. "We could return to profitability in four to six quarters," he adds. "We will remain cautious, however, as we continue our process of integrating Santur and given persistent uncertainty in the macro-economic environment in Europe, as well as a view of potentially moderating spending at carriers, particularly in North America, which could impact our network equipment manufacturer customers."

www.neophotonics.com

NeoPhotonics completes Phase I production expansion for narrow-linewidth tunable lasers

Critical to 40 & 100G coherent systems for metro and long-haul

NeoPhotonics Corp of San Jose, CA has completed the first phase in its plan to significantly increase production capacity of narrow linewidth tunable lasers (NLW-TL) in support of rapidly growing demand. NLW-TL output has doubled since initiating the production plan in fourth-quarter 2011. The firm says that demand for the products has outstripped industry capacity due to the rapid uptake of coherent optical technology coupled with industry supply constraints attributable to the flooding in Thailand last October.

"With the flooding in Thailand, the supply of narrow-linewidth tunable lasers has become a limiting factor in the shipment of 40 and 100Gbps coherent optical transport systems," says chairman & CEO Tim Jenks. "Accordingly, we have stepped up our production to

help satisfy this critical need. Since we first announced our expansion plans, we have added seven additional customers and are engaged with several more," he adds.

"Our first-phase capacity expansion is now full and we are again expanding to help meet industry requirements," Jenks continues. "We expect the growth in demand for NLW-TLs to continue for the next several years in concert with the rapid adoption of coherent transport technology."

NeoPhotonics' NLW-TLs are compact, widely tunable and narrow-linewidth assemblies with launch power up to 35mW in the C-band and 20mW in the L-band. Narrow linewidths are designed to facilitate digital signal processing, which is used in coherent optical transmission to analyze the incoming signal when it is mixed with a

local oscillator laser in a coherent receiver. Coherent transmission is capable of increasing the bandwidth of an optical channel from 10Gbps to 100Gbps, and is designed to enable carriers to add 'backbone' network capacity economically and accommodate the surge of wireline and wireless broadband services hitting the network.

NeoPhotonics says that the narrow linewidth and frequency stability of its NLW-TL are enabled by a phase-shifted DFB (distributed feedback) laser chip and proprietary packaging technology, and the laser assembly includes an integrated wavelength locker as well as electrical and firmware interfaces.

NeoPhotonics is showcasing its products at OFC/NFOEC 2012 in Los Angeles (4–8 March).

Inphi and NeoPhotonics team on 100G optical modules Firms to accelerate transition to integrated, efficient 100GbE for cloud and data-center applications

Inphi Corp of Santa Clara, CA,, a fabless provider of high-speed analog ICs for the communications and computing markets (using InP, GaAs, SiGe or silicon bipolar as well as CMOS), is collaborating with NeoPhotonics Corp of San Jose to facilitate and speed deployment of next-generation 100G optical solutions for high-density data center and cloud computing as well as 100G transport applications.

NeoPhotonics makes photonic integrated circuits (PICs) based on hybrid silica-on-silicon technology, but last October acquired Santur Corp of Fremont, CA, a vertically integrated manufacturer focused on commercializing InP PIC-based tunable laser array and packaging technologies for communications.

Inphi will offer its portfolio of 100G TIA and 100GbE iPHY solutions — which include PHY and clock data recovery (CDR) chipsets along with its transimpedance amplifiers (TIAs) — for NeoPhotonics to use in its 100G optical product developments. Inphi's mixed-signal devices are designed to provide NeoPhotonics higher performance and lower power consumption for next-gener-

ation optical modules and subsystems for high-speed transport and client-side applications.

Based on its patented iPHY architecture, Inphi last October announced the availability of its low-power CMOS PHY and CDR solutions for 100GbE alongside the availability of its high-performance 100GbE TIA. Its CMOS PHYs and CDRs offer a substantial savings in power — 3x less than currently available offerings, it is claimed — in an area footprint reduced by 2x, while improving reliability without sacrificing performance.

"We continue to demonstrate our commitment to the ultra-high-speed segment of the optical market by working with industry leaders like Inphi to offer high-speed products for transport, cloud and data center applications," says NeoPhotonics' chairman & CEO Tim Jenks. "Our next-generation 100G optical solutions can benefit from Inphi's technology leadership position in the 100G market and help us deliver high levels of performance and low power consumption for our PIC-based product portfolio," he adds.

The collaboration with NeoPhotonics

aims to accelerate the deployment of power- and area-efficient, cost-optimized 100G products for cloud and enterprise data centers as well as for transport applications, according to Inphi's president & CEO Young K. Sohn. "Inphi remains uniquely positioned to deliver a platform-level 100GbE solution with its portfolio of CMOS PHY ICs and high-performance PMD products, which will allow for faster deployment of next-generation 100GbE optical solutions in enterprise, data-center and service provider networks," he claims.

Cost-effective, energy-efficient 100GbE links will soon become essential tools for data-center and service provider networks, which are struggling to satisfy the global economy's hunger for more bandwidth, the firms say. With service providers and data centers demanding technology with low power consumption, Inphi's iPHY CMOS PHY solutions and NeoPhotonics PIC-based modules and sub-systems are designed to provide easy upgrades to 100GbE networks while retaining a lower carbon footprint.

www.neophotonics.com

Inphi appoints Ford Tamer as CEO as president & CEO Sohn retires

Inphi has hired Ford Tamer as CEO. Tamer has more than 20 years of experience building technology businesses, with particular expertise in the semiconductor sector.

Prior to joining Inphi, he was CEO of Telegent Systems, senior VP & general manager of Broadcom's Infrastructure Networking Group (which he grew to \$1.2bn in revenue in five years), CEO of Agere Inc (acquired by Lucent Microelectronics), and VP at Agere Systems. Tamer was also a partner at Khosla Ventures, assisting in the growth of cleantech and IT businesses. He has M.S. and Ph.D. degrees in

engineering from Massachusetts Institute of Technology (MIT). He is also chairman of Sentons Inc.

"Inphi's core competencies in advanced analog circuit design, signal integrity, power management, packaging, and process technologies should bolster the company's ability to pursue solid growth in the years ahead," says Tamer.

He succeeds president & CEO Young K. Sohn, who stays on as a senior adviser during the transition. Sohn, who is retiring from Inphi, will not seek re-election as a director at the annual general meeting of stockholders in May.

"I am proud to have been so closely involved in building Inphi's position as a leading provider of high-speed interface products that enable cloud infrastructure," says Sohn. "Ford's expertise in the semiconductor space makes him well suited to take over the leadership position at Inphi and drive long-term growth," he adds.

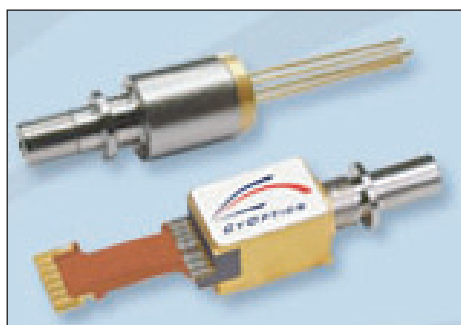
"Young has played a significant role in the creation and successful development of Inphi over the past five years, resulting in its successful IPO in November 2010," comments chairman Dado Banatao.

www.inphi.com

CyOptics launches compact 40Gbps TOSA and ROSA devices for QSFP+ optical transceivers

CyOptics Inc of Lehigh Valley, PA, USA, which makes indium phosphide (InP)-based and silica-on-silicon optical chips and components, has announced the availability of a new series of 40Gbps transmit optical subassemblies (TOSA) and receive optical subassemblies (ROSA) for use in quad small-form-factor pluggable (QSFP+) transceivers targeting high-bandwidth routers and switches in data-center and enterprise networks. The TOSA and ROSA expand CyOptics' growing portfolio of component solutions leveraging monolithic and hybrid photonic integrated circuits (PICs).

The TPIC-10410-A1 TOSA delivers four coarse dense wavelength division multiplexed (CWDM) wavelengths in the 1310nm window on a single optical output. The TOSA integrates four uncooled 10Gbps directly modulated lasers (DMLs), an optical multiplexer to combine the laser wavelengths, and four PIN photo-detectors for backfacet power monitoring. The RPIC-10410-A1 ROSA integrates an optical de-multiplexer to separate the four incoming CWDM wavelengths,



an array of four 10Gbps PIN photo-detectors and a quad trans-impedance amplifier (TIA).

"Data-center operators and equipment manufacturers don't have to worry about the interconnect flavor now that QSFP+ is available for both SR4 and LR4," comments Ovum's principal analyst Karen Liu. "CyOptics' 40GE TOSA and ROSA enable this attractive high-density form factor for single-mode transceivers. We project 40G QSFP+ for LR4 applications to overtake CFP quickly, growing at a compounded annual growth rate [CAGR] of over 79% from 2012 through 2015; they represent one of the fastest-growing market segments in the optical component space," she adds.

"Our new TOSA and ROSA address

the needs for very compact 40GE [40 Gigabit Ethernet] QSFP+ solutions to provide higher faceplate density and lower power consumption in data-centers," says Stefan Rochus, CyOptics' VP of marketing & business development. "We are leveraging our extensive portfolio of high-speed InP components together with our automated precision-robotic integration and packaging platforms to deliver these high-performance and low-cost 40Gbps TOSA and ROSA solutions," he adds.

The TOSA and ROSA are packaged in hermetic, planar packages with an LC receptacle optical interface and two flex connects for the electrical interface. The compact 15.8mm x 5.8mm TOSA and 17.2mm x 5.8mm ROSA packages are compliant for use in the QSFP+ transceiver form factor and serve the 40GBASE-LR4 (10km) application per the IEEE 802.3ba standard.

CyOptics is sampling the TPIC-10410-A1 and RPIC-10410-A1 now, with general availability planned for July.

www.cyoptics.com

Advanced Photonix establishes credit facility with Silicon Valley Bank

Advanced Photonix Inc (API) of Ann Arbor, MI, USA (which designs and makes silicon, InP- and GaAs-based APD, PIN, and FILTRODE photodetectors, HSOR high-speed optical receivers, and terahertz instrumentation) has established a new credit facility with Silicon Valley Bank (the commercial banking operation of SVB Financial Group), which has regional headquarters in Chicago, IL.

As part of the new banking relationship, Advanced Photonix has repaid the short-term note and line of credit previously held by The PrivateBank and Trust. The new credit

facility initially consists of a three-year term-note of \$1m and a two-year \$5m revolving line of credit.

Silicon Valley Bank is "a strong bank with a rich history of working with growing high-technology businesses like API," comments president & CEO Richard Kurtz. "I would also like to thank The PrivateBank and Trust for their support over the past four years," he adds.

"This new credit facility makes possible an increase in foreign receivable coverage up to \$3m as part of the \$5m total line," Kurtz continues. "This increase in total credit facility will help us fund our

growth, including our international revenue growth," he adds.

"We aim to increase the probability of our clients' success and we're looking forward to working closely with the Advanced Photonix team as they continue to grow," says Mike Kohnen, senior relationship manager, Silicon Valley Bank. "Since we are focused on technology innovators like API, we are able to provide them with the services and financing they need to expand internationally and tackle their ambitious goals."

www.advancedphotonix.com

www.svb.com

Emcore's revenue falls 28% due to Thailand flood

Fiber Optics recovery to drive rebound in March quarter

For fiscal first-quarter 2012 (to end-December 2011), Emcore of Albuquerque, NM, USA, has reported revenue of \$37.5m, down 28% on \$52m last quarter and a year ago.

Of total revenue, 51% came from the Photovoltaics segment (up from 41% last quarter). However, revenue of \$19.1m is still down 7% on \$20.3m a year ago and 10% on last quarter's record \$21.2m.

Fiber Optics fell from 59% of total revenue to 49%: \$18.4m is down about 40% on both last quarter (\$30.9m) and a year ago (\$31.8m). In October, flooding in Thailand caused primary contract manufacturer Fabrinet Co Ltd to suspend operations (which support half of Emcore's Fiber Optics revenue). Most process and test equipment (and inventory) was submerged, impacting the ability to meet demand for three main product lines: telecom products such as integrable tunable laser assemblies (ITLAs) and tunable XFP modules; cable TV lasers, components and transmitters; and legacy products.

But, thanks to the firm's original tunable XFP manufacturing line in the San Francisco Bay Area, Emcore shipped \$1m from this product for the first time, after qualifying three more telecom customers (boosting design-wins to 10). Also, revenue for unaffected product lines — e.g. video transport and specialty photonics, fiber-to-the-home (FTTH) and active optical cable (AOC) products — grew 25% sequentially. Emcore shipped over 15,000 AOCs in its second quarter of product release, including the first commercial shipment of its 12x10Gb/s CXP AOC.

Due to the flood, gross margin has fallen further, from 24.3% a year ago and 19.2% last quarter to just 9.3%. Photovoltaics gross margin of 22.7% is down from 33.3% a year ago but up on 21% last quarter (as manufacturing yield has been improving while new CPV products ramp up, and the more profitable Space Pho-

tovoltaics business continues to take up most of the solar product mix). However, Fiber Optics gross margin has fallen further, from 18.4% a year ago and 18% last quarter to -4.8%.

Manufacturing of some fiber optics-related components was moved to Emcore facilities, involving higher costs (such as labor). Instead of rebuilding all flood-damaged production lines, it was decided to realign the product portfolio and focus on areas with strong technology differentiation and growth opportunities. Management identified \$0.9m of inventory on order related to manufacturing lines for legacy products that will not be replaced. Also, there was \$1.5m of expenses for excess and obsolete inventory. Such charges reduced gross margin by more than 15 percentage points for the Fiber Optics segment, which otherwise would have been almost +10% rather than -4.8%.

Overall, Emcore recorded \$5.7m in flood-related losses (\$3.9m for inventory; \$1.8m for equipment). However, the firm also claimed damages and received proceeds of \$5m under its insurance policy.

Excluding these, operating expenses were cut by \$1.9m from last quarter to \$14.5m, due mainly to cost-reduction activities put in place after the flood, including temporary salary reductions and rotating furloughs.

A loss of about \$1m was recorded related to the Suncore concentrated photovoltaic (CPV) component- and system-making joint venture with San'an Optoelectronics Co Ltd in Xiamen, China.

Net loss was \$14.2m, level with last quarter but up on \$3.6m a year ago. Net cash provided by operating activities totaled \$20.8m, but this was due mainly to an increase in customer deposits of \$9.7m and a reduction in accounts receivable of \$9.4m. During the quarter, cash, cash equivalents, and restricted cash rose from \$16.1m to \$23.8m.

As of end-December, Photovoltaics order backlog was \$51.7m, up 19% on \$43.5m last quarter, driven by a large solar cell order from Suncore. For Fiber Optics, Emcore is reviewing its manufacturing capacity and customer commitments, but backlog reporting will resume once the manufacturing infrastructure is rebuilt.

Emcore is rebuilding the impacted production lines at another Fabrinet site and at its own manufacturing plant in China. This should be completed for its CATV production line [including the high-volume tunable XFP line] by the end of March and for its telecom-related production line by the end of May.

Due to the partial recovery of Fiber Optics capacity, for fiscal Q2 (to end-March) Emcore expects revenue to rise to \$38-40m. Revenue from tunable XFP products should to \$2m (internal capacity in the Bay Area is \$3m per quarter).

"Into the June quarter, that's where you should start to see more of a ramp up in our Fiber Optics revenues, as we start to have our other lines up and running [back to pre-flood levels by the end of the quarter]," notes chief financial officer Mark B. Weinswig.

www.emcore.com

Emcore completes 4:1 reverse stock split

Emcore has completed its 4:1 reverse stock split (announced on 27 January).

This has reduced the number of issued and outstanding shares from about 94.1 million to 23.5 million,

and the number of authorized shares from 200 million to 50 million. Proportional adjustments were also made to options, warrants and other securities, entitling holders to purchase Emcore shares.

JDSU down just \$8m despite \$15m hit from flood

On a non-GAAP basis, for fiscal second-quarter 2012 (to end-December 2011) JDSU of Milpitas, CA, USA has reported net revenue of \$413.1m, down 1.9% on \$421.1m last quarter and 13.4% on \$477.2m a year ago, but well above the forecast \$375–405m.

Of total revenue, 51% came from the Americas, 24% from EMEA (Europe, Middle East and Africa) and 25% from Asia-Pacific.

Communications Test & Measurement revenue was \$196.2m (47.5% of total revenue), up 5.9% on \$185.2m last quarter but down 15.2% on \$231.4m a year ago.

Advanced Optical Technologies (AOT) revenue was \$53.7m (13% of total revenue), down 3.4% on \$55.6m last quarter and 1.8% on \$54.7m a year ago.

Communications and Commercial Optical Products (CCOP) revenue was \$163.2m (39.5% of total revenue), down 9.5% on \$180.3m last quarter and 14.6% on \$191.1m a year ago, due mainly to a \$15m impact from October's flooding in Thailand at contract manufacturer Fabrinet.

Within CCOP, Lasers revenue (which includes Commercial Lasers and Photovoltaics) was \$25.1m (flood-hit by \$3m), down 16.9% on \$30.2m last quarter but up 10.6% on a year ago. Gas and Solid-State Laser revenue fell due to low demand from semiconductor equipment makers. Fiber Laser revenue continued to grow (to almost \$5m). However, this was constrained by the delay in migrating manufacturing and procurement from North America to Fabrinet, which also hit gross margin. CPV products had their highest revenue levels as JDSU shipped to installations in Italy and Western China. "We are currently undergoing qualifications at two additional customers," says CEO & president Thomas H. Waechter. "We have demonstrated greater than 40% efficiency, with plans to increase this level by merging JDSU's CPV technology with that of QuantaSol [acquired last July]," he adds.

Optical Communications revenue was \$138.1m (flood-hit by \$12m), down 8% on \$150.1m last quarter and 18% on a year ago. Nevertheless, 6 out of 12 product lines saw sequential growth, since most flood-related impact was in ROADM and tunable XFP product lines. Even so, ROADM revenue fell only slightly to \$38.9m (28% of Optical Communications revenue) while tunable XFP revenue still grew by 21%, up \$3.4m to \$19.3m (rising from 10% of Optical Communications revenue to 14%). JDSU now has 41 tunable XFP clients (many with two configurations, and JDSU is adding new configurations this quarter).

Revenue from new products (less than two years old) remained strong (62% of Optical Communications revenue; 56% of CommTest revenue).

"The outstanding efforts of our team and our manufacturing partner in Thailand, coupled with our continued focus on expense control, resulted in revenue and operating income that exceeded our guidance," says Waechter. Full production at Fabrinet's manufacturing facilities in Thailand resumed more quickly than expected. The net revenue impact of the flooding (on CCOP) was a less-than-expected \$15m.

Gross margin has fallen further, from 48.8% a year ago and 47.3% last quarter to 46.8%, due mainly to product mix in CCOP and CommTest and a rise in inventory reserves. CCOP gross margin fell from 32.3% last quarter to 30.5%, due to a higher mix of Optical Communications revenue (29% margin) relative to Laser revenue (38.8% margin) as well as Laser margin being lower (down from 49.3% last quarter).

Likewise, operating margin has fallen from 15.3% a year ago and 10.9% last quarter to 9.6% (above the forecasted 5.5–8.5%), due also

to operating expenses rising by \$1m on last quarter. CCOP margin fell from 14.2% last quarter to 10.2%.

Net income is down from \$67m a year ago and \$40.9m last quarter to \$35.8m.

During the quarter, JDSU generated \$45.7m of cash from operations. Capital expenditure has been cut further, from \$21.2m last quarter to \$19.6m. Total cash and investments is up from \$723.3m to \$755.6m.

"We are pleased with the improving demand for our products, as evidenced by a book to bill of greater than 1 in each of our business segments [the highest bookings level in the past year], although we expect macro-economic conditions to cause margin pressure in the near-term," says Waechter.

For fiscal Q3/2012 (to end-March), JDSU expects revenue of \$410–425m, including 7–10% sequential growth for CCOP. Yet operating margin is expected fall to 6–7.5%, including CCOP margin falling to 8–9.5% due to higher-than-average reductions in average selling price (ASP) from annual contract negotiations.

"We are going through an abnormal quarter," reckons Waechter. JDSU's targeted total operating margin remains 14–17% when quarterly revenue is \$460m or more and gross margin is 49% or higher. This includes targeted CCOP operating margin of 16–20% for revenue above \$190m (since, for all of fiscal 2011, CCOP margin was over 16%, including almost 18% one quarter and almost 19% another). Within CCOP, targeted Optical Communications gross margin is still 30–35%. After rising from 28.8% in fiscal Q1 to 29% in fiscal Q2, Optical Communications margin is expected to improve further from fiscal Q3 to Q4, as current inventories are sold and vendor cost reductions take effect. In addition, Fiber Laser margin should improve once JDSU has completed the transition to Fabrinet, localized its supply chain and increased volumes.

www.jdsu.com

Production at Fabrinet's manufacturing facilities resumed more quickly than expected

IN BRIEF

Soitec gains funding for 50MW CPV plant in South Africa

Soitec of Bernin, France has secured financing from Investec Bank Ltd to build its planned 50MW solar power plant in Touwsrivier, near the Aquila Private Game Reserve in Western Cape, South Africa.

Investec has committed to raise the equity to construct the plant, which will be equipped with Soitec's fifth-generation Concentrix CPV systems. All financial arrangements are expected to be finalized by the end of Q2/2012.

In December, Soitec was chosen by South Africa's Department of Energy as one of the preferred bidders under the country's independent power producer (IPP) program. Touwsrivier is Soitec's initial project in this program.

According to the Department of Energy, the country's goal is that 42% of all new capacity in the next 20 years will be based on renewable-energy sources.

"With financing now in place, we are moving forward to provide South Africa with its first large-scale CPV renewable-energy plant," says Soitec's chairman & CEO André Jacques Auberton-Hervé. "Following our previous construction of a pilot facility at Aquila and the 500kW CPV plant near Durban that helped to power the United Nation's recent conference on global climate change, Soitec is helping South Africa to realize its ambitious renewable-energy objectives," he adds.

Soitec says that its durable, high-efficiency Concentrix systems are well suited for installation in South Africa and other sites with high direct solar radiation. They produce a high, constant power output curve throughout the day and are able to match peak-load demands, it adds.

www.soitec.com

Alta's single-junction GaAs solar panel verified by NREL as 23.5% efficient

Firm building-out pilot manufacturing line as it plans full-scale production

Alta Devices of Santa Clara, CA, USA says that its most recent solar panel has been verified by the US National Renewable Energy Laboratory (NREL) to have a solar energy conversion efficiency of 23.5%, demonstrating progress toward its aim of developing photovoltaic (PV) solutions that are competitive (without subsidies) with fossil fuels.

Founded in 2007, Alta is a development-stage firm focused on improving the production economics of high-efficiency solar PV applications, as well as on making breakthroughs in both manufacturing and form factor. So far it has received \$72m in venture capital funding from investors including August Capital, Kleiner Perkins Caufield & Byers, Crosslink Capital, DAG Ventures, New Enterprise Associates (NEA), Presidio Ventures, Technology Partners, Dow Chemical and Alberta Investment Management Corporation (AIMCo).

The latest panel uses the same technology as the firm announced at last June's IEEE Photovoltaic Specialist Conference (PVSC37) in Seattle, which achieved record conversion efficiency for single-junction solar cells of 28.2%, resulting from technical breakthroughs in harnessing the high efficiency of GaAs in cost-effective ways.

Alta says it chose to focus on GaAs because of its intrinsic efficiency advantages as well as its ability to generate electricity at high temperatures and in low light. Panels hence have substantially higher energy density than other technologies, generating more kilowatt-hours of energy over the course of a year in real-life conditions.

"Our goal is to optimize the production economics of solar so that it is competitive with fossil fuels without subsidies, leading to broad adoption of solar generated elec-

tricity," says president & CEO Christopher Norris. In addition to technology advances which push the limits of energy density, Alta is also focused on changing the manufacturing economics of solar and enabling formats and form factors that were previously not possible.

Although GaAs is known for being expensive to produce, Alta has invented a manufacturing technique that enables cells to be about 1µm thick (a fraction of the thickness of earlier GaAs solar cells). The cell then lifts off the growth GaAs substrate (which can then be reused multiple times to amortize its high cost). In using very thin devices that have the highest energy density possible, the cost of the material needed in the panels remains low and the potential costs of an entire solar energy system based on the technology could be reduced dramatically, the firm reckons.

Moreover, because the PV film is thin and can be placed on a flexible substrate, it can be integrated in unique ways and into a variety of applications – including roof and building materials, as well as many military, consumer and transportation products, the firm claims.

According to Norris, Alta is making substantial progress on the build-out of its pilot manufacturing line, which uses mostly off-the-shelf equipment with some proprietary optimizations unique to Alta's process. It is also starting to plan for full-scale production, via activities such as building strategic manufacturing partnerships and selecting its first large, commercial manufacturing site.

"Alta has perfectly and very systematically met its plan for achieving, and then continually improving on record efficiency since the company was first funded," comments August Capital's Andy Rappaport.

www.altadevices.com

Astrium installs millionth solar cell as it delivers its 300th array

Long-term cooperation agreement signed with supplier AZUR Space

Astrium — the space subsidiary of the European Aeronautic Defence and Space Company (EADS) — says its centre of competence for solar arrays in Ottobrunn, Germany, which has been equipping spacecraft with power plants for nearly 50 years, has installed the 1 millionth cell from its supplier AZUR Space Solar Power GmbH of Heilbronn, Germany, and delivered its 300th solar array. Astrium has also signed a long-term cooperation agreement with AZUR Space.

The 100-strong Astrium team is currently preparing the solar arrays for the European Space Agency's BepiColombo interplanetary probe to Mercury. It is also developing a solar array for the new European ALPHABUS telecoms satellite.

"Weather observation, environmental monitoring, disaster management, navigation, telecommunications from space and numerous scientific missions — all these applications would be impossible without Astrium's particularly reliable solar arrays," says Evert Dudok, CEO of Astrium Satellites. "Today's modern GaAs solar cells, that we install in space, have now reached an efficiency of up to 28%, making them more than twice as efficient as the solar cells currently used for roof installations," he adds. "As the number one European company for space technologies, we are acting as an innovation driver for terrestrial applications."

The environmental conditions in space are very harsh, with extreme temperatures ranging from -180°C to $+130^{\circ}\text{C}$, so solar cells on spacecraft need to be extremely robust. The arrays developed and made by Astrium have an output ranging from a few hundred watts up to 26kW. Featuring about 20,000 solar cells and a wingspan of up to 19m (for each panel either side of the

spacecraft), a solar array weighs no more than 145kg and is folded during launch to a thickness of 30cm. Once the satellite is in space, two of these solar wings are deployed either side of the satellite. To date, no Astrium solar arrays have failed while in operation.

The Astrium solar panel production facility in Ottobrunn features three parallel integration lines, enabling up to nine large arrays to be in production simultaneously. A 4200m² cleanroom provides space for production, integration and testing, benefiting from all development and manufacturing processes being carried out in a single place.

We are acting as an innovation driver for terrestrial applications

To be able to withstand the challenging conditions they will experience in space, the solar panels are coated with a protective layer made from glass, bonded to a carbon-fiber substrate and then wired. The electrical configuration must be designed to ensure that the satellite receives the necessary power at all times. Astrium guarantees that the arrays will still be able to deliver the final service agreed with the customer after 15 years in service.

Astrium has also developed a patented method of detecting potential breakages and other defects in its solar cells, further increasing the arrays' quality. Though normally programmed to receive light and emit power, solar cells can also be operated in reverse — i.e. consuming power and emitting light as electroluminescence. A special camera can then be used to examine the illuminated solar cells to detect breakages and other defects.

www.astrium.eads.net

IN BRIEF

OPEL management change

OPEL Technologies Inc of Toronto, Ontario, Canada, which makes high-concentration photovoltaic (HCPV) panels and solar tracker systems through its subsidiary OPEL Solar Inc and develops III-V devices and processes at US affiliate OPEL Defense Integrated Systems (ODIS Inc) of Shelton, CT, has made changes to its management team.

Chief operating officer Frank Middleton came out of retirement 6 years ago to develop OPEL's HCPV technology and solar tracking systems. Over the years, he has seen the rise of OPEL's worldwide acceptance within the CPV and tracker businesses. Now that OPEL is experiencing continuing growth, especially with its solar trackers, Middleton is transitioning back into retirement.

On an interim basis, OPEL Technologies' CEO Leon M. Pierhal will direct OPEL Solar's marketing activities. "At the Annual General Meeting, I discussed refocusing OPEL Solar to meet the increasing worldwide demand for tracking systems," says Pierhal. "Our pivot to tracking systems has generated such activity that, to meet the demand, OPEL has shifted resources from our CPV business in order to devote the required attention to solar trackers."

"ODIS continues to successfully forge ahead in its POET development program to achieve its expected milestones," says Pierhal. Dr Javier Berrios is taking on an expanded role as VP of engineering & new product development. He will continue in his current engineering capacity in the solar business, but his background in photonics will support the ongoing development of ODIS' POET technology and semiconductor business plan.

www.opeltechinc.com

CPV firm Semprius sets record 33.9% module efficiency

Siemens partner to ramp pilot production in second-half 2012

Semprius Inc of Durham, NC, USA, which designs and makes high-concentration photovoltaic (HCPV) solar modules, has set a new record for photovoltaic module efficiency of 33.9% (active area). The latest prototype module was tested indoors under Standard Test Conditions (850W/m², 25°C cell temperature, and a spectrum matched to AM1.5D) by the Instituto de Energía Solar at the Universidad Politécnica de Madrid (IES-UPM). Certified by IES-UPM and corroborated by outdoor measurements made at the Institute of Concentration Photovoltaic Systems (ISFOC) in Puertollano, Spain, the efficiency significantly exceeds the previous record of 32.0%.

"For the first time, we have been able to convert more than one-third of the sun's energy into usable electricity," says VP of technology Scott Burroughs. "This demonstrates how concentrated PV can leverage rapidly increasing efficiencies to continue driving down the cost of solar generated electricity," he adds.

Developed with the support of the US Department of Energy's National Renewable Energy Laboratory (NREL), Semprius' HCPV modules use high-performance glass lenses to focus sunlight 1000-fold onto highly efficient triple-junction gallium arsenide-based microcells (600µm by 600µm in area and less than 10µm thick) that cover just 0.1% of the module area. The microcell's small size enables the use of low-cost optics and electrical interconnects, which remove the heat, eliminating the need for costly thermal management solutions. In addition, Semprius grows its cell structures on top of a release layer so that they can be epitaxially lifted-off as part of its patented micro-transfer printing process, allowing it to reuse the GaAs substrate and hence cut costs dramatically. Semprius also uses an automated manufacturing process,



The latest prototype HCPV modules.

leveraging standard manufacturing equipment and commodity materials, to reduce capital and labor costs.

"We looked carefully at each component of our module — cell, optics, enclosure and the manufacturing process — to develop a competitive solution that embodies high efficiency, performance and reliability," says CEO Joe Carr. "Important to our customers is the fact that the module chosen for this third-party evaluation is part of the normal production distribution that will be commercially available later this year," he adds.

Depending on the specific location and irradiation, the HCPV modules can deliver an energy output per square meter twice that of common polycrystalline silicon solar modules, it is reckoned. Leading module makers of conventional PV technologies achieve a maximum module efficiency of about 20% with monocrystalline PV modules and about 16% with polycrystalline technology.

In June 2011, Germany's Siemens AG acquired a 16% stake in Semprius (as part of a \$20m Series C round of venture capital funding), becoming a strategic partner with the aim of scaling up the HCPV technology to market

maturity. "Semprius, as a leader in HCPV modules, shows us that we have bet on the right technology," says Martin Pfund, CEO of the Siemens Energy Photovoltaic business unit. "Combined with our expertise in turnkey solutions business, it has the potential to become a game changer for the solar markets in regions with high irradiation," he reckons. "With Semprius as a partner, we will further broaden our portfolio in the photovoltaics market."

While Semprius will further develop its modules, Siemens is focusing its R&D activities on optimizing system components such as the trackers, field design and inverters (components for photovoltaic installations are part of Siemens' Environmental Portfolio). Together with Semprius, Siemens aims to provide the best possible integrated solution.

The first full test installation has been operational in Arizona since August 2010, at UniSource Energy Corp subsidiary Tucson Electric Power (TEP) in Arizona as part of a joint development agreement signed in January 2010 between Semprius and Atlanta-based Siemens Industry Inc (the US affiliate of Siemens' global Industry Sector business). Semprius is now ramping up global deployment of numerous demonstration systems at test sites around the world. "Our world record efficiency modules, combined with our low-cost manufacturing processes and Siemens' PV system expertise, will deliver a best-in-class global solution for utility-scale solar plants," reckons Carr.

Meanwhile, Semprius is completing construction of a pilot plant in Henderson, NC, to validate the technology for larger installations. Ramp up of commercial production of HCPV modules from the pilot line will begin in second-half 2012.

www.semprius.com

www.siemens.com/energy

IQE raises £10.5m; invests in CPV cell firm Solar Junction

Epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK has signed a strategic investment deal and an exclusive wafer supply agreement with Solar Junction Corp (SJC) of San Jose, CA, USA, which manufactures III-V multi-junction solar cells for concentrated photovoltaic (CPV) modules.

SJC was founded in 2007 with seed funding from New Enterprise Associates (NEA), plus Draper Fisher Jurvetson and Advanced Technology Ventures. Its solar cell incorporates proprietary lattice-matching technology (developed at Stanford University) based on dilute nitride materials, enabling it to more optimally partition the solar spectrum for maximum efficiency and greater reliability. Last April, SJC achieved record energy conversion efficiency of 43.5% for a commercial production cell (raised from the previous record of 42.3%).

IQE has placed 43,750,000 new ordinary shares with institutional investors at 24 pence per ordinary share to raise £10.5m (\$16.7m). Net proceeds will be used to:

- fund an equity investment to take a 9% stake in SJC (about \$5m);
- buy high-volume MBE production tools dedicated to manufacturing epiwafers for SJC's cells (\$8m); and
- fund the cost of ancillary quality control equipment, process transfer and to establish initial wafer manufacturing at IQE (\$2m).

SJC is in the process of raising about \$20m, mostly to fund its move into high-volume chip manufacturing. As part of this funding, IQE will be SJC's strategic epitaxy partner (via an exclusive seven-year epiwafer supply contract and exclusive rights to supply all of SJC's products), enabling it to benefit from IQE's materials intellectual property and expertise in high-volume MBE-based epiwafer manufacturing. In exchange, IQE secures a partnership for developing CPV technology with SJC and exclusive access to SJC's on-going R&D program at no additional cost.

"A combination of Solar Junction's core materials IP and technology, together with our own IP and manufacturing capabilities provides a compelling route to significantly higher cell efficiency and cost-effective, high-volume production," says IQE's CEO Dr Drew Nelson.

SJC is in qualification with major CPV system makers, being close to full International Electrotechnical Commission (IEC) certification with its lead customer. In early February, it signed a multi-megawatt CPV cell supply agreement with system maker Semprius Inc of Durham, NC, USA (which has just set a new record for PV module efficiency of 33.9%). IQE's investment in SJC is hence expected to accelerate its strategy to become a global supplier of CPV wafers for solar power markets.

As the cost of CPV power generation has fallen rapidly, the CPV market has reached an inflection point in terms of cost comparisons with fossil fuels and is promising impressive growth potential, says Nelson. At SJC's record 43.5% cell efficiency, in sunny regions the cost of electricity generated using CPV can be lower than other technologies, including fossil fuels and renewables. This is reflected by the capacity of CPV installations under construction or announced during 2011 growing to almost 690MW, on a total installed base of 28MW at the start of 2011. IQE says that, using their combined IP, IQE and SJC have a roadmap to increase CPV cell efficiency to over 50% in the next few years.

For CPV systems, a 10% increase in relative efficiency (e.g. from 40% to 44%) can cut the total cost of energy generation by 10%. The future cost for CPV is expected to continue to drop rapidly in the coming years, driven by increasing cell efficiency, greater concentration levels and the production ramp-up.

According to analysts, the CPV market will grow to 1.5GW by 2015. IQE hence expects the epi market for CPV to grow to \$250m by 2015 and to equal the total wireless epi market in 2017. "We look forward to developing our CPV offering further alongside our strongly growing optoelectronic business and our well established wireless-related products," says Nelson.

After completing the investment in February, IQE expects process transfer from SJC, MBE tool installation and their qualification with SJC's customers to take the rest of 2012, with sales of CPV wafers starting in 2013. IQE anticipates receiving \$1.2m of R&D income in 2012, so it expects the investment to be earnings neutral in 2012.

Process optimization for the new tools during their first two years is expected to boost IQE's throughput and revenue. Once the tool-sets are running at full capacity, IQE expects above-average EBITDA margins. Based on the expected timetable for customer qualifications, the investment should be earnings enhancing in 2013.

www.sj-solar.com

www.iqep.com

Solar Junction signs multi-megawatt supply agreement with module maker Semprius

In early February, Solar Junction announced a deal with Semprius outlining a multi-megawatt order.

Over the past two years, Solar Junction has been working closely with Semprius to deliver cell technology contributing to Semprius' record HCPV module efficiencies.

"Collaboration with Solar Junction

not only helped us set the world record for solar module efficiency but, much more importantly, we believe that Solar Junction can help us meet our goal of delivering large-scale, cost-competitive, sustainable solar electricity," says Semprius' VP of technology Scott Burroughs.

www.semprius.com

IN BRIEF

Abound Solar produces 82.8W CdTe PV module

Mass production due in second-half 2012; 85W modules in first-half 2013

Cadmium telluride (CdTe) thin-film photovoltaic (PV) module maker Abound Solar of Loveland, CO, USA has announced the production at its factory in Longmont, CO of 82.8W modules. This represents an aperture efficiency of 12.2%, as is being verified by the US Department of Energy's National Renewable Energy Laboratory (NREL).

The first 82W module was produced in early January on existing production equipment, and several hundred modules reaching that wattage have been manufactured so far. Abound expects to begin mass production of 82W modules in second-half 2012 and 85W modules in first-half 2013.

The achievement "underscores the tremendous capabilities of CdTe thin-film technology as a leading solution for competitive, reliable solar power made in the USA," says president & CEO Craig Witsoe. "Abound's R&D team continues to innovate, and we expect to continue increasing our module efficiency and performance," he adds. "We believe thin-film will soon outpace other forms of PV in regards to cost-efficiency."

Abound produced its one-millionth module in December. Expansion of the Longmont factory is currently underway, with further expansion efforts within the USA coming in 2013.

www.abound.com

Sonnedix completes 7.5MW solar farm in Thailand, largest First Solar plant in South-East Asia

Sonnedix Group of Amsterdam, The Netherlands, which develops, builds, owns and operates solar power plants globally, has completed the Nakhon Ratchasima Solar Farm in Khorat region, northeastern Thailand. The 7.5MW (DC) solar power plant, which is one of the biggest to date in Thailand, was built by Sonnedix with the support of Assyce Fotovoltaica and Ch Karnchang Group using about 95,000 CdTe PV modules made by First Solar Inc of Tempe, AZ, USA.

Sonnedix owns over 50MW of PV plants in operation or construction in Italy, France, Spain, the USA and Thailand, and has several hundred MW in development. "As a global solar independent power producer (IPP) whose management has an extensive track record of more than 15 years in Asia, we are confident that this project — our first to become operational in Thailand — will serve as a strong base for our strategy of developing and building utility-size world-class solar farms and large rooftop solar power plants," says Sonnedix chairman Franck Constant.

"Completion of the Nakhon Ratchasima Solar Farm is a consid-



Nakhon Ratchasima Solar Farm.

erable achievement and supports our commitment, shared with the Thai government, of reducing fossil-fuel dependence and greenhouse-gas emissions," says Jack Curtis, First Solar's VP, sales & business development. The Thai authorities are increasingly adopting utility-scale PV solar as a clean, affordable source of renewable energy, adds Kevin Berkemeyer, First Solar's senior manager, business development.

Covering about 20 hectares, the Nakhon Ratchasima Solar Farm can supply enough electricity to meet the annual needs of about 5100 average Thai homes. It is expected to generate more than 10,500MW-hrs of electricity per year, offsetting CO₂ emissions of more than 6500 tons annually.

www.sonnedix.com

CLP Resources names First Solar as 2011 Safety Partner of the Year

CLP Resources Inc of Reno, NV, USA (a subsidiary of TrueBlue Inc) has named First Solar as its 2011 Safety Partner of the Year in honor of its commitment to safety, extraordinary safety record, and safety partnership efforts.

CLP is celebrating its 25th year as supplier of skilled tradespeople to commercial, industrial and institutional building contractors. The firm recognized 18 customers across the USA as 2011 Safety Partners from among the thou-

sands it worked with last year, and First Solar ranked first, based on hours worked, hours between incidents, overall safety performance of CLP's employees on the customer's jobsite, and safety culture.

"First Solar joins us in our commitment to safe workplaces and has consistently proven that safety is one of their highest priorities," says Eric Feinberg, VP of strategic markets at CLP.

www.clp.com

www.firstsolar.com

MidAmerican completes acquisition of 550MW Topaz Solar Farm from First Solar

MidAmerican Renewables LLC (a subsidiary of global energy provider MidAmerican Energy Holdings Company of Des Moines, Iowa) has completed its acquisition of the Topaz Solar Farm from First Solar Inc of Tempe, AZ, USA, which makes cadmium telluride (CdTe) thin-film photovoltaic (PV) modules and provides engineering, procurement & construction (EPC) services. The 550MW photovoltaic power plant being built in San Luis Obispo County, CA will have the capacity to generate enough renewable energy to power about 160,000 average California homes.

"There is a growing desire to utilize renewable energy," comments MidAmerican Renewables' president Bill Fehrman. "Solar plays a crucial role in meeting renewable energy targets and portfolios. The closing of the Topaz project acquisition makes it the second solar project in our renewables business, and we look forward to evaluating and acquiring additional opportunities," he adds. MidAmerican announced in mid December that it is acquiring

a 49% stake in the 290MW Agua Caliente project (in Yuma County, between Yuma and Phoenix in Arizona) from power generation firm NRG Energy Inc (which had previously acquired the project from First Solar).

"There is a growing desire to utilize renewable energy," comments MidAmerican Renewables' president Bill Fehrman. "Solar plays a crucial role in meeting renewable energy targets and portfolios. The closing of the Topaz project acquisition makes it the second solar project in our renewables business, and we look forward to evaluating and acquiring additional opportunities," he adds. MidAmerican announced in mid December that it is acquiring a 49% stake in the 290MW Agua Caliente project (in Yuma County, between Yuma and Phoenix in Arizona) from power generation firm NRG Energy Inc (which had previously acquired the project from First Solar).

The Topaz project will be built, operated and maintained by First Solar. Construction began in

December and is expected to be complete by early 2015. The project will create about 400 construction jobs and 15 ongoing operations and maintenance jobs.

The Topaz project is one of the world's two largest PV projects, which are both being built by First Solar, says Frank De Rosa, First Solar's senior VP for business development — the Americas. "First Solar is the leading developer of utility-scale PV projects," he claims, "and MidAmerican Renewables' investment in these renewable resources is a significant endorsement."

Pacific Gas and Electric Company will purchase the electricity from the Topaz project under a 25-year power purchase agreement, helping California meet its mandate to generate 33% of its power from renewable sources by 2020. Electricity generated from the Topaz project will displace about 377,000 metric tons of carbon dioxide per year (equivalent to taking about 73,000 cars off the road).

www.midamericanrenewablesllc.com

First Solar co-sponsors Chipotle development cycling team

Team Chipotle of Boulder, CO, USA, the development cycling squad owned by Slipstream Sports, has become Team Chipotle-First Solar with the addition of CdTe PV module maker First Solar Inc of Tempe, AZ as a co-title sponsor. The team made its season debut in mid-February at the 2012 Valley of the Sun race in Phoenix, AZ.

Apart from being the largest manufacturer of thin-film solar modules and building complete PV power plants for customers in many countries, including the two largest PV projects in the world (currently under construction), First Solar says it created the solar industry's first pre-funded collection and recycling program.



Team Chipotle-First Solar outfit.

"Our sponsorship of the Chipotle-First Solar team is part of our broader commitment to a cleaner, healthier environment," says Ted Meyer, VP of global corporate communications. "Cycling is a sport with global appeal that promotes hard work, competition and excellence, values we share," he adds.

"They are a huge global company and the team is competing in locations where some of their most important projects are underway, so we will be bringing their message straight to the communities and markets most important to them," says Slipstream Sports' president Matt Johnson about First Solar.

www.firstsolar.com

CIGS PV panel market to grow rapidly to \$4.4bn by 2017

Improved cost per watt vital to combat low-cost crystalline silicon

Revenues from copper indium gallium diselenide (CIGS) thin-film photovoltaic (PV) panels will reach \$4.4bn by 2017, forecasts 'CIGS Photovoltaics Markets – 2012', the latest in an ongoing series of reports on CIGS solar markets from industry analyst firm NanoMarkets.

However, while the recent announcement of a 150MW solar farm supports the notion that CIGS technology is finally ready for prime time, CIGS manufacturers will have to adopt new strategies to protect themselves from falling solar panel prices, notes NanoMarkets.

To meet the challenge of very low-cost crystalline silicon (c-Si) solar panels, CIGS will need to continue to improve on its cost per watt, reckons the firm. NanoMarkets expects CIGS to succeed in this regard through volume production and manufacturing efficiencies such as thinner absorber layers and aggressive recycling of absorber materials. CIGS can also compete with c-Si based on superior aesthetics and good performance in indirect light.

NanoMarkets believes that reducing the cost of encapsulation is the key to success for flexible CIGS panels, which will generate more than \$635m of the market by 2017. Current use of complex dyadic film encapsulation is proving very expensive, and the report suggests that there may be some potential for lowering costs by using overcoats of silicon nitride, silicon oxide, and/or silicon oxynitride before final module encapsulation. Also, the CIGS industry will embrace low-cost advanced plastic substrates as a replacement for polyimide, forecasts the report.

The analyst firm also believes that CIGS manufacturing will take new directions resulting in higher efficiencies and lower costs. Laser annealing of the absorber layer will become more common and will enable more thermally sensitive substrates to be used. However, before this can happen, the cost of laser annealing equipment will need to be reduced.

NanoMarkets also foresees solution-based deposition as playing a

growing role in the creation of CIGS panels based on new types of solvents. In the past, this type of approach has suffered as the result of high levels of impurities in the materials, says the firm. However, hydrazine is now proposed as a solvent system for solution-based deposition, and has shown promising results in the lab. This new approach seems likely to considerably improve CIGS efficiency, the firm concludes.

Applications sectors covered in the report include rigid panels (conventional and BIPV), flexible PV, portable PV and building-integrated PV (BIPV) glass. The report also includes in-depth analysis of the latest trends in CIGS manufacturing and the market impact. Eight-year forecasts — including both revenue and volume (MW) — are broken out by application sector and by type of deposition/manufacturing. The report also discusses the strategies of key suppliers of both CIGS panels and materials.

www.nanomarkets.net

CIGS PV firm MiaSolé hits 17.3% efficiency with champion module; 14% now in production

Advances in R&D and manufacturing efficacy yield achievements ahead of schedule

MiaSolé of Santa Clara, CA, USA, which was founded in 2001 to make copper indium gallium diselenide (CIGS) thin-film photovoltaic panels, says that it has achieved a solar energy conversion efficiency of 17.3% for a champion device, while its manufacturing process for 14% efficiency is now in production.

These latest achievements are ahead of schedule, and represent an increase of more than 30% in efficiency from the same time a year ago.

"The progress in efficiency gains we've repeatedly demonstrated are further proof that we're aggressively moving toward a cost structure that is competitive with top-tier global solar manufacturers," reckons CEO John Carrington.

MiaSolé says that, with increased manufacturing efficiency and investment in R&D, it has been able to unlock the vast potential for CIGS thin-film in the solar industry. To date, the firm has shipped more than 55MW, with its panels being used for a wide range of projects

globally, in North America, Europe and Asia. The panels have been selected for a range of segments, from utility-scale fields to rooftops, and unique applications such as electric vehicle recharging stations.

"Our ability to deliver 14% in production, with the capability to achieve efficiency up to 17%, further emphasizes the progress we are continuously making against our roadmap," says Carrington. "Our ultimate goal is to continue scaling innovation and deliver the lowest levelized cost of electricity."

www.MiaSolé.com

Ascent appoints TFG director as CEO in focus on Asia

Ascent Solar Technologies Inc of Thornton, CO, USA, which makes lightweight copper indium gallium diselenide (CIGS) thin-film photovoltaic modules on flexible substrates, has appointed Victor Lee (executive director of its largest shareholder, TFG Radiant Group Ltd and its affiliates) as president & CEO.

Last August, TFG Radiant acquired about 20% of Ascent's shares. In December, it agreed to purchase a further 21% of the outstanding stock in a private transaction, through the acquisition of stock owned by Norsk Hydro Produksjon AS. Upon closing of that transaction, TFG Radiant will own about 41% of Ascent's outstanding stock.

Lee, a current and continuing board member, will take on his new role voluntarily without any compensation. He will focus on ramping up production, establishing relationships with partners, and developing sales opportunities primarily in Asia.

"Victor, representing our largest shareholder, has tremendous relationships in Asia that will be valuable to Ascent," says chairman Dr Amit Kumar. "As we evaluate the changing dynamics of the solar industry, we have been aware for some time that the greatest market opportunities are in Asia, and this change in leadership enables us to take advantage of these changing market dynamics," he adds. "Victor and his team at

TFG Radiant have substantial financial management backgrounds, have run multiple large organizations, and have very strong financial, government and business relationships in China and East Asia." Lee is also fluent in English, Mandarin and multiple Chinese dialects.

Last August, as well as investing in Ascent, TFG reached a joint development agreement to establish CIGS PV module manufacturing facilities in East Asia. TFG committed \$165m for the initial fabrication plant. Ascent also agreed to exclusively license its technology for fabrication and distribution of CIGS PV modules to TFG for East Asia (including China, Taiwan, Hong Kong, Malaysia, Indonesia, Thailand, Korea and Singapore).

"We thank Ron Eller for his contribution to Ascent in his role as CEO," says Kumar. "I have thoroughly enjoyed helping the development of Ascent, initially as a director and then as CEO," comments Eller. "As the company continues to move to high-volume production, having Victor's capabilities and relationships in the CEO role will be valuable," he adds.

"We continue to see tremendous market opportunities for Ascent's products, and I look forward to personally helping develop those markets and close valuable sales opportunities," says Lee. "We [TFG] are making commitments of time, capital and relationships to hasten

that success. While many public and private solar panel manufacturers are having financial troubles, we want to send a very clear message to the marketplace that we believe in a bright future for Ascent," he notes.

Lee is the managing director of Tertius Financial Group Pte Ltd, a boutique corporate advisory and private investment firm he founded in February 2009. He has over 17 years of experience in corporate banking, real-estate finance and investment management, and corporate advisory services at leading worldwide financial institutions. Lee began his career at Citibank N.A. in 1993, handling small- and medium-sized corporate finance, and progressed to a VP position in the International Personal Banking Division. In 1999 he moved to Deutsche Bank AG as VP, and in 2004 was promoted to managing director and Singapore Market Head in the Private Wealth Management Division, responsible for managing about \$1bn of assets. From 2007 until 2009 he was with Morgan Stanley Private Wealth Management as executive director and head of Singapore/Malaysia markets. Lee has a Bachelor's degree in Accounting from the University of Wisconsin and a Master's in Wealth Management from the Singapore Management University.

www.ascentsolar.com

MiaSolé hires VP of global business development & sales

MiaSolé has appointed Richard (Rich) Hossfeld as VP of global business development & sales. He will also be part of the executive management team. MiaSolé says that the appointment underscores its continued strategy to expand its business model globally and to execute on strategic partnerships.

Hossfeld has proven experience in developing and leading market entry and go-to-market strategies in North America, Asia and Latin America. As VP of business devel-

opment at cadmium telluride (CdTe) thin-film PV panel maker First Solar Inc of Tempe, AZ, USA, the firm entered the North America market, compiled a 2.2GW pipeline of contracted projects, acquired project development and engineering, procurement & construction (EPC) businesses, and launched operations in Asia. Prior to joining First Solar, Hossfeld practiced corporate law at Cravath, Swaine & Moore LLP.

"MiaSolé's CIGS technology pro-

duces the highest-efficiency thin-film solar panels in the world at low cost," claims CEO John Carrington (executive VP of global marketing & business development at First Solar until last November), "and we will continue to push the boundaries of what is possible," he adds. "Rich's experience will be invaluable in driving further growth of our company... I look forward to working with Rich again to open new markets and drive our sales execution."

www.MiaSolé.com

Japan's Mt Komekura PV project activated after Solar Frontier supplies 10MW of CIS modules

On 27 January, Shigeaki Kameda, president of Tokyo-based Solar Frontier (a subsidiary of Japanese energy business Showa Shell Sekiyu K.K.) attended a ceremony to activate the Mt Komekura Solar Power Plant in Yamanashi Prefecture, central Japan. Solar Frontier supplied 10MW of CIS (copper indium selenium) thin-film photovoltaic (PV) modules to the plant through Meidensha Corp. Operated jointly by Yamanashi Prefecture and Tokyo Electric Power Company (TEPCO), the facility is among the largest solar power plants in Japan.

The plant has been built as part of Yamanashi Prefecture's Global Warming Countermeasures Plan for cutting greenhouse-gas emissions. It is expected to generate about 12 million kWh of electricity annually (equal to the electricity use of about 3400 households) and reduce annual CO₂ emissions by



The Mt Komekura Solar Power Plant.

about 5100 tons (equivalent to the emissions of 1000 households). Solar Frontier claims that its PV modules have achieved a higher conversion efficiency rate than many other thin-film modules, and are able to deliver higher overall energy output (kWh) under real weather conditions. In Japan, the performance of CIS PV modules has already been demonstrated at the Yukigunigata Megasolar power

plant in Niigata Prefecture and at large-scale solar power production facilities at Solar Frontier's CIS module production plants in Miyazaki. Solar Frontier says that, as it proves the performance of its CIS modules, the panels are being adopted in more utility-scale solar power plants in Japan and around the world.

Solar Frontier started operation of all production lines at its gigawatt-scale Kunitomi Plant in Miyazaki in 2011, becoming one of the world's largest solar module factories. The firm says that, due to its large-scale production enterprise, it will be able to supply increasing demand for solar power in Japan (as a result of the enactment of feed-in-tariffs this July) while continuing to supply customers around the world.

www.solar-frontier.com

Solar Frontier ships 13.2MW of CIS PV modules to NRG

After signing a module supply agreement in December, Solar Frontier has delivered 13.2MW of its CIS PV modules to NRG Solar LLC of Carlsbad, CA, USA.

NRG Solar owns and operates some of the largest solar power plants in the USA, and has more than 2000MW of solar projects under development or in construction across the southwest US.

It is a subsidiary of NRG Energy Inc of Princeton, NJ, USA, which owns and operates one of the USA's largest and most diverse power generation portfolios (with over 25GW of capacity).

The deal marks the first agreement between the two firms and the first purchase of thin-film CIS technology by NRG Solar. Although the purchase is not set for a specific project, Solar Frontier says that the transaction demonstrates the confidence NRG Solar

has in CIS technology for future installations.

"NRG Solar's leadership in the industry makes them an extremely valuable long-term customer of Solar Frontier," comments Gregory Ashley, chief operating officer of subsidiary Solar Frontier Americas Inc in Santa Clara, CA.

The modules are produced at Solar Frontier's gigawatt-scale Kunitomi factory in Miyazaki, Japan, which combines automation, scale, and low-energy, end-to-end processing of CIS modules. Solar Frontier claims that the 'light soaking' effect of CIS modules significantly increases output from initial values, while a lower temperature coefficient than crystalline silicon means that more kWh are produced under real conditions in hotter climates. The firm also claims that its modules also involve lower overall energy con-

sumption in the manufacturing process, yielding one of the fastest energy payback times in the solar industry.

Solar Frontier total shipments have grown from 46MW in 2009 to 70MW in 2010 then 577MW in 2011. As well as being the world's largest CIGS PV panel maker, Solar Frontier is now the second largest thin-film PV module maker, behind cadmium telluride (CdTe) PV maker First Solar Inc of Tempe, AZ, USA (which shipped 2GW in 2011). In mid-January, Solar Frontier signed a \$100m-plus agreement to supply renewable energy project developer enXco of San Diego, CA, USA with up to 150MW of modules, delivering 26MW in fourth-quarter 2011 for the Catalina Solar Project in Kern County, CA (to supply power to San Diego Gas & Electric).

www.nrgsolarenergy.com

CIGS PV firm Nanosolar raises \$20m

New investment to fund expansion and new projects

Nanosolar Inc of San Jose, CA, USA, which makes thin-film photovoltaic cells and panels based on depositing copper indium gallium diselenide (CIGS) and nanoparticle inks on flexible substrates (using roll-to-roll solar cell printing), has closed a \$20m round of financing involving existing investors Mohr Davidow Ventures and OnPoint Technologies Inc together with new investor aeris CAPITAL (a Swiss private investment firm). The new investment will fund continued expansion as well as newly committed projects.

Nanosolar operates what is claimed to be the first roll-to-roll solar cell printing factory (in San Jose), as well as a panel-assembly factory in Luckenwalde, Germany.

In the last six months, Nanosolar has announced a number of mile-

stones and projects, including:

- the appointment of Eugenia Corrales (former executive VP of engineering and operations) to CEO as part of a planned transition as prior CEO Geoff Tate retires;

- an expansion of production capacity to 115MW;

- certification by the US Department of Energy's National Renewable Energy Laboratory (NREL) of solar cell aperture efficiency of 17.1%; and

This represents the beginning of an exciting new period of growth for Nanosolar. With our team firmly entrenched, we will be unveiling new projects and new partners

- two new projects with EDF EN (EDF Energies Nouvelles) in Oregon totaling 3MW, and two new projects totaling 1.5MW at US National Guard bases in Ohio and California.

"This represents the beginning of an exciting new period of growth for Nanosolar," says Corrales.

"With our team firmly entrenched, we will be unveiling new projects and new partners," she adds.

Nanosolar says that it combines proprietary technology with its system design and manufacturing processes to reduce both panel and balance of system costs, driving the firm's aim to be a low-cost solar provider, independent of subsidies.

"We believe solar printing is the future of low-cost harvesting of solar energy," comments Erik Oldekop of aeris CAPITAL.

www.nanosolar.com

Sofradir becomes top supplier of cooled MCT IR detectors for military applications

According to 'The World Market for Military Infrared Imaging Detectors and Systems' from market research firm Maxtech International Inc, Sofradir of Châtenay-Malabry, near Paris, France (which makes cooled infrared detectors for military, space and commercial applications) says that it has secured global market leadership, with more than 25% market share in volume for supplying second-generation mercury cadmium telluride (MCT/HgCdTe) IR detectors to the military and space markets (previously dominated by US suppliers).

Sofradir's IR detectors are used in thermal imagers, missile seekers, infantry fighting vehicles (IFVs), such as those used by the French army in Afghanistan, other surveillance, targeting and homing infrared equipment, and spaceborne observation satellites. In particular, Sofradir's critical

scanning and staring arrays enable highly accurate detection and identification of threats and day/night surveillance. In 2011, Sofradir delivered 5000 units (up from the 4400 delivered in 2010), enabling Sofradir to eclipse its predecessor.

Compared to the manufacture of components in other industries, volumes for cooled MCT IR detectors may appear small. However, system integrators in the defense industry are well aware of the extreme complexity of producing cooled MCT IR detectors, with only a handful of IR manufacturers able to produce more than 2000 units per year.

After making and selling IR detectors since 1986, Sofradir credits its increased market share to its longevity in meeting customer demands for cutting-edge and innovative products, and its capacity to run a safe and reliable

production line and to anticipate market needs for new standards (such as the 15µm pitch).

"It acknowledges the robustness of our business strategy and technological choices," says chairman & CEO Philippe Bensussan about the ranking. "It is recognition that we have been carrying out the right analysis on the problems customer face and bringing them winning solutions," he adds. "In addition, with the recent strengthening of our shareholder structure, new assets from Safran and Thales will broaden our IR technology portfolio," Bensussan notes.

At the end of January, Sofradir's defense group shareholders Thales SA and Safran SA increased their shareholdings from 40% to 50% each, through the purchase of the 20% holding of nuclear energy group Areva.

www.sofradir.com

Honeycomb sweetens nitride solar cell performance

A silicon dioxide honeycomb structure that reduces light reflection can increase short-circuit current and fill factor, boosting energy conversion.

Taiwan researchers have been using silicon dioxide (SiO_2) honeycomb structures to increase the performance of nitride semiconductor solar cells [P. H. Fu et al, Appl. Phys. Lett., vol100, p013105, 2012]. The research was carried out by participants from National Taiwan University, Genesis Photonics Inc, and National Central University.

The honeycomb structure reduces the amount of light reflected from the cell's top surface, hopefully allowing more light to enter into the active region and creating more electrical power. Performance under simulated 1.5 air-mass (AM1.5G) solar illumination showed 7% increased short-circuit current density (J_{sc}) over a bare comparison device (Table 1). The open-circuit voltage (V_{oc}) was the same in the two devices. The energy conversion efficiency is boosted by some 34%, thanks both to the increased current and an enhanced fill factor (maximum converted power/ $(V_{oc} \times I_{sc})$).

[Actually there is a slight error in Table 1, as published in Appl. Phys. Lett. Using the given values of V_{oc}

Table 1. Photovoltaic characteristics of the MQW solar cells with bare surfaces and nano-honeycombs.

AR layers	Bare surfaces	Nano-honeycombs
V_{oc} (V)	1.9	1.9
J_{sc} (mA/cm^2)	0.84	0.90
Fill factor (%)	25.94	32.23
Energy conversion (%)	0.41	0.55*

* This value is given incorrectly as 0.51 in the original paper.

J_{sc} fill factor, and standard test condition solar power of $1000\text{W}/\text{m}^2$, one gets a higher value of 0.55% for the conversion efficiency, rather than the published value of 0.51. This has been confirmed with the corresponding author.]

The values of the conversion efficiency are less than 1% because the peak wavelength of the device for energy conversion is somewhat shorter (380nm) than that of the incident solar radiation ($\sim 500\text{nm}$).

The epitaxial material for the Taiwan device was grown on c-plane sapphire using metal-organic chemical vapor deposition (MOCVD). The undoped

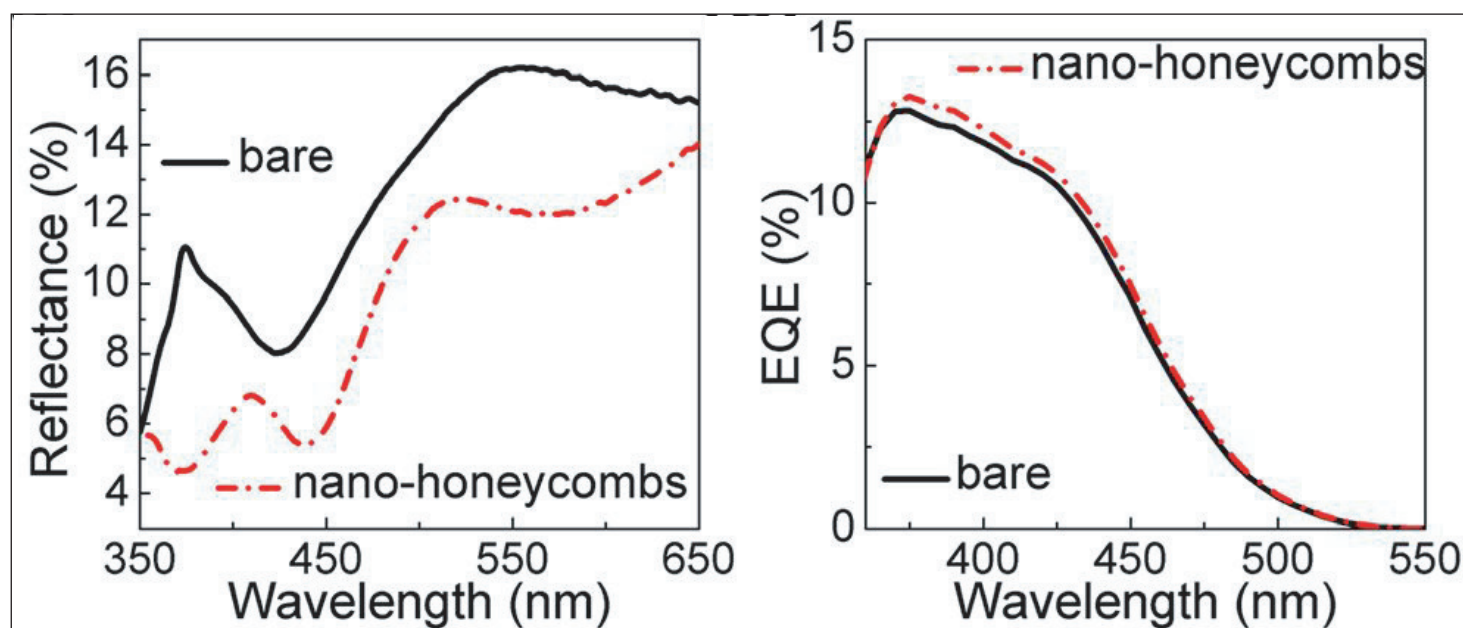


Figure 1. (a) Specular reflectance and (b) external quantum efficiencies (EQEs) measured on the MQW solar cells with bare surface and

active layer consisted of a 9-period multi-quantum well structure of 3nm indium gallium nitride ($\text{In}_{0.3}\text{Ga}_{0.7}\text{N}$) wells separated by 17nm GaN barriers. The n-type layer was $2.5\mu\text{m}$ and the p-type layer was $0.2\mu\text{m}$.

The device was formed from this material by first depositing an indium tin oxide (ITO) transparent conductive layer on the p-GaN contact layer, etching $1\text{mm} \times 1\text{mm}$ of LED mesas, and deposition of titanium/aluminum/nickel/gold contacts. The p-metal was patterned in an interdigitated grid format, either deposited on the bare ITO or on the nano-honeycomb.

The nano-honeycomb was produced by depositing 450nm of SiO_2 by electron-beam evaporation. A 5-minute oxygen plasma treatment made the surface hydrophilic. Polystyrene 450nm-diameter spheres in deionized water were then coated onto the SiO_2 to serve as an etch mask. The wafer was then put in an incubator at $50^\circ\text{C}/87.5\%$ humidity for two hours. This resulted in a close-packed monolayer of spheres. To create gaps between the spheres, they were next subjected to oxygen plasma. This was followed by trifluoromethane to etch the SiO_2 . Further oxygen plasma was used to remove the nano-sphere residue.

The effect of the SiO_2 structure is to reduce reflection that blocks sunlight from entering the device (Figure 1). One aspect of this is that the SiO_2 has a refractive index that is intermediate between that of air (1) and that of the ITO (2.04 at a wavelength of 500nm). The external quantum efficiency (EQE) measured under monochromatic illumination from a halogen lamp is thus enhanced by several percent. The peak wavelength is 380nm in both cases. Simulations suggest that the honeycomb structuring broadens the light intensity distribution within the device through scattering.

The increased slope of the current-voltage curve (Figure 2) with honeycomb structure under AM1.5G

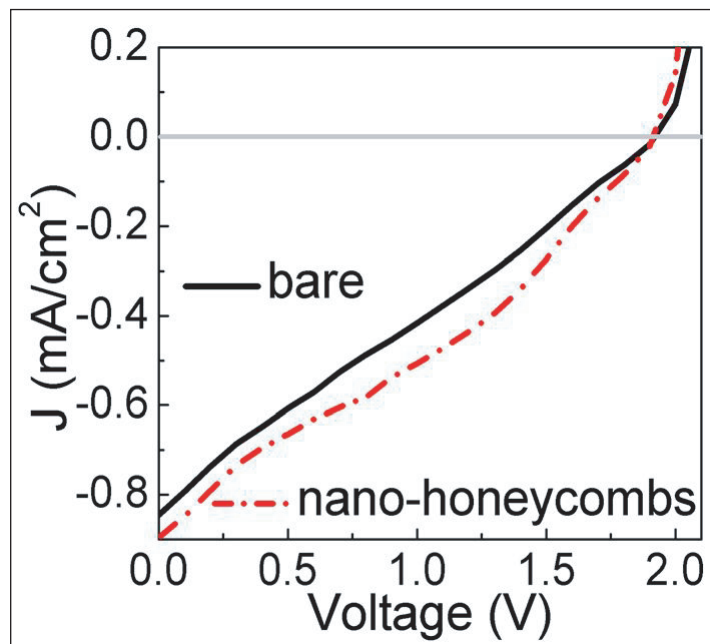


Figure 2. Current density-voltage (J-V) characteristics measured on MQW solar cells with

illumination indicates reduced series resistance, and thus a larger fill factor.

The leader of the team, Jr-Hau (JH) He, comments: "Since the fabrication process of SiO_2 honeycombs does not induce any damage to the internal device structures, the increased fill factor can be mainly attributed to the improved quality of the SiO_2 /ITO interface. Due to the dielectric properties of SiO_2 , the photo-generated carriers are more likely to be collected by the electrodes by the path inside the device (under ITO/GaN interface) instead of trapped by surface defects at the ITO surface." ■

<http://link.aip.org/link/doi/10.1063/1.3673838>

www.g-photonics.com/ENG/index.htm

Author: Mike Cooke

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All-silicon light emission through nanocrystal confinement

Silicon nanocrystal-based devices use technology developed for third-generation photovoltaics.

Researchers in Australia and Italy have demonstrated all-silicon light-emitting diodes (LEDs) using p-type silicon nanocrystals produced by material technology that has been developed for third-generation photovoltaics (PV) [Dawei Di et al, Appl. Phys. Lett., vol99, p251113, 2011]. The electroluminescence from the devices ranged from the visible to infrared, with emissions strongest at 750nm, 980nm

and 1150nm, depending on the barrier material (silicon dioxide or silicon nitride). The research team consisted of participants from University of New South Wales, University of Sydney, and University of Trento.

In bulk silicon (c-Si), the emission and absorption of light are severely constrained by the need to conserve crystal momentum of the electrons and holes. Emission is particularly difficult since the thermally excited

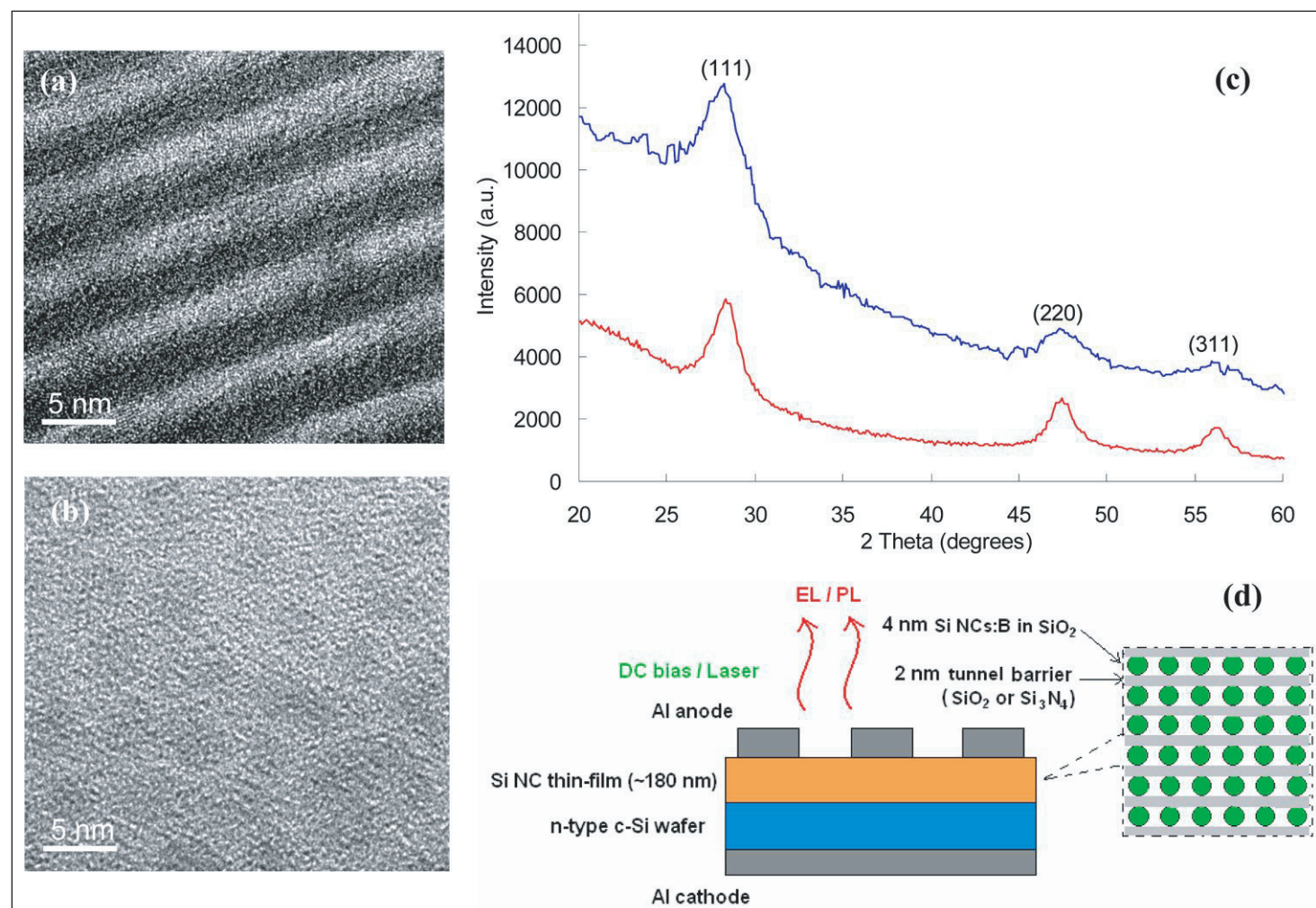


Figure 1. Structural information of materials and devices. HRTEM images of the samples with (a) Si₃N₄ barriers and (b) SiO₂ barriers. The dark stripes are Si₃N₄ barriers. The light grey areas correspond to SiO₂ and the dark grey 'clouds' are Si NCs. (c) XRD patterns of the samples with Si₃N₄ barriers (upper curve) and SiO₂ barriers (lower curve). (d) Schematic diagram of a Si NC/c-Si diode.

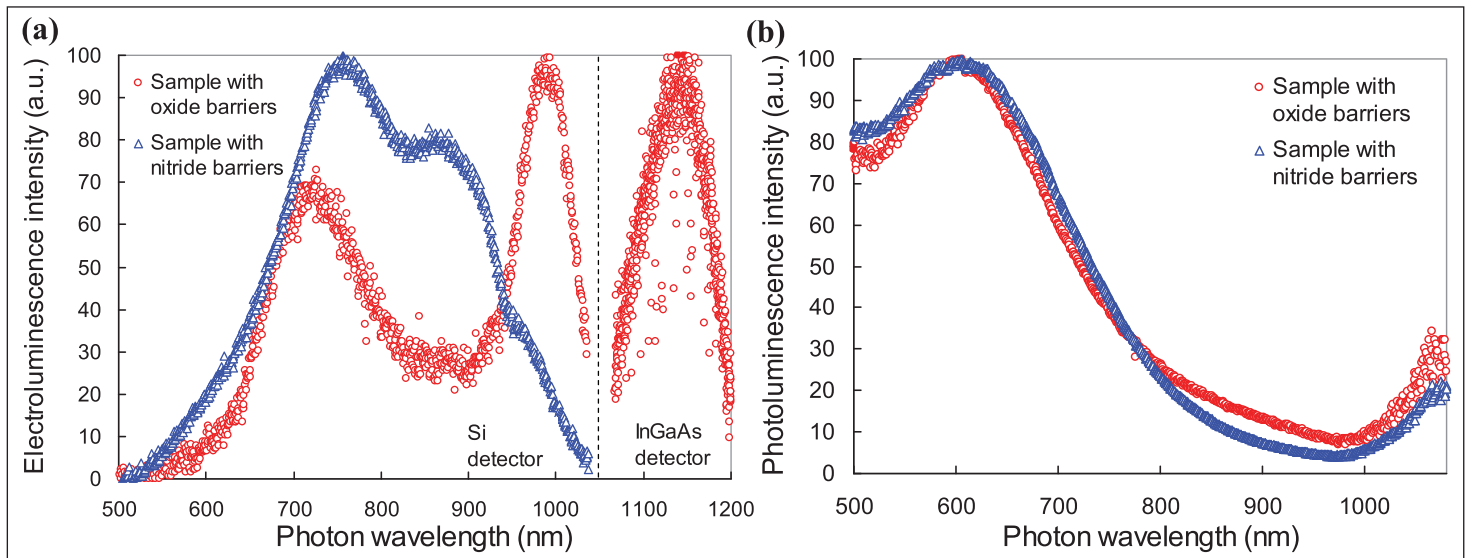


Figure 2. Normalized (a) electroluminescence and (b) photoluminescence spectra of Si NC/c-Si diodes with different barrier dielectrics (at room temperature ~ 300K).

holes and electrons have very different crystal momenta — that of the holes is around zero since the valence band has its peak there, but electrons gather in six valleys at the conduction band edge, away from zero. The normal LED process of electron–hole recombination producing a near-zero-momentum photon is thus very unlikely.

With Si nanocrystals (NCs), it is hoped to use quasi-particle confinement of electrons and holes to introduce momentum uncertainty (Heisenberg's $\Delta x \times \Delta p \geq h/2$) to improve probabilities for both absorption (PV) and emission (LED).

The device material (Figure 1) was constructed by RF sputtering of 30 bi-layers consisting of 2nm of silicon nitride (or silicon dioxide) and 4nm of boron-doped silicon-rich oxide (SRO) onto n-type silicon wafers. The boron doping gives p-type conduction in silicon. After the deposition, the material was annealed at 1100°C in nitrogen for 1 hour to create the silicon nanocrystals.

X-ray and electron microscope measurements gave typical sizes for the silicon nanocrystals of 3–5nm. Crystals in silicon dioxide (SiO_2) seem to be of better quality than those in silicon nitride (Si_3N_4), according to x-ray analysis.

Aluminum front and rear electrodes were deposited with windows cut on the nanocrystal side using photolithography techniques. A rather high series resistance was found in current–voltage measurements: 240Ω for the silicon dioxide structure and 100Ω for the silicon nitride. The high values are blamed on the multiple numbers of tunneling dielectrics and interfaces, along, possibly, with use of non-ideal metal contacts and current crowding due to unoptimized material structure and metallization.

Clear electroluminescence signals were seen with voltages exceeding 5V (Figure 2). The emissions fell in the 500–1200nm wavelength range, as detected by nitrogen-cooled silicon and indium gallium arsenide

charge-coupled detectors (CCDs). The short-wavelength end is blue-green and the long-wavelength end is infrared. The red/infrared border comes at ~740nm.

With the silicon dioxide barriers, the researchers see three main humps at 720nm, 980nm and 1150nm, with a weaker structure at ~870nm. The team ascribes the 1150nm peak to the crystalline bulk silicon. However, the 980nm peak is 0.145eV higher than the silicon bandgap of 1.12eV. The researchers associate the 720nm peak with nanocrystal transitions with a gap of almost 1.7eV.

The silicon nitride devices have a stronger peak at 750nm that is also associated with nanocrystals. The shift in wavelength is ascribed to the lower quantum confinement offered by silicon nitride (bandgap ~5.3eV) barriers, compared with silicon dioxide (~9eV). Also, with a lower barrier, carriers can tunnel into the nanocrystals more easily. A secondary peak in the silicon nitride device is seen at 870nm and the 980nm peak is very weak. No emissions were seen in the 1050–1200nm range of the InGaAs detector. It is thought that the higher tunneling probability could lead to a larger nanocrystal emission signal compared with other channels, enhancing the 750nm peak at the expense of the others.

Photoluminescence excited by a 409nm laser was also measured. The nanocrystal peak blue-shifted to the shorter wavelength of 600nm (2.06eV). The researchers say that they are still discussing the source of the shift.

The team says that the devices are far from optically and electrically optimized and that “their strengths and limitations are yet to be tested in further studies”. One of the first steps will be to study color tunability achieved through tailoring the nanocrystal sizes. ■

<http://link.aip.org/link/doi/10.1063/1.3671671>

Author: Mike Cooke

Growth-mode transition to higher UV output

Taiwan researchers use heavy silicon doping to block threading dislocations in ultraviolet nitride LEDs.

Researchers in Taiwan have used a heavily silicon-doped layer to improve the performance of ultraviolet light-emitting diodes (LEDs) [Shih-Cheng Huang et al, J. Appl. Phys., vol110, p123102, 2011]. The silicon doping created a growth-mode transition layer (GMTL) that was designed to bend or stop threading dislocations (TDs) in the nitride semiconductor material from affecting light emission.

It is thought that the incorporation of silicon in the undoped gallium nitride (GaN) partially relaxes residual stress arising from the large lattice mismatch with the sapphire substrate. The researchers also believe that the GMTL transforms the growth from a 'two-dimensional' (2D) layer-by-layer mode to a 3D 'island' mechanism.

In the latter mode, the TDs are reduced by growth that bends their orientation into a lateral direction.

The LEDs were grown on 2-inch c-plane sapphire using metal-organic chemical vapor deposition (MOCVD). The layers were designed for the emission of 375nm ultraviolet light (Figure 1). Aluminum gallium nitride (AlGaN) grown on a GMTL had TD densities reduced by an order of magnitude compared with layers grown without the GMTL; the density values were $8 \times 10^7/\text{cm}^2$ and $8 \times 10^8/\text{cm}^2$, respectively.

X-ray diffraction peaks also narrowed with GMTL material, indicating improved crystalline quality: the peak arising from the (002) plane was 270 arcsec with GMTL and 360arcsec without; and from the (102) plane the

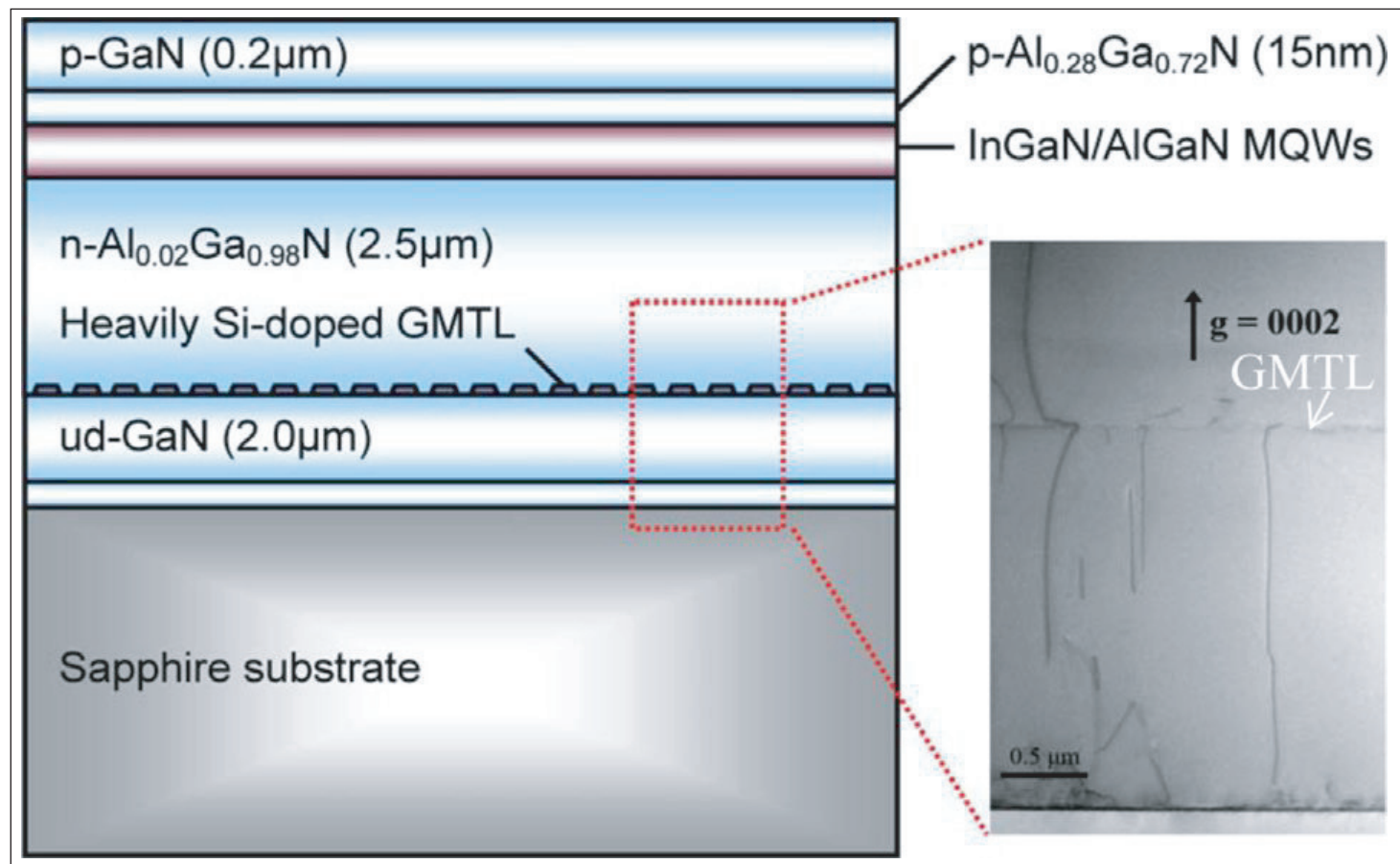


Figure 1. Schematic structure of UV-LEDs. Inset: TEM images show the effect of GMTL on threading dislocations. The multi-quantum well layer consisted of a ten-period structure with 3nm indium gallium nitride (3% indium) wells and 11nm aluminum gallium nitride (6% aluminum) barriers. A 30nm GaN buffer was grown before the undoped 2.0μm GaN layer. The GMTL was 50nm thick.

values were 380 arcsec and 460 arcsec, respectively.

For electroluminescence testing up to 1A (Figure 2), the devices were gold wire-bonded and packaged into TO-66 epoxy-free metal cans. At 350mA, the output powers were 286.7mW and 204.2mW for the GMTL and conventional devices, respectively, representing a 40.4% enhancement for the new device structure.

The researchers see applications for UV-LEDs coming from sensing, curing, and photocatalysis. Also, there is potential for white light with better color-rendering indices than the present blue-LED-pumped YAG-phosphor combination.

The research team consisted of participants from National Chung Hsing University, National Chiao-Tung University, Chung Yuan Christian University, Da-Yeh University, Advanced Optoelectronic Technology Inc., and National Cheng Kung University.

The internal quantum efficiency (IQE) of the epitaxial material structures was assessed through photoluminescence (PL) measurements at low temperature (20K) and room temperature. The dependence of the IQE values varied with excitation carrier density. The peak IQE value was assumed to be 100% at 20K. This peak occurred around $10^{16}/\text{cm}^3$.

The researchers describe the decrease in IQE at 20K beyond the peak as being similar to the droop phenomenon that reduces the external quantum efficiency of visible LEDs at high current injection. The researchers comment: "According to our experimental data, we infer that the low-temperature IQE decrease at high excitation carrier density is due to the carrier overflow and dislocation density."

Spectral measurements of PL intensity at 20K give a main peak at 375nm and a shoulder at 380nm at higher excited carrier densities that is attributed to

overflow into the p-AlGaIn layer. At room temperature, there is no shoulder. Although the electroluminescence peaks are no doubt in this region, the presence of electric fields and free charge carriers tends to shift the emission wavelength as the current changes.

The room temperature IQE of the LED with GMTL was enhanced by 40.6% over that of the conventional device. The peak IQE occurred at higher carrier densities beyond $10^{17}/\text{cm}^3$. The peak IQE of the GMTL device was around 45%.

Electrically, the reverse current is reduced by the presence of the GMTL layer to $0.005\mu\text{A}$ at 5V, compared with $0.048\mu\text{A}$ for the conventional LED. This also indicated improved material quality. ■

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www.aot.com.tw/en/index.htm

Author: Mike Cooke

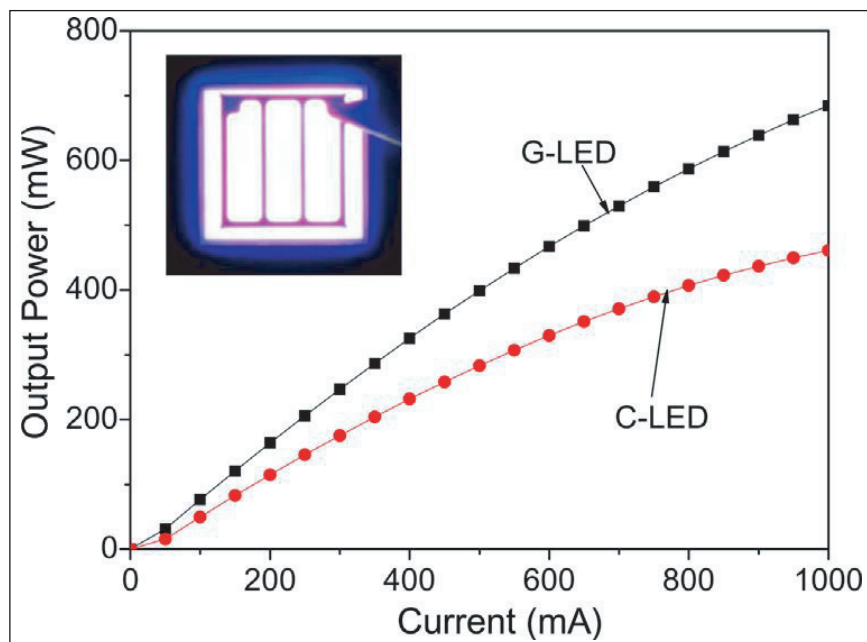


Figure 2. LED output power vs injection current for GMTL and conventional LEDs. Inset: photograph of GMTL LED at an injection current of 350mA.

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SiO₂/GaN nano-rods give new base for high light output

Growing LEDs on nano-rods reduces dislocations and boosts light generation, while reflective air-void layer improves light extraction.

National Chiao Tung University researchers in Taiwan have improved nitride semiconductor light-emitting diode (LED) performance by growing the structures on silicon dioxide on gallium nitride (SiO₂/GaN) nano-rods [Ching-Hsueh Chiu et al, *Nanotechnology*, vol23, p045303, 2012]. The effect is to produce nano-scale epitaxial lateral overgrowth (NELOG) material with lower densities of dislocations, boosting light generation, and to create a reflective bottom layer of air-voids that improves light extraction through the top of the device.

At 20mA, devices grown on nano-rods reduce the forward voltage to 3.37V and have light output power of 21.6mW, compared with a conventional device that offers 3.47V and 13.1mW, respectively. The researchers believe that improved material quality (i.e. reduced dislocations) and light extraction explain these results. A reduction in dislocation densities is also suggested by a reduced reverse-bias leakage current. Simulations suggest a 1.45x enhancement in light extraction from reflection by the nano-rod layer. Measurements gave a smaller boost of around 30% (1.3x), which

Cap	p-GaN	0.2μm
Multi-quantum well	10x(InGaN/GaN)	
Contact	n-GaN	3μm
Nanorods	SiO ₂ /GaN	2.2μm
Substrate	Sapphire	

Figure 1. Epi structure grown on SiO₂/GaN nano-rods.

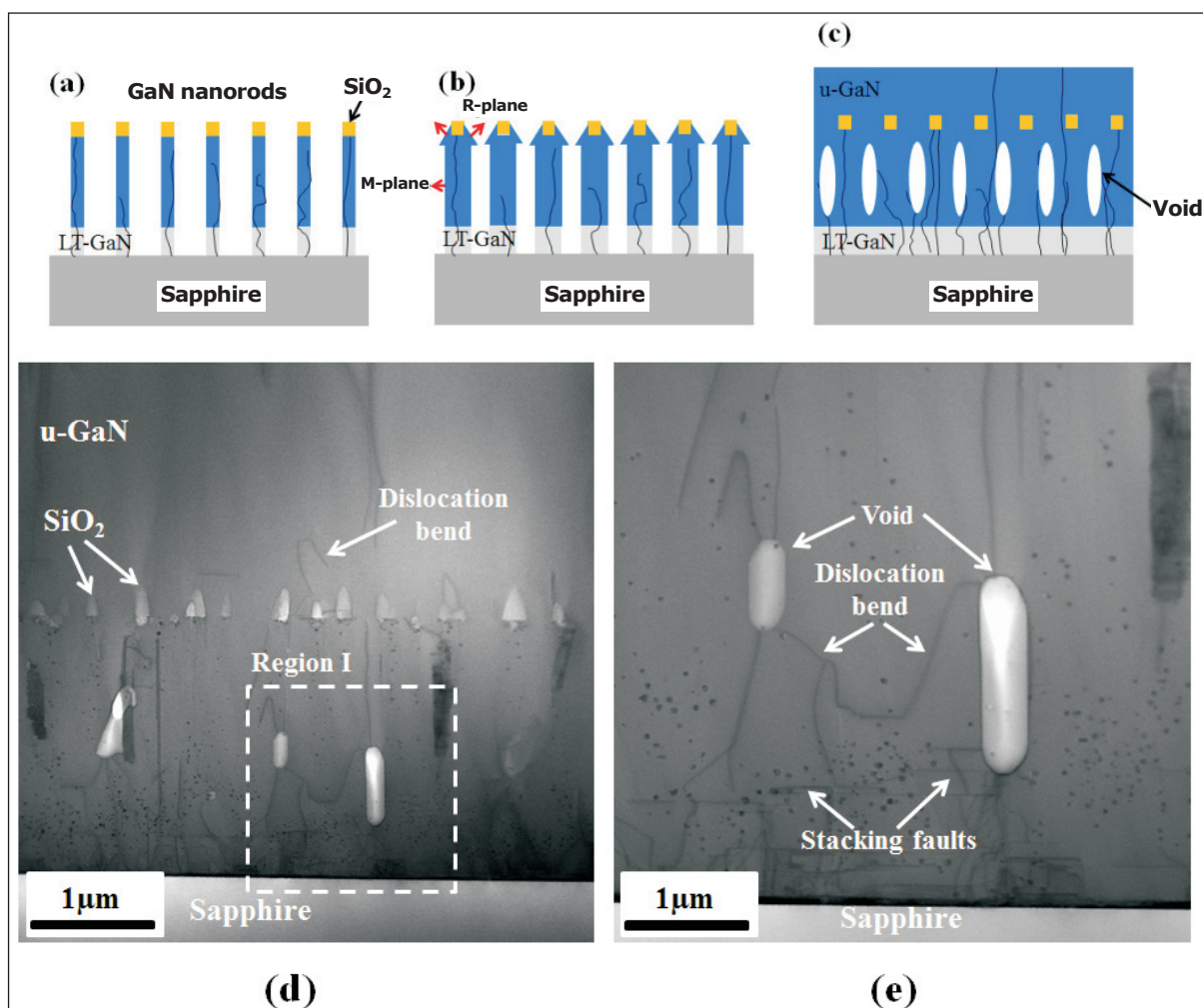


Figure 2. Procedure for air-void formation between a GaN NRs and u-GaN epitaxial layer. (d) TEM image of GaN epilayer overgrowth on GaN NRs, (e) HRTEM image of region I in (d). The diffraction condition is $g = 0002$.

the researchers suggest may be due to imperfections of the air-void shapes and sizes, compared with a simulation.

The nano-rods/air-voids are formed by first plasma-enhanced chemical vapor depositing 200nm SiO₂ on a 2µm GaN-on-sapphire layer, followed by evaporation of a 10nm nickel mask. The structure was then annealed at 850°C for one minute. The 250–500nm diameter nano-rods (NRs) were formed by reactive ion etch of the SiO₂ (carbon tetrafluoride, 3min) and inductively coupled plasma etch of the GaN (chlorine/argon, 34min). A heated nitric acid dip was used to remove nickel residue.

The process resulted in a nano-rod density of $3.3 \times 10^8/\text{cm}^2$.

Photoluminescence measurements were used to derive internal quantum efficiencies (IQEs) of 46% for the conventional LED and 53% for the air-void device (a15% enhancement). Combining this with the simulated improvement in light extraction of 1.45x gives a 67% increase in performance, compared with the measured result of 65%

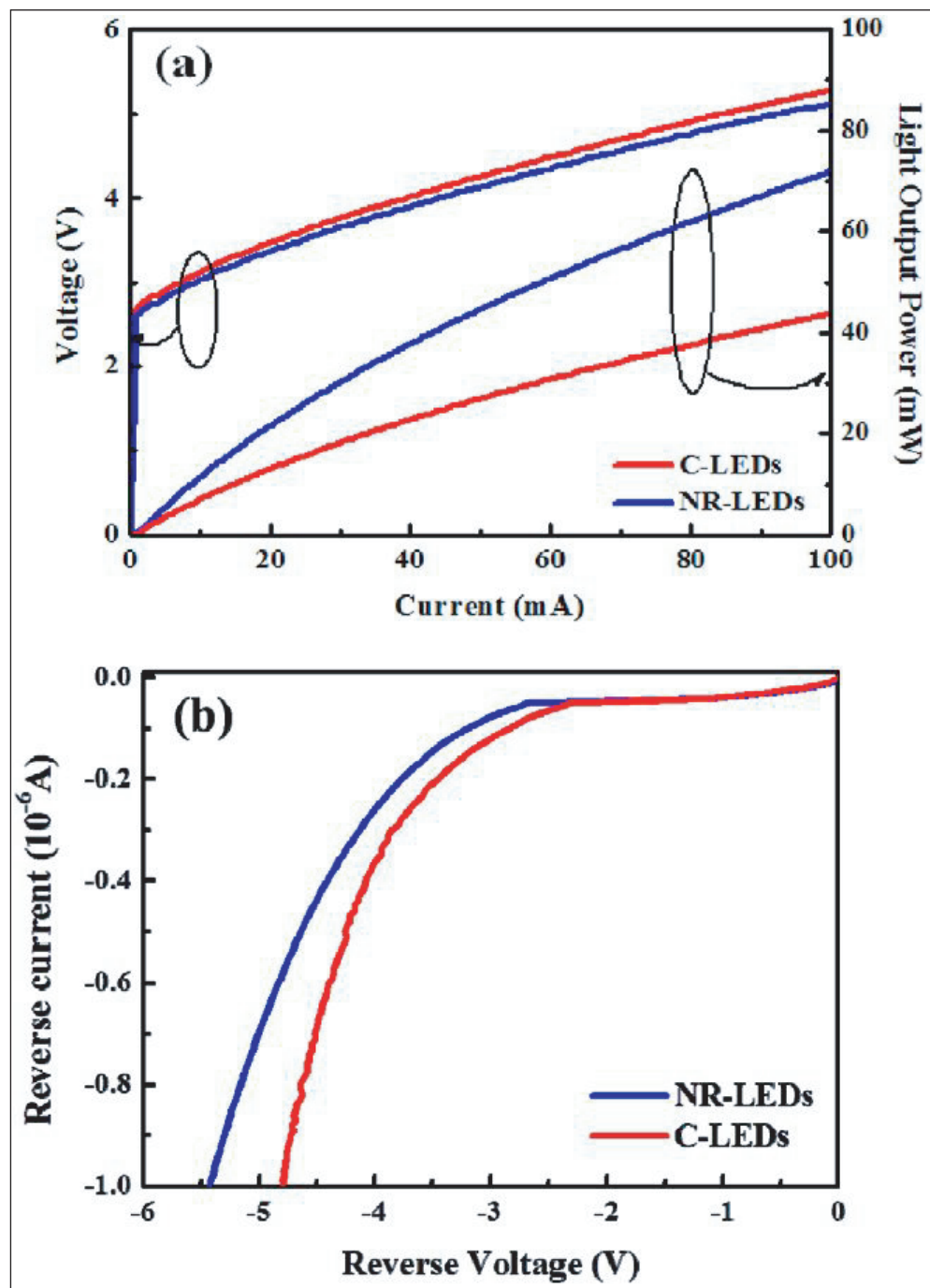


Figure 3. (a) Forward voltage and light output power characteristics with drive current of fabricated LEDs. (b) Reverse voltage characteristics.

Further nitride semiconductor layers (Figure 1 and 2) were then grown on the nano-rods using a Veeco metal-organic chemical vapor deposition (MOCVD) system. Comparison devices without nano-rods were also produced.

One effect of growing epitaxial layers on the nano-rods was to reduce threading dislocation densities (TDDs) to around $5 \times 10^7/\text{cm}^2$. Electron microscopy suggested that the TDD reduction can be attributed to misfit and dislocation bending just above the air-voids. Also, Raman scattering analysis that reveals phonon/sound-wave characteristics and hence stress in the material showed a reduction in residual stress in the epitaxial

GaN from 1.73GPa in material without air-voids to 0.88GPa with air-voids.

Photoluminescence measurements were used to derive internal quantum efficiencies (IQEs) of 46% for the conventional LED and 53% for the air-void device (a15% enhancement). Combining this with the simulated improvement in light extraction of 1.45x gives a 67% increase in performance, compared with the measured result of 65% ($1.65 = 21.6/13.1$). ■

<http://iopscience.iop.org/0957-4484/23/4/045303/>
The author Mike Cooke is a freelance technology journalist who has worked in the semiconductor and advanced technology sectors since 1997.

Increased mobility and reduced residual electron concentration indium nitride

Boundary-controlled temperature molecular beam epitaxy yields best performance so far for indium nitride.

Researchers based in China and Germany have used boundary-controlled temperature molecular beam epitaxy (MBE) to improve indium nitride (InN) quality, giving the best mobility and residual electron concentration figures achieved so far [Xinqiang Wang, *Appl. Phys. Express*, vol5, p015502, 2012]. The work was carried out by researchers at Peking University, Hong Kong University of Science and Technology, Helmholtz-Zentrum Dresden-Rossendorf (HZDR),

Direct measurements of Hall characteristics of the InN material varied with layer thickness (Figure 1a), giving an increase in mobility and decrease in electron concentration. At 5 μm , the Hall mobility reaches 3010 $\text{cm}^2/\text{V}\cdot\text{s}$ and the residual electron concentration is $1.77 \times 10^{17}/\text{cm}^3$. These values compare with previous reports of 2370 $\text{cm}^2/\text{V}\cdot\text{s}$ electron mobility and down to $3 \times 10^{17}/\text{cm}^3$ residual electron concentration.

Temperature-dependent measurements were also carried out on the 5 μm InN layer between 120K and 500K. At the lowest temperature, the mobility reached 4370 $\text{cm}^2/\text{V}\cdot\text{s}$.

InN has a narrow bandgap of 0.63eV and low effective mass for the electron of about 0.055 that of the free-space value. Low effective masses tend to be associated with high mobility. However, growing high-quality InN is a challenge.

Defects, impurities, non-uniformities etc reduce mobility through electron scattering effects and tend to increase the number of electrons in the conduction band. Achieving p-type conductivity through holes in the valence band is difficult to achieve in nitride semiconductors anyway, and large numbers of residual electrons just makes it harder.

One of the major spurs to InN study is the prospect of the wide electromagnetic wavelength range potentially accessible to alloys of the InN ($\sim 1970\text{nm}$, infrared),

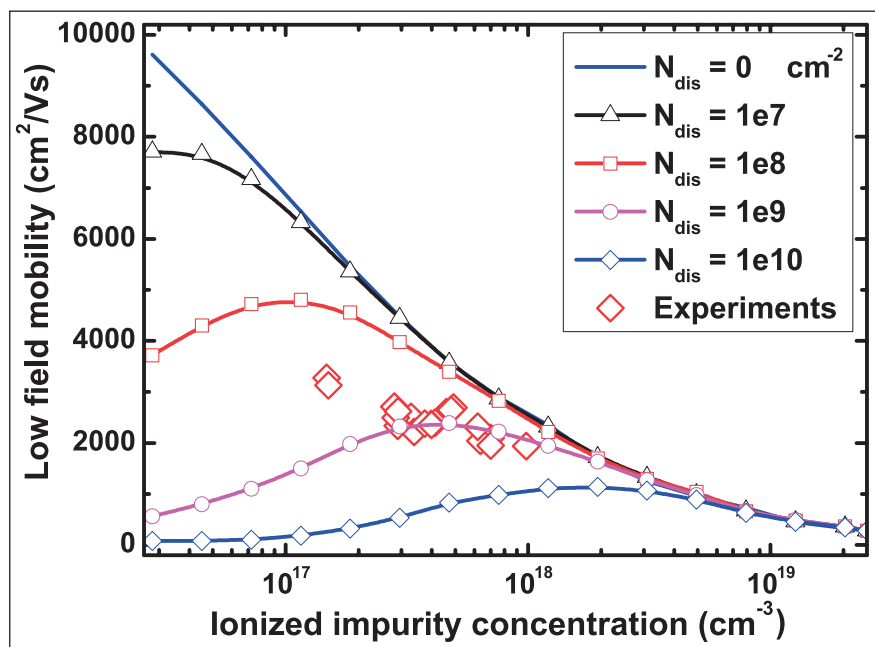


Figure 1. (a) Directly measured Hall mobility (diamonds) and residual electron concentration (circles) of InN layers as functions of layer thickness. Lines are merely guides for the eye. (b) Temperature-dependent mobilities and (inset) electron concentrations: solid squares are directly measured values and solid triangles are extracted values for InN bulk layer. Solid line is ensemble Monte Carlo (EMC) result. Electron concentration in bulk layer is fitted by standard single shallow-donor.

gallium nitride (3.4eV \sim 365nm, ultraviolet), aluminum nitride (6.2eV \sim 200nm, deep UV) semiconductor material system. The higher mobility of up to 3010 $\text{cm}^2/\text{V}\cdot\text{s}$ is also attractive for high-speed electronics. Bulk mobility in gallium nitride is usually less than 1000 $\text{cm}^2/\text{V}\cdot\text{s}$. Higher values can be attained in confined 'two-dimensional electron gas' (2DEG) structures at nitride semiconductor interfaces.

InN grows at best quality in MBE when the temperature is maintained close to the maximum before dissociation at around 500 $^{\circ}\text{C}$. MBE growth temperatures for the other nitride semiconductors are higher (typically at least 700 $^{\circ}\text{C}$ for gallium nitride, more than 800 $^{\circ}\text{C}$ for

aluminum nitride). Temperature control using a thermocouple is tricky since, as the material grows, the location of the temperature reading recedes from the growth front. Hence one has to reduce the temperature of the thermocouple reading control point to maintain 500°C at the growth point.

The Peking/Hong Kong/HZDR InN layers were grown with a GaN buffer on sapphire by MBE using an SVT Associates system. Buffer layers grown both by MBE and metal-organic chemical vapor deposition (MOCVD) were used. Indium-rich conditions were used for InN growth.

In addition to the direct measurements quoted earlier, the researchers also sought to correct the characteristics for the electron-accumulation effect that has been found for InN layers. This effect results in electrons collecting on the surface of the material, affecting measurements of mobility and conductivity.

Peking University has recently measured the properties of the surface electron-accumulation layer, and these results were used to extract bulk values (Figure 1b). The room-temperature value for bulk mobility was increased to 3280cm²/V-s and residual electron concentration reduced to 1.47x10¹⁷/cm³.

The temperature-dependent bulk mobility results were also modeled using an ensemble Monte Carlo (EMC) that included scattering effects from polar optical phonons, deformation potential and piezoelectric-mode acoustic phonons, ionized impurities, neutral impurities and threading dislocations. The electron concentration was fitted using a standard single shallow-donor level. A deep donor would not fit the results.

Further simulations suggest that with zero dislocations the mobility could reach ~10000cm²/V-s when the electron densities from ionized impurities were less than 10¹⁶/cm³ (Figure 2). In the more realistic situation of 10¹⁷–10¹⁸/cm³ densities, the mobility ranges between 6900cm²/V-s and 2600cm²/V-s. The adding of dislocation scattering mainly affects mobility at lower electron densities.

The researchers comment: "From the theoretical result shown in Figure 2, we can see that it is very important to reduce the density of dislocations and electron concentration to improve the electron mobility."

Comparison of the simulation with the experimental results for layers with thickness greater than 0.5μm shows comparability with the values for dislocation densities of 10⁹/cm². This dislocation level is slightly lower than that suggested by x-ray diffraction analysis,

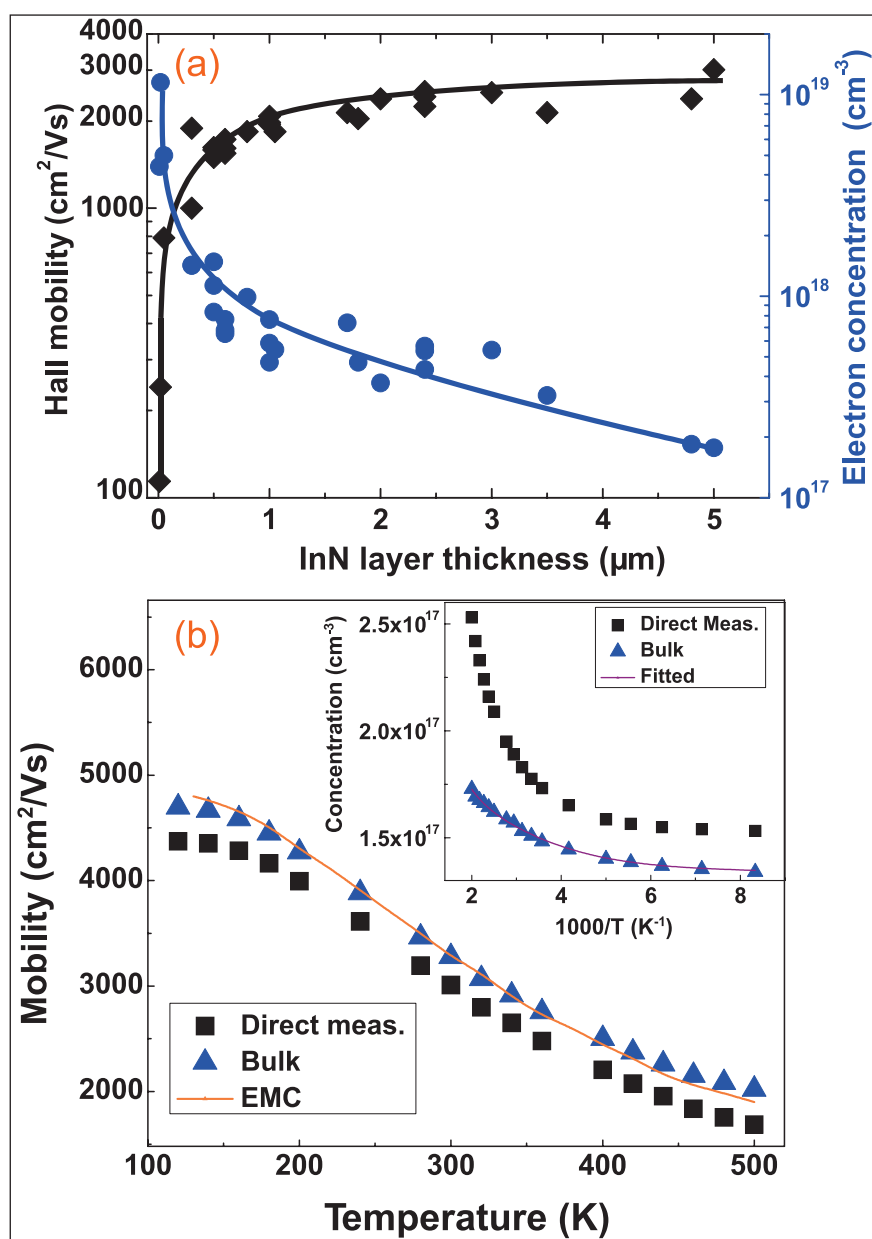


Figure 2. Calculated low-field electron mobility in InN as function of ionized impurity concentration at different dislocation density (N_{dis}) levels. Experimental results are bigger open diamonds.

possibly due to only partial ionization of the dislocations.

Further x-ray analysis showed that the effect of growing thicker InN layers was to reduce the width of diffraction peaks, suggesting better crystal quality. The full-width at half-maximum (FWHM) of the peak from the symmetric (002) plane reduced from 900arcsec at 0.5μm thickness to 250arcsec at 5μm. The asymmetric (102) plane had a FWHM of 1600arcsec at 0.5μm and 820arcsec at 5μm.

"This implies that the densities of both the screw- and edge-component threading dislocations are reduced with increasing thickness, which is most likely the main reason for the reduction of electron concentration and improvement of electron mobility," the researchers write. ■

<http://apex.jsap.jp/link?APEX/5/015502>

Author: Mike Cooke

Aluminum oxide passivation reduces off-current in AlN/GaN transistors

Leakage current decreased by almost four orders of magnitude in MOSHFET compared with a Schottky-gate FET device.

Hong Kong University of Science and Technology has used aluminum oxide (Al_2O_3) gate dielectric and passivation on aluminum nitride/gallium nitride (AlN/GaN) transistors to reduce off-state leakage currents by almost four orders of magnitude [Tongde Huang et al, IEEE Electron Device Letters, published online 27 December 2011].

High-quality AlN/GaN structures have only recently become available in metal-organic chemical vapor deposited form (as opposed to that from molecular beam epitaxy). Their advantage lies in the material polarization contrast between AlN and GaN offering higher two-dimensional electron gas densities (2DEGs) than AlGaIn/GaN or InAlN/GaN. In addition, researchers have been able to grow AlN/GaN on silicon substrates, promising lower-cost products.

In comparison with Schottky heterostructure field-effect transistors (HFETs, i.e. without gate insulation), the off-state drain current leakage was reduced in the metal-oxide-semiconductor HFET (MOSHFET) by almost four orders of magnitude from $2.5 \times 10^{-1} \text{mA/mm}$

(HFET) to $7.6 \times 10^{-5} \text{mA/mm}$ (MOSHFET) at 6V drain bias. This increased the on/off current ratio ($I_{\text{on}}/I_{\text{off}}$) to 10^8 (measured at gate potentials of +2V and -5V, respectively). The maximum drain current and peak transconductance were 745mA/mm and 280mS/mm, respectively.

The nitride semiconductor heterostructure for the MOSHFET was grown on (111) silicon using MOCVD (Figure 1). The superlattice interlayer, designed to relax strain in the structure, consisted of some 9 periods of alternate layers of 6nm of AlN and 28nm $\text{Al}_{0.19}\text{Ga}_{0.81}\text{N}$ to make 300nm. Room-temperature Hall measurements gave a mobility of $1050 \text{cm}^2/\text{V-s}$ and an electron density of $1.44 \times 10^{13}/\text{cm}^2$. These factors combine into a sheet resistance of $415 \Omega/\text{sq}$.

The MOSHFETs were processed by beginning with etch of the isolation mesa and deposition and annealing of titanium/aluminum/nickel/gold source-drain electrodes. The annealing was at 850°C and gave contact resistance values of $0.34 \Omega\text{-mm}$ and a specific contact resistance of $3.7 \times 10^{-6} \Omega\text{-cm}^2$. The surface was

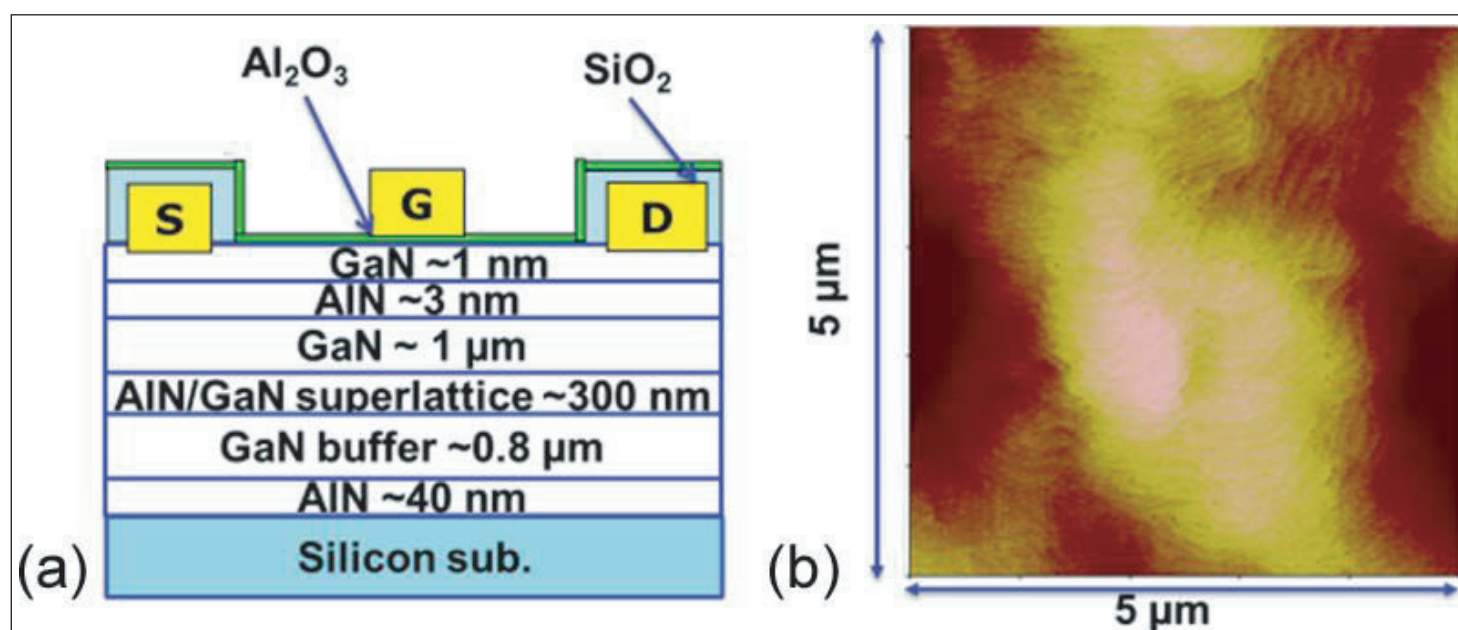


Figure 1. Cross-sectional schematic of the AlN/GaN MOSHFETs (a), and AFM image of AlN surface (b).

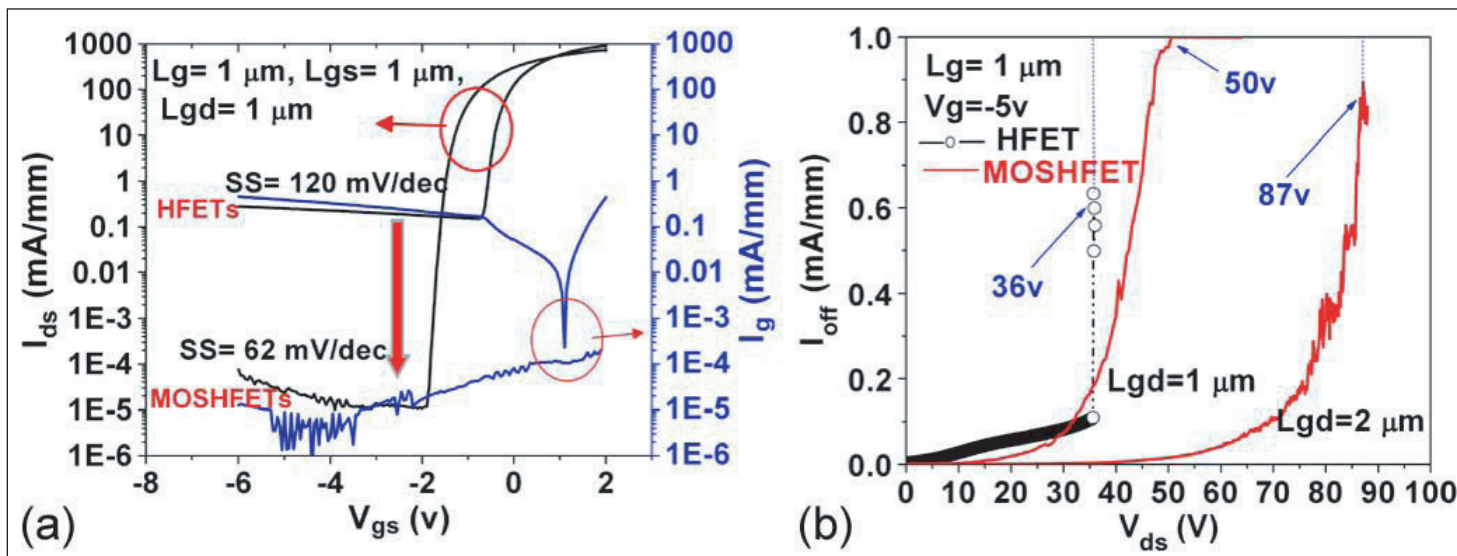


Figure 2. (a) Semilog transfer curves of drain current and gate leakage current in HFETs and MOSHFETs. (b) Breakdown voltage curves of HFETs with gate-drain distance (L_{gd}) of $1\mu\text{m}$ and MOSHFETs with distances of $1\mu\text{m}$ and $2\mu\text{m}$.

covered with silicon dioxide to protect the atomic layer deposition (ALD) chamber from metal contamination during the growth of the amorphous aluminum oxide dielectric layer. The silicon dioxide in the active gate region was removed before aluminum oxide deposition.

Finally the gate electrode (consisting of nickel/gold) was deposited. The gate length was $1\mu\text{m}$ and the gate-source spacing was also $1\mu\text{m}$.

The aluminum oxide passivation layer is seen as an essential component of AlN/GaN devices since the thinness of the AlN layer makes the 2DEG channel particularly sensitive to surface states. Devices produced without aluminum oxide passivation suffered from current and transconductance degradation during repeated sweeps of the gate-voltage characteristics with drain bias of 6V. Eventually, the drain current and transconductance were not measurable. The effect is due to electrons being trapped in the surface states, but not being released in time to restore the device performance. This negative charge depletes the 2DEG cutting off drain current flow.

The researchers report: "We found that this degradation phenomenon could be completely eliminated by adding an Al_2O_3 passivation layer on the transistor surface."

In addition, the aluminum oxide insulates the gate electrode. The researchers also tested transistors with silicon nitride passivation, which has also been found effective in eliminating current degradation.

Comparisons between aluminum oxide and silicon nitride passivation showed increased current with thicker Al_2O_3 layers, the enhancement saturating around 15nm thickness. With 7nm aluminum oxide, the current was higher than that given by 15nm silicon nitride. The researchers conclude that Al_2O_3 is a better candidate for passivation than SiNx .

Direct current characteristics were also compared

with 500 μs pulses applied to the gate of Al_2O_3 passivated devices once a second from a -4V base condition where the device is pinched off. The current is only slightly lower in the pulsed measurements at low drain bias. At higher biases, the current was actually higher than the DC condition, likely due to self-heating during measurement releasing charge from the trap states. By contrast, unpassivated devices suffer from significantly reduced current in pulsed operation. Another advantage of the passivation is more uniform performance between devices.

The effect of Al_2O_3 layer thickness on the 2DEG Hall measurements was an increase in electron density above 7nm to almost $3 \times 10^{13}/\text{cm}^2$. However, the mobility was reduced to around $600\text{cm}^2/\text{V}\cdot\text{s}$. The combined effect was a slight reduction in sheet resistance.

The researchers explain these results: "The proposed mechanism for the increased 2DEG density is the positive charges in the dielectric/semiconductor interface and stress due to the deposited Al_2O_3 . The mobility drop after Al_2O_3 passivation may be a result of increased scattering among interfacial charges and electrons."

Perhaps one of the most impressive results was a sub-threshold slope of 62mV/dec, which is close to the theoretical limit for planar MOSHFET structures at room temperature (300K). By contrast, the Schottky gate device had a sub-threshold value of 120mV/dec. The researchers comment: "The improved SS obviously is also due to the large $I_{\text{on}}/I_{\text{off}}$ ratio in the MOSHFETs."

The MOSHFET also had improved breakdown characteristics. With a gate-drain distance of $1\mu\text{m}$, the breakdown at gate potential of -5V (BV_{off}) was 36V for the HFET and 50V for the MOSHFET. Increasing the gate-drain distance improved the MOSHFET breakdown to 87V. ■

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Author: Mike Cooke

IMEC/AMAT produce first crack-free MOCVD nitride DH-structures on 200mm Si

IMEC and Applied Materials reduce wafer bowing to under 20 μm for AlGaN double heterostructures compatible with CMOS processing.

IMEC and Applied Materials researchers say that they have shown for the first time that it is feasible to grow crack-free aluminum gallium nitride (AlGaN) double heterostructures (DH) with thick AlGaN buffer layers on 200mm silicon (Si) substrates using metal-organic chemical vapor deposition (MOCVD) [Kai Cheng et al, Appl. Phys. Express, vol5, p011002, 2012]. Such DH structures are aimed at producing field-effect transistors (DHFET) with high breakdown voltage for

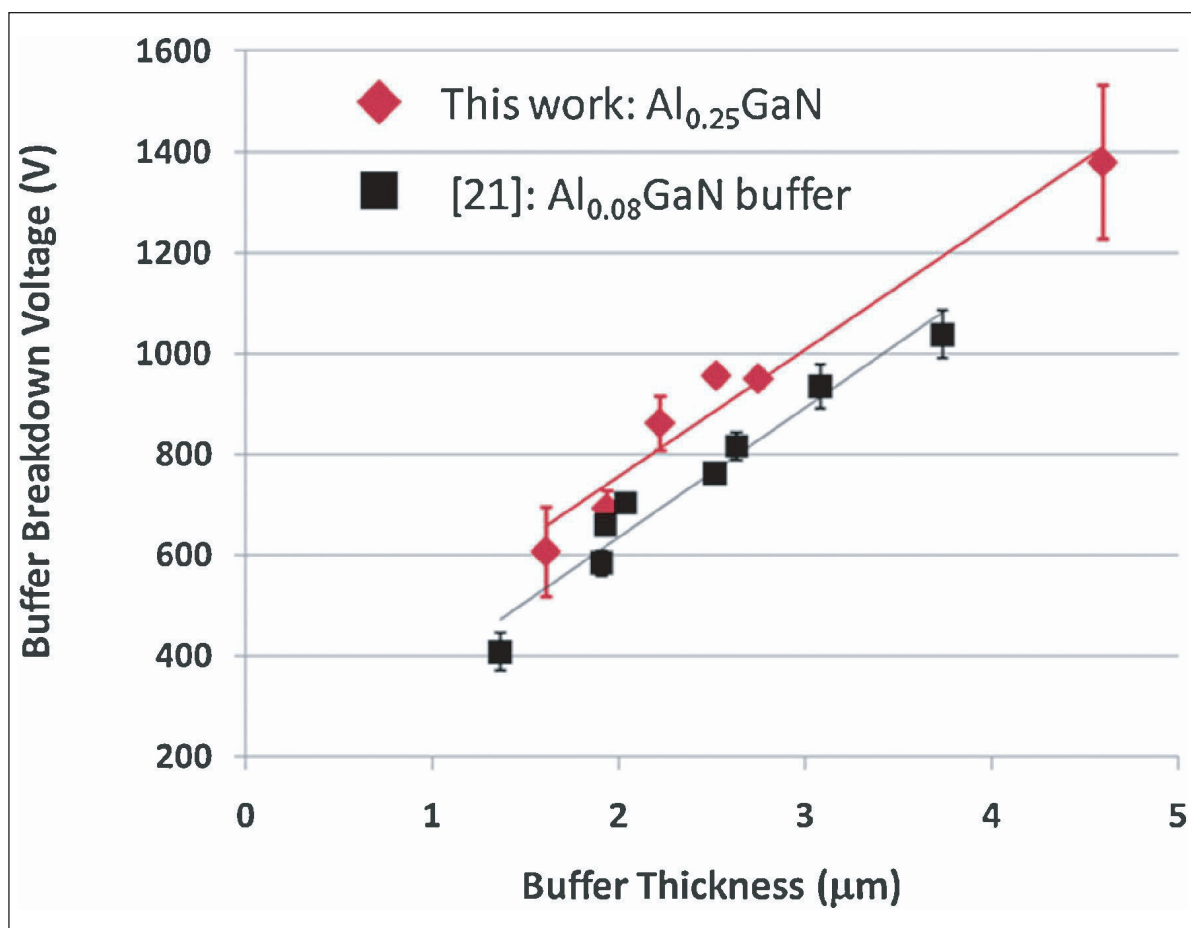


Figure 1. Buffer breakdown voltage versus total layer thickness. The comparison with the paper's ref. [21] is with previous IMEC/Katholieke Universiteit Leuven work published in 2009.

Table 1. Overview of characterization results of Sample Series A and B.

Sample	$\text{Al}_{0.5}\text{Ga}_{0.5}\text{N}/\text{Al}_{0.75}\text{Ga}_{0.25}\text{N}$ thickness (nm)	$\text{Al}_{0.25}\text{Ga}_{0.75}\text{N}$ thickness (nm)	Wafer bow (μm)	$\text{Al}_{0.25}\text{Ga}_{0.75}\text{N}$ (002)	$\text{Al}_{0.25}\text{Ga}_{0.75}\text{N}$ (102)
A1	200/200	970	67	777	1029
A2	200/200	1260	73	700	934
A3	200/200	1590	59	653	843
A4	200/200	1870	38	645	840
B1	400/400	1900	13	539	1020
B2	600/600	3170	130.1	499	914

next-generation power switching devices.

In creating DH wafers, the researchers were particularly keen to reduce wafer-bowing effects to less than 50 μm , since that is the limit set by equipment designed for mainstream silicon complementary metal-oxide-semiconductor (CMOS) integrated circuit mass production.

Double heterostructures of $\text{Al}_{0.35}\text{Ga}_{0.65}\text{N}/\text{GaN}/\text{Al}_{0.25}\text{Ga}_{0.75}\text{N}$ were grown on 200mm Si(111) wafers using an Applied Materials shower-head reactor. A 220nm AlN nucleation layer was grown first, followed by two intermediate layers of $\text{Al}_{0.75}\text{Ga}_{0.25}\text{N}$ and $\text{Al}_{0.5}\text{Ga}_{0.5}\text{N}$, before the thick buffer of $\text{Al}_{0.25}\text{Ga}_{0.75}\text{N}$. The purpose of the intermediate layers was to counter-balance thermal tensile stress in the nitride layers imposed by the silicon substrates.

Previous work with only a single intermediate layer of $\text{Al}_{0.45}\text{Ga}_{0.55}\text{N}$ had a radius of curvature of wafer bowing out to 40 meters, but this needed to be extended further to beyond 100 meters to meet the 50 μm specification. With GaN buffer layers, it had been found that a single $\text{Al}_{0.5}\text{Ga}_{0.5}\text{N}$ layer allowed 2.3 μm -thick GaN wafers to be produced with less than 20 μm wafer bowing.

The new work introduces a second stress management layer of $\text{Al}_{0.75}\text{Ga}_{0.25}\text{N}$ to allow growth of thick (more than 1 μm) $\text{Al}_{0.25}\text{Ga}_{0.75}\text{N}$, as needed to achieve high breakdown voltage in the DHFET. A series of experiments was carried out (Table 1) to optimize the buffer growth thickness, material quality and wafer bowing.

With 200nm-thick intermediate layers (samples A1–4), the material quality indicated by x-ray diffraction rocking curves (sample A4) is comparable with previous results on smaller 4-inch diameter silicon wafers and the best values in the literature. Samples B with thicker intermediate layers were tested with thicker buffer layers, as needed for high breakdown voltage (Figure 1). While sample B2 had the highest breakdown voltage at 1380V, it also has a large concave bowing parameter. Positive bow indicates convex surfaces.

The DHFET material was also tested for mobility and carrier concentration of the two-dimensional electron gas (2DEG) of the channel, using van der Pauw

In situ passivation	SiN	1nm
Barrier	$\text{Al}_{0.35}\text{Ga}_{0.65}\text{N}$	10nm
Channel	GaN	150nm
Buffer	$\text{Al}_{0.25}\text{Ga}_{0.75}\text{N}$	1.87 μm
Intermediate	$\text{Al}_{0.5}\text{Ga}_{0.5}\text{N}$	400nm
Intermediate	$\text{Al}_{0.75}\text{Ga}_{0.25}\text{N}$	400nm
Nucleation	AlN	220nm
Substrate	Si (111)	

Figure 2. DHFET structure.

Hall measurements. The average electron mobility was $\sim 1766\text{cm}^2/\text{V}\cdot\text{s}$ and the carrier concentration $1.16 \times 10^{13}/\text{cm}^2$. These values result in a low sheet resistance of 306 Ω/sq . "These values even outperform the ones obtained on 150mm silicon substrates," the researchers write.

DHFETs (Figure 2) were produced based on buffers grown as for sample B1, which has a breakdown voltage above 950V. After the buffer, a 150nm GaN channel and a 10nm $\text{Al}_{0.35}\text{Ga}_{0.65}\text{N}$ barrier were grown. Finally, a Si_3N_4 layer was grown to stabilize and passivate the $\text{Al}_{0.35}\text{Ga}_{0.65}\text{N}$ surface. Processed devices delivered currents up to 0.65A/mm. "More detailed device results will be published elsewhere," the team promises.

The paper concludes: "GaN-based power devices grown on 200mm Si substrates show great potential for integrating GaN processing on a standard silicon technology platform." ■

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Compound semiconductor logic development intensifies

The International Electron Devices Meeting in December contained a wide range of compound semiconductor developments. Here, **Mike Cooke** reports on efforts towards large-scale integration of high-performance logic and analog devices based on compound semiconductor materials.

Complementary metal-oxide semiconductor (CMOS) transistors face an increasing number of short-channel effect (SCE) challenges as manufacturers and consumers continue to expect smaller, faster and more efficient devices from technology developers. Devices with III-V and germanium channels are attractive for increasing speed performance and decreasing power waste over mainstream logic devices using silicon channels. However, these devices also suffer from their own SCEs, such as poor values of off-state leakage, subthreshold swing and drain-induced barrier lowering.

Mobility enhancement

Researchers from the University of Tokyo, NAIST and Sumitomo Chemical Co Ltd reported on two types of mobility enhancement for InGaAs channels: strain and MOS interface buffer engineering [session 13.4]. These options are being explored to enable III-V channels to be implemented in extremely-thin-body (ETB) structures, as needed to tackle such SCEs.

The strained devices (Figure 1a) were produced with biaxial strain using a relaxed substrate buffer layer under the channel. A similar technique has been used with silicon on a relaxed SiGe layer.

The InGaAs devices were grown on InP substrates. The InGaAs buffer layers were 500nm and had various In contents of 0.5, 0.53 (lattice matched to InP) and 0.6. The channel layer consisted of 20nm of InGaAs with In content 0.53. The lattice mismatch with the buffer was used to stress the channel. X-ray diffraction analysis gave strain values of -0.23% (compression) and $+0.46\%$ (tension) for channels grown on 0.5-In and 0.6-In buffers, respectively.

This strained epitaxial material was used to create self-aligned source-drain MOSFETs. The tensile-strained

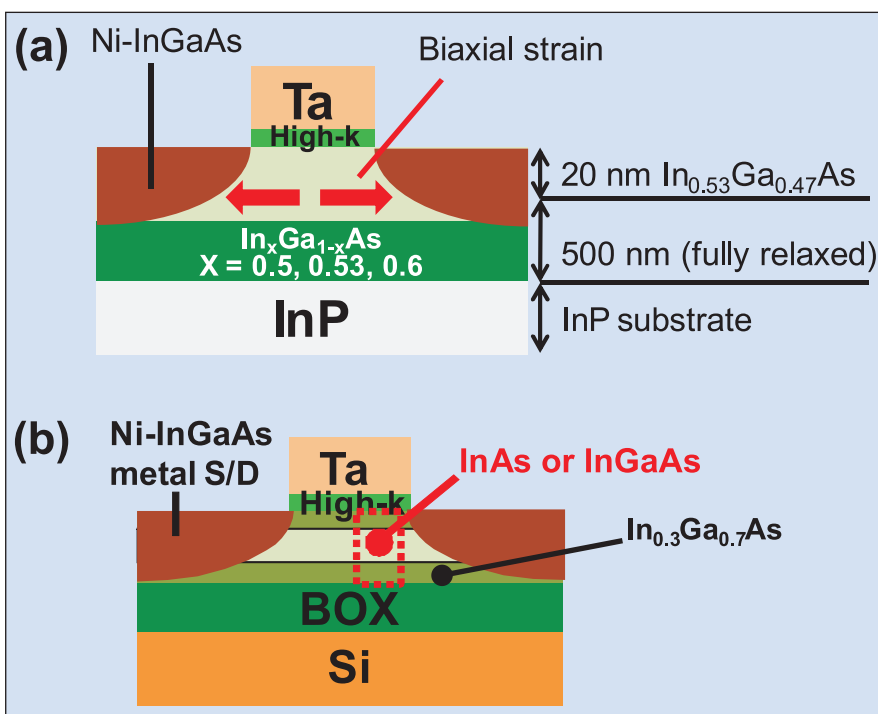


Figure 1. (a) Schematic of University of Tokyo/NAIST/Sumitomo strained $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ MOSFETs on $\text{In}_x\text{Ga}_{1-x}\text{As}$ relaxed layer. (b) Schematic of ETB $\text{In}_x\text{Ga}_{1-x}\text{As}$ -OI MOSFETs and proposed channel engineering for μ_{eff} enhancement from high indium content and MOS buffer giving reduced phonon and interface scattering, respectively.

device gave the best performance, with an on/off current ratio of 10^3 and effective mobility $3.7\times$ that of silicon.

In separate work, ETB $\text{In}_x\text{Ga}_{1-x}\text{As}$ ($x=0.53, 0.7, 1$) channels with $\text{In}_{0.3}\text{Ga}_{0.7}\text{As}$ interface buffers were fabricated by direct wafer bonding on silicon substrates with a buried oxide (BOX) layer (Figure 1b). Using InAs (i.e. $x = 1$) channels gave an on/off current ratio of 10^4 . A 3nm channel had a record high peak mobility of $3180\text{cm}^2/\text{V}\cdot\text{s}$.

Gaining access

Tokyo Institute of Technology researchers reported on using InP source regions to increase the drain current through InGaAs channels to $2.4\text{A}/\text{mm}$ at 0.5V drain

bias with a 50nm-long channel [session 13.3]. The team was aiming to overcome carrier starvation problems arising from low carrier densities and level quantization effects of thin InGaAs channels. The use of heavily doped InP gives a band discontinuity and raises the Fermi level so that the InGaAs levels become more populated, increasing carrier concentrations (Figure 2). Future MOSFETs will need at least 2A/mm current at drain voltages of 0.6V.

The devices were grown on p-InP substrates using metal-organic chemical vapor deposition (MOCVD). The maximum transconductance was 1.17S/mm with the gate and drain both at 0.5V. The researchers note that, although the transconductance is higher than in their previous work, the value is relatively poor when the drastic increase in drain current is considered. Extraction of the sheet resistance (1100 Ω /sq) and effective mobility (1500cm²/V-s, based on 10 μ m devices; confusingly split C-V methods gave 4500cm²/V-s, that "needs further consideration", according to the authors) indicated a poor-quality Al₂O₃/InGaAs interface. Also, the equivalent oxide thickness (EOT) was quite large (~5nm). The parasitic source-drain resistance was lower than for previous devices, at 0.093 Ω -mm. SCEs began to be observed around 100nm. These effects are expected to be ameliorated by thinner channels.

Lund University reported on high-frequency compatible self-aligned gate-last surface channel MOSFETs with selectively regrown source and drain contacts [session 13.2, see www.semiconductor-today.com/news_items/2012/FEB/LUND_210212.html]. Access resistance was improved so that a 55nm-gate-length device demonstrated a transconductance of 1.9mS/ μ m and an on-resistance of 199 Ω - μ m.

Straining for p-MOSFET performance

MIT and State University of New York at Albany (SUNY) have used InGaAs to produce p-type MOSFETs, rather than the usual n-MOSFETs [session 13.5]. InGaAs p-MOSFETs are usually hampered by low performance due to low hole mobility. However, as with silicon and germanium devices, applying suitable strain to the channel can enhance hole mobility. MIT applied a combination of compressive uniaxial strain and compressive

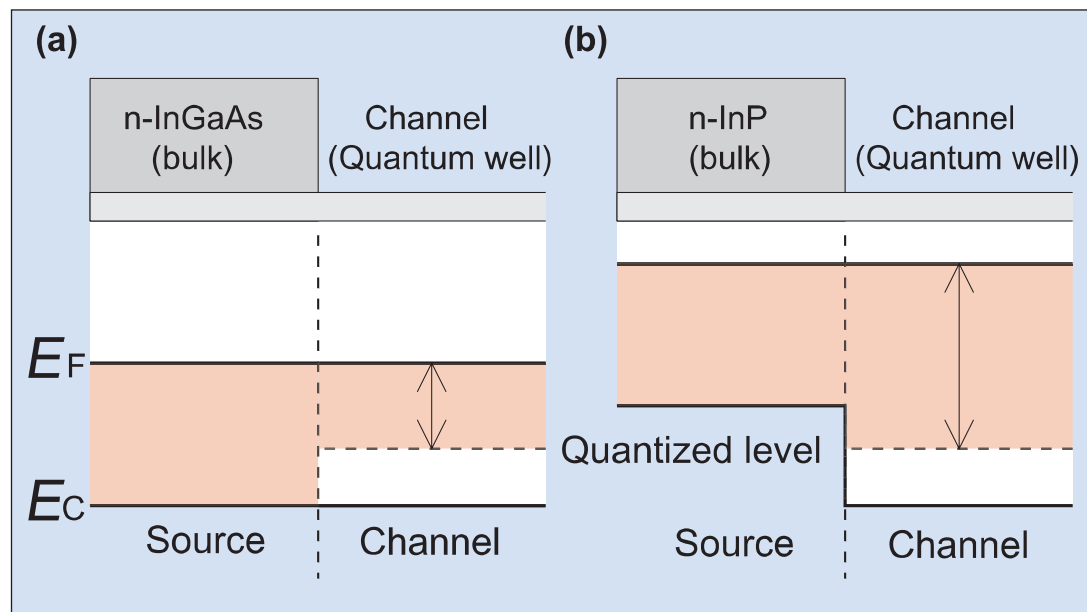


Figure 2. Schematic of source and drain (top) and band diagrams (bottom) with conventional InGaAs (a) and Tokyo Institute of Technology InP (b) source contacts. Carrier concentration in channel decreases/increases according to position of quantized level/band discontinuity.

epitaxially grown biaxial strain to increase the intrinsic transconductance by 36% in a 2 μ m-gate device (Figure 3).

The InGaAs channel layer, grown on GaAs with a AlGaAs buffer and barrier using molecular beam epitaxy (MBE), was put under -1.7% compressive biaxial strain. Uniaxial strain was introduced using a silicon nitride layer deposited using plasma-enhanced CVD. The compressive stress in two types of SiN layer that were tested were -2.1GPa and almost zero.

The two different devices had similar subthreshold swing (~103mV/dec) and gate current, although there was a slight shift in threshold voltage. Enhancements

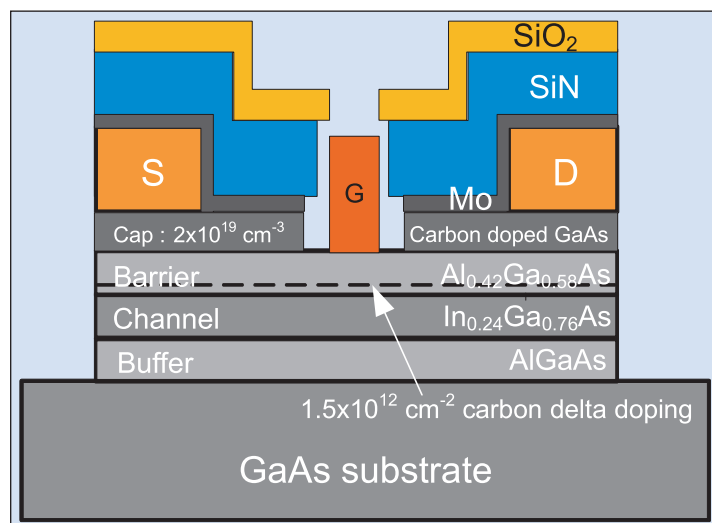


Figure 3. MIT/SUNY p-channel InGaAs FET with built-in stressors. A refractory contact metal layer and SiN stressor are both self-aligned to the gate edge. High- (-2.1 GPa) and zero-stress SiN films were used for comparison.

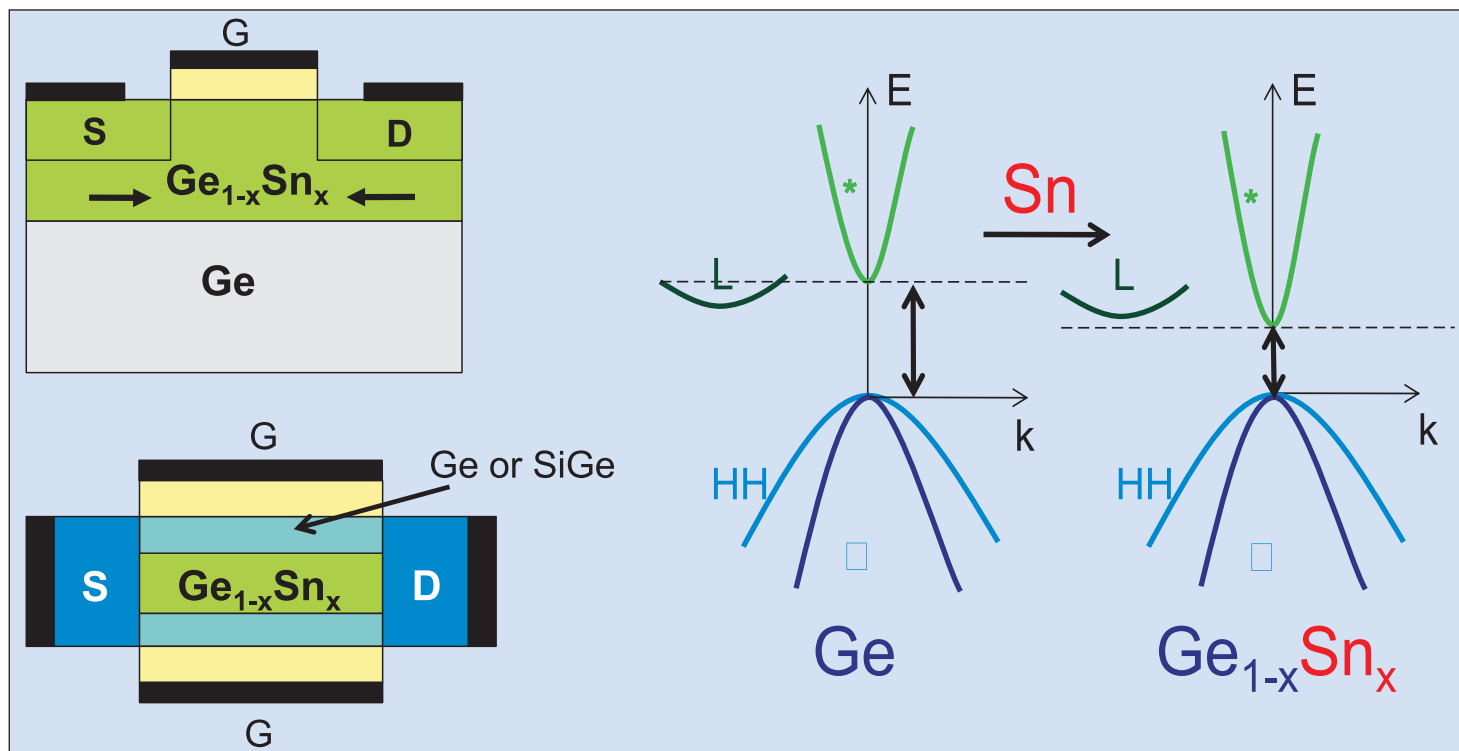


Figure 4. Possibility of high carrier mobilities, bandgap and strain engineering make GeSn alloys an attractive channel material for high performance CMOS (left). A tunable direct gap in some varieties of GeSn could even open up optoelectronics applications (right).

in transconductance were strongest when the channel pointed in the $[-110]$ crystal direction. The gate-length dependence of the transconductance performance suggests that further improvement could come from even shorter gate lengths. Simulations suggest a 160% enhancement could be reached for gates shorter than 50nm.

The work was sponsored by Intel Corp and the Semiconductor Research Corporation (SRC) Focus Center Research Program (FCRP) Center for Materials, Structures and Devices (MSD) based at MIT Microsystems Technology Laboratories.

Teledyne Scientific Company worked with another MIT team (led by Jesus del Alamo, as was the MIT contribution above), presenting record-breaking frequency performance for 40nm-gate-length InGaAs metamorphic HEMTs (mHEMTs) [session 13.6].

The cut-off (f_T) reached 688GHz and the maximum oscillation f_{max} was 800GHz. The researchers commented: "To the best of the author's knowledge, this is the highest f_T ever reported in any FET on any material system."

The peak transconductance of 2.75mS/ μ m at 0.8V drain bias is described as 'outstanding'. The transconductance was in excess of 2mS/ μ m even at 0.3V drain. The low on-resistance of 280 Ω - μ m, along with the high transconductance, make the device technology "attractive for high-performance and very low-power applications." In addition, the devices operate in enhancement-mode — i.e. normally off — with a threshold voltage of +0.05V.

The epitaxial device layers were grown on GaAs substrates. The metamorphism consists in using a graded buffer that bridges the lattice mismatch between the device layers and substrate by slowly changing the composition of the alloy and thus lattice parameters from that of GaAs to the 300nm In_{0.52}Al_{0.48}As buffer. Without the grading there would be large strains set up in the device layers.

A platinum gate was formed using a sinking process that thinned the InAlAs used as a barrier layer between the channel and gate. Dual silicon delta-doping was used to lower the barrier in the source-drain access region.

The researchers also developed models of the device with the aim of designing future transistors. On the basis of the analytical model, the researchers say that a 1THz f_T "is an eminently attainable goal." This would be achieved by reducing parasitic resistance and capacitance in addition to gate-length reduction to 20nm.

Germanium tin alloy

Stanford University, GLOBALFOUNDRIES and Applied Materials presented "for the first time" a surface-channel high- κ (dielectric constant) pMOSFET on germanium-tin (GeSn) with 3% Sn, showing a 20% improvement in hole mobility over bulk Ge devices [session 16.6]. Tin falls in the same column of the periodic table of elements as carbon, silicon and germanium, and hence may be expected to have interesting effects on the semiconductor properties of these elements and is particularly seen as potentially extending the use of

germanium p-channels (Figure 4).

The n-type layers of GeSn that constitute the p-channel were grown on semi-insulating (100) GaAs and (100) Ge wafers using MBE at the low temperature of 200°C. A post-deposition anneal at 600°C was used to annihilate bulk point defects. The pMOSFETs produced from the material achieved a sub-threshold swing of 250mV/dec and on/off current ratio of 10^3 .

The National University of Singapore (NUS), the Chinese Academy of Sciences, and Nanyang Technological University also reported the realization of "the world's first" GeSn channel pMOSFETs [session 16.7].

The channel material was grown on n-type Ge(100) substrates using solid-source MBE at 180°C. X-ray diffraction (XRD) analysis gives a tin composition of 5.3% and suggests that the film is fully compressively strained at a value of 0.8%. The source/drain (S/D) contacts consisted of nickel stanogermanide ($\text{Ni}_{0.5}\text{Ge}_{0.5-x}\text{Sn}_x$ or NiGeSn) created using temperatures less than 370°C. The gate stack consisted of a hafnium dioxide insulator and tantalum nitride metal. The transistors were produced in a self-aligned process.

A 58% enhancement in median on-current was observed in the GeSn devices over a Ge-channel control.

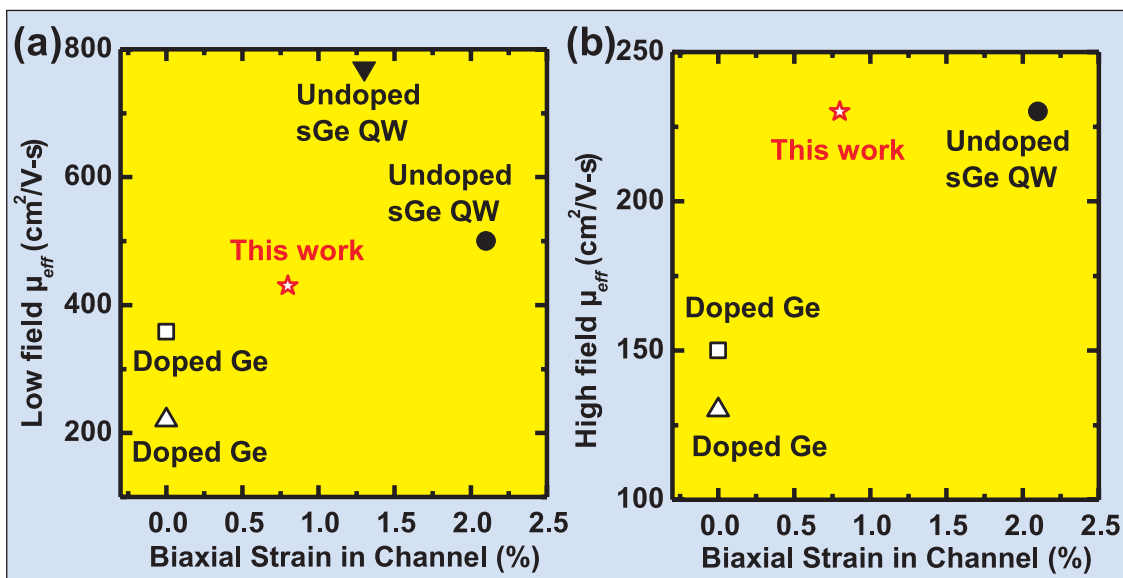


Figure 5. Benchmark of effective mobility at (a) low effective field and (b) high effective field (1MV/cm) for NUS/CAS/Nanyang Technological University GeSn pMOSFETs with HK/MG gate stack and Si surface passivation vs competing devices.

The new devices benefited from both lower source/drain resistance (reduced by 64% relative to control, due to a lowered Schottky barrier) and higher effective mobility in the channel. The peak effective mobility was $430\text{cm}^2/\text{V}\cdot\text{s}$. In low fields, the effectively mobility was enhanced by 66% over the control. In high fields, the enhancement was 55%. The enhancements are seen as resulting from the higher mobility of GeSn over pure Ge and from the strain of the channel.

The researchers compared their results with the work of others (Figure 5). Although at low field the mobility performance is less than that of undoped strained Ge quantum well devices, in higher fields the performance becomes comparable. The reduced mobility in low field is attributed to Coulomb scattering. ➤

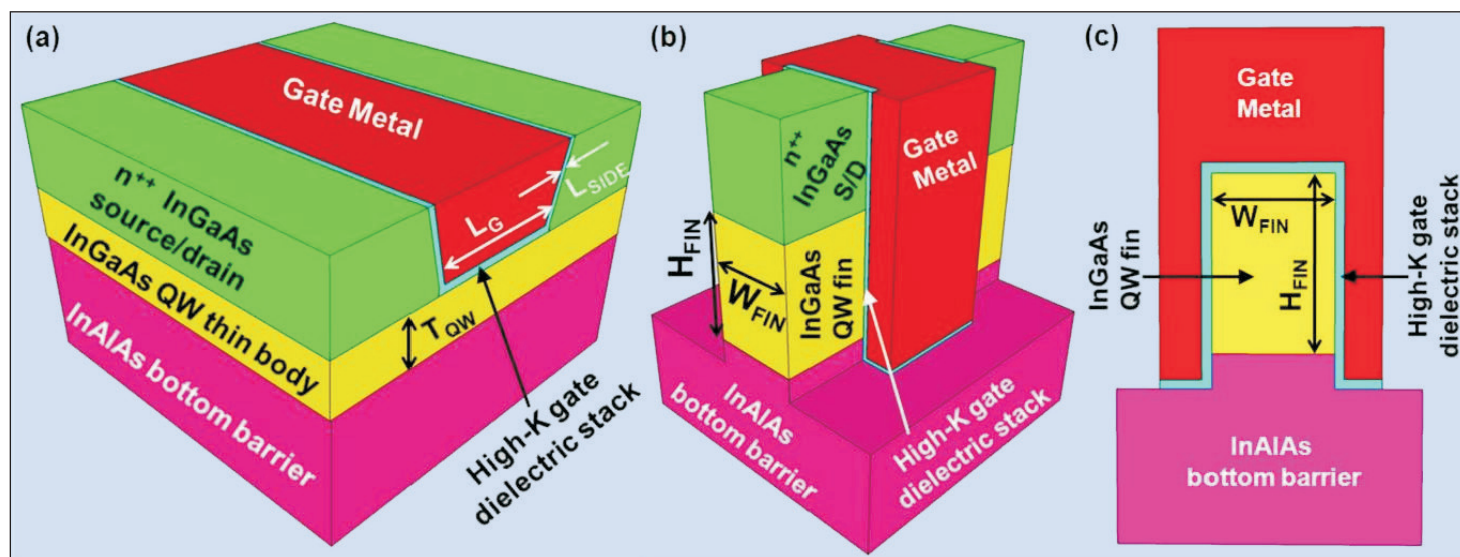


Figure 6. (a) Intel/IQE thin-body planar InGaAs QWFET with high-k dielectric gate stack and body thickness of 10–50nm. (b) 3D tri-gate InGaAs QWFET with high-k dielectric gate stack, fin width of 30–60nm, and fin height of 30–50nm. (c) Cross-section of (b) perpendicular to the InGaAs QW fin through the gate.

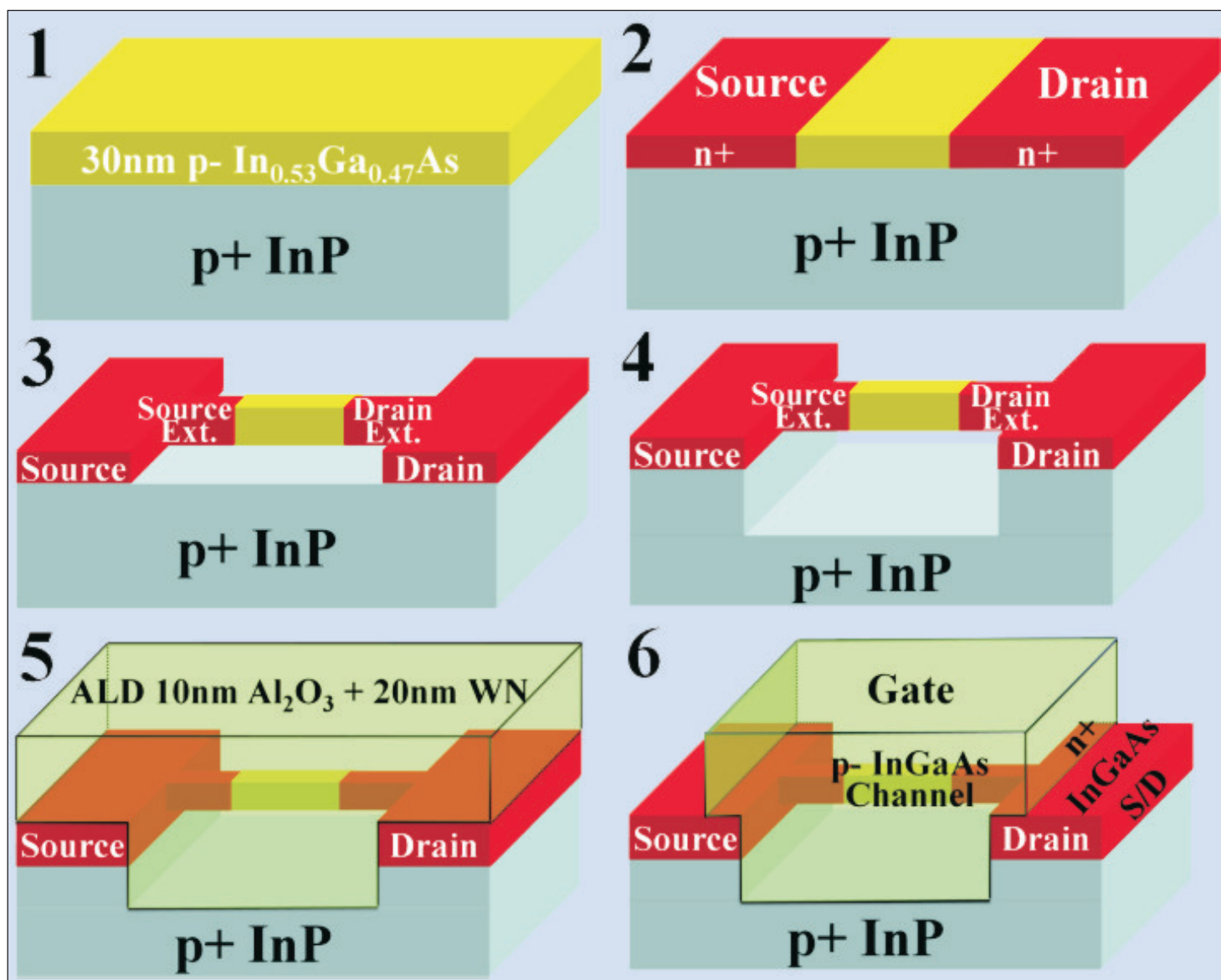


Figure 7. Schematic diagram of key process steps in the fabrication of Purdue/Harvard InGaAs GAA MOSFETs.

► Gate technology

Intel/IQE have continued the development of quantum well InGaAs devices, improving electrostatic control through a 3D tri-gate [session 33.1]. The researchers comment: "the 3D tri-gate InGaAs devices in this work achieve the best electrostatics, as evidenced by the steepest subthreshold swing (SS) [down to $\sim 80\text{mV/dec}$] and the smallest drain-induced barrier lowering (DIBL) [down to $\sim 25\text{mV/V}$], ever reported for any high-k III-V field-effect transistor."

It was also the first time that the 3D fin structure in III-V MOSFETs has demonstrated improvement over the performance of ultra-thin-body planar InGaAs devices. The tri-gate structure consisted of a narrow fin of 30nm width, combined with a high-quality high-k gate dielectric interface (Figure 6). The epitaxial layers were grown using molecular beam epitaxy.

Purdue and Harvard universities in the USA presented the first demonstration of inversion-mode indium gallium arsenide ($\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$) gate-all-around (GAA)

metal-oxide-semiconductor field-effect transistors (MOSFETs) by a top-down approach [session 33.2]. GAA is the ultimate structure in the wrap-around gate trend to improve electrostatic control and hence enhance features such as subthreshold swing and low off-current (Figure 7).

The Purdue/Harvard team comments on its achievement: "Benefiting from the GAA structure, we have demonstrated the shortest channel length ($L_{\text{ch}} = 50\text{nm}$) III-V MOSFETs to date, with well-behaved on- and off-state characteristics."

Normalizing to the perimeter of the channel (i.e. $2 \times (\text{height} + \text{width of fins}) \times \text{number of channels}$), the typical on-current and extrinsic transconductance of a 50nm-long channel were $720\mu\text{mA}/\mu\text{m}$ and $510\mu\text{S}/\mu\text{m}$, respectively. A 'hero' device achieved an on-current of $1.17\text{mA}/\mu\text{m}$ (with a drain voltage of 1V) and a maximum transconductance of $701\mu\text{S}/\mu\text{m}$.

The off-state is described as 'reasonable'. The subthreshold swing and drain-induced barrier lowering

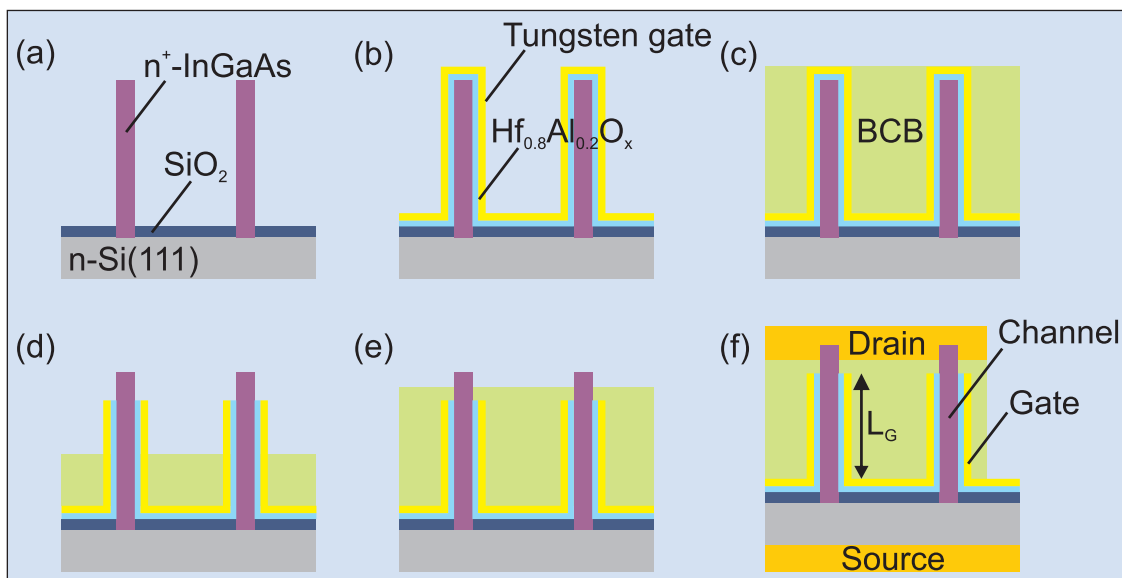


Figure 8. Hokkaido University device fabrication processes: (a) InGaAs NW growth. (b) Atomic layer deposition of $\text{Hf}_{0.8}\text{Al}_{0.2}\text{O}_x$ and sputtering of W-gate metal. (c) Spin-coating of BCB polymer. (d) RIE of BCB, gate oxide and W metal. (e) Spin-coating of BCB and RIE etch back for electrical separation layer formation. (f) Drain and source metal evaporation.

were 150mV/dec and 210mV/V, respectively. InGaAs quantum well devices have achieved (desirable) lower subthreshold swings of $\sim 120\text{mV/dec}$.

The devices work in inversion-mode, meaning that the channel is constructed of p-type material (majority carriers are holes), but the on-current is negatively charged 'electrons'. However, unlike with traditional silicon complementary metal oxide semiconductor (CMOS) transistors, the threshold voltage is negative (-0.68V), giving a current when the gate potential is

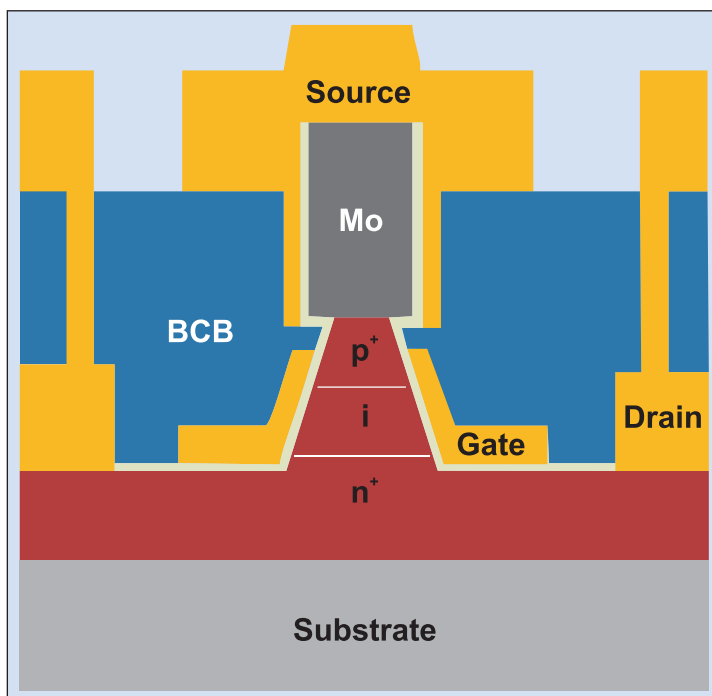


Figure 9. Schematic cross-section of Penn State/IQE tunneling FETs.

zero (i.e. normally-on). Normally-off, positive thresholds are preferred for low power consumption. The negative threshold is blamed on the low work function of the tungsten nitride gate metal.

Corrections for the effects of contacts gives an intrinsic transconductance of the channel of $750\mu\text{S}/\mu\text{m}$. The relatively large effect of the contacts is blamed on non-optimal ion implantation, resistance from the channel/source-drain link, and the use of a non-self-aligned process.

The researchers believe that the subthreshold swing performance could be improved with thinner or higher dielectric constant gate insulation. Thinning the aluminum oxide to 5nm or 2.5nm should give subthreshold swings of 105mV/dec or 82mV/dec, respectively, on the basis of simple calculations.

Hokkaido University researchers [session 33.3] have used vertical InGaAs nanowires grown directly on silicon (Figure 8) to produce surrounding-gate transistors (SGTs). This resulted in transconductance of $500\mu\text{S}/\mu\text{m}$ and on/off current ratios of $\sim 10^9$ with 1V drain bias.

The InGaAs nanowires (NWs) were grown on n-type Si(111) using low-pressure metal-organic chemical vapor deposition. The average diameter and height of the resulting nanowires were 90nm and $1\mu\text{m}$, respectively. The indium composition was around 70%. The silicon-doped wires were n-type with a carrier concentration of about $10^{18}/\text{cm}^3$.

The wires were covered with hafnium aluminum oxide as gate dielectric (with a relative permittivity constant of 20.3). These layers were 10–20nm thick, with an equivalent oxide thickness of 1.86–3.72nm. The dielectric was followed by tungsten gate metal. A sequence of spin coatings of benzocyclobutene (BCB) and reactive ion etch was used to isolate the gate and drain contacts. The drain consisted of nickel/germanium/gold/nickel/gold. A titanium/gold source contact was deposited on the back-side of the silicon wafer.

The devices consisted of 10 parallel nanowires with a gate length of 200nm. The researchers say that one of their final goals is to integrate NW-based high-electron mobility transistors (HEMTs) that have a surrounding-

gate architecture on silicon platforms as well as alternative channels for n-FET in CMOS technology.

The devices showed “moderately good switching properties” such as average drain-induced barrier lowering of 160mV/V and sub-threshold swing of 97mV/dec. However, there was no variation of these values with EOT, indicating depletion-layer rather than oxide capacitance effects. The researchers believe that reducing surface states should improve the switching behavior.

Core-shell (CS, InGaAs/InAlAs) and core-multishell (CMS, InGaAs/InP/InAlAs/ δ -doped layer/InAlAs/InGaAs) heterostructure nanowires were also produced with a view to enhanced drain current from two-dimensional electron gas flow, as used by HEMTs. The maximum transconductance of 500 μ S/ μ m and on/off current ratio of 10^9 were achieved with a CMS device. The maximum drain current was 320 μ A/ μ m at 1V drain bias.

The researchers say: “Further optimizing the uniformity of the InGaAs cap layer and shell layer thickness is expected to produce much higher switching performance in the InGaAs-related CMS NW-SGT on silicon platforms.”

Tunneling to electronic riches

Pennsylvania State University and IQE reported on tunneling field-effect transistors with a view to beating the theoretical limits on the switching slope of conventional devices [session 33.5]. Different types of hetero-junction (GaAsSb/InGaAs) and homo-junction (InGaAs) structures were grown either lattice matched or using a graded buffer to transition between lattice constants (i.e. metamorphically) on indium phosphide substrates using MBE.

A self-aligned process was used to create the TFET pillars (Figure 9). “By ‘self aligned’ we refer to the isolation of the top contact and the side-wall gate as a result of wet etch undercut of the pillar,” the researchers comment.

The gate dielectric of 1nm aluminum oxide and 3.5nm of hafnium dioxide was deposited using atomic layer techniques. The platinum gate metal was deposited on the side wall of the pillar.

The GaAs_{0.35}Sb_{0.65}/In_{0.7}Ga_{0.3}As highly staggered type II hetero-junction TFET demonstrated record high drive currents of 190 μ A/ μ m at 750mV drain bias and 100 μ A/ μ m at 300mV. However, the device suffered from degraded pinch-off (off-current leakage) that the researchers believe needs further scaling in terms of reduced pillar width and EOT to overcome. The gate length was 150nm.

‘Type II’ refers to the conduction and valence band shifts being in the same direction, unlike ‘type I’ well structures where the conduction band falls and the valence band rises. The tunneling is set up to occur between the valence band in one region and the con-

duction band in the other region. The gate is used to control the amount of tunneling. This allows steeper threshold slopes and thus subthreshold voltage swings between ‘on’ and ‘off’ that are less than the theoretical minimum of 60mV/dec at room temperature for conventional planar devices.

One homo-junction device had a very low sub-threshold swing of 53mV/dec (indicating a steep switching behavior) at 77K, which increased to 216mV/dec at room temperature. The high drive current hetero-junction had high swing (shallow switching slope) at all temperatures.

IQE has also worked with Intel on III-V heterojunction tunneling field-effect transistors (H-TFET) [session 33.6].

For the first time, the III-V tunneling field-effect transistors exhibits significantly steeper subthreshold swing than the best thin-body III-V metal oxide semiconductor high-electron mobility transistor reported in the literature

One device had the steepest room-temperature sub-threshold swing of 60mV/dec ever reported in a III-V TFET. The researchers comment: “For the first time, the III-V TFET exhibits significantly steeper SS than the best thin-body III-V MOS HEMT reported in the literature.”

Intel and IQE have also worked together to show that the material quality of III-V QWFET structures on silicon grown using metal-organic chemical vapor deposition can meet the mobility performance of the best structures grown

using molecular beam epitaxy [session 35.1]. MOCVD generally has a faster growth rate but lower quality than MBE. A faster process means lower cost from higher throughput.

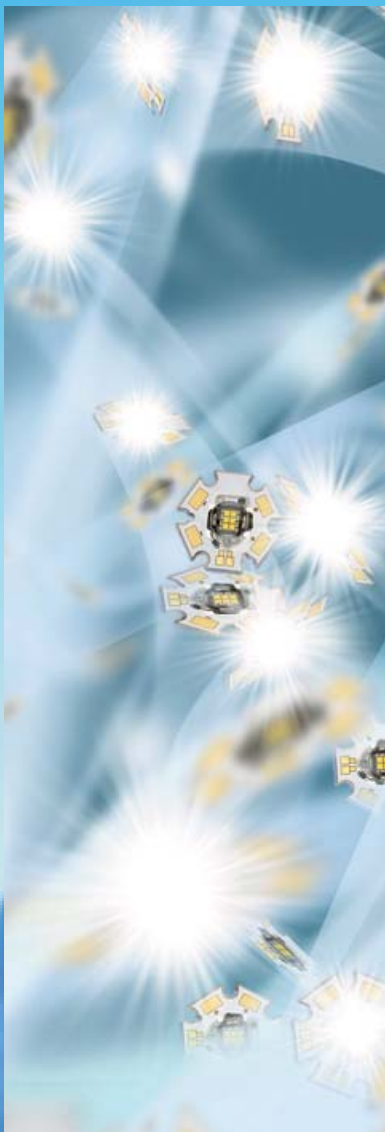
Other work and reports

IMEC reviewed a wide range of its work in “Advancing CMOS beyond the Si roadmap with Ge and III/V devices” [session 13.1], including direct growth of Ge and III-Vs on silicon (particularly difficult to grow InP using thin Ge buffer), Ge surface and III-V passivation, border trap modelling, a common Ge/III-V gate stack, strain engineering, GeSn source-drain regions, ammonium sulfide vapor (ASV) treatment for III-V transistors, gallium antimonide/aluminium antimonide QWs, etc. The researchers also believe that new device concepts with Ge/III-V-source silicon tunnel FETs and nanowires on silicon may be of future interest beyond silicon scaling. ■

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



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Index

- | | |
|---|---|
| 1 Bulk crystal source materials p96 | 14 Chip test equipment p100 |
| 2 Bulk crystal growth equipment p96 | 15 Assembly/packaging materials p100 |
| 3 Substrates p96 | 16 Assembly/packaging equipment p100 |
| 4 Epiwafer foundry p97 | 17 Assembly/packaging foundry p101 |
| 5 Deposition materials p97 | 18 Chip foundry p101 |
| 6 Deposition equipment p98 | 19 Facility equipment p101 |
| 7 Wafer processing materials p99 | 20 Facility consumables p101 |
| 8 Wafer processing equipment p99 | 21 Computer hardware & software p101 |
| 9 Materials and metals p99 | 22 Used equipment p101 |
| 10 Gas & liquid handling equipment p99 | 23 Services p101 |
| 11 Process monitoring and control p99 | 24 Consulting p101 |
| 12 Inspection equipment p100 | 25 Resources p101 |
| 13 Characterization equipment p100 | |

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www.substrates.umicore.com

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French's Road, Cambridge CB4 3NP,
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The Fox Group Inc

(see section 3 for full contact details)

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Fax: +1 972 234 0069
www.intelliepi.com

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5 Deposition materials

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www.camchem.co.uk

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USA
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(see section 1 for full contact details)**Power + Energy Inc**

(see section 10 for full contact details)

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www.praxair.com/electronics

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6 Deposition equipment

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7 Wafer processing materials

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Tel: +1 617 965 5511
Fax: +1 617 965 5818
www.microchem.com

Power + Energy Inc
(see section 10 for full contact details)

Praxair Electronics
(see section 5 for full contact details)

8 Wafer processing equipment

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TECDIA Inc
(see section 16 for full contact details)

Veeco Instruments Inc
(see section 6 for full contact details)

9 Materials & metals

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www.cambridge-fluid.com

CS CLEAN SYSTEMS AG
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Fax: +49 89 96 24 00 122
www.cscleansystems.com

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Fax: +1 215 942-9300
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SAES Pure Gas Inc
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www.saesgetters.com

11 Process monitoring and control

k-Space Associates Inc
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Fax: +1 734 426 7955



www.k-space.com

k-Space Associates Inc specializes in in-situ, real-time thin-film process monitoring tools for MBE, MOCVD, PVD, and thermal evaporation. Applications and materials include the research and production line monitoring of compound semiconductor-based electronic, optoelectronic, and photovoltaic devices.

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www.wepcontrol.com

12 Inspection equipment

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13 Characterization equipment

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14 Chip test equipment

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15 Assembly/packaging materials

ePAK International Inc

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Gel-Pak

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Fax: +1 716 833 2926
www.williams-adv.com

16 Assembly/packaging equipment

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Switzerland
Tel: +41 329257111
Fax: +41 329257115
www.ismeca.com

Kulicke & Soffa Industries

1005 Virginia Drive,
Fort Washington,
PA 19034,
USA
Tel: +1 215 784 6000
Fax: +1 215 784 6001
www.kns.com

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Carlsbad,
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USA
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Fax: +1 8586 74 4681
www.quikicpak.com

18 Chip foundry

Compound Semiconductor Technologies Ltd

Block 7, Kelvin Campus,
West of Scotland, Glasgow,
Scotland G20 0TH,
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Tel: +44 141 579 3000
Fax: +44 141 579 3040
www.compoundsemi.co.uk

United Monolithic Semiconductors

Route departementale 128,
BP46, Orsay, 91401,
France
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Fax: +33 169 33 02 92
www.ums-gaas.com

19 Facility equipment

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Fax: +1 541 917 3623
www.marlerenterprises.net

20 Facility consumables

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Fax: +1 410 506 8749
www.gore.com

21 Computer hardware & software

Ansoft Corp

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Tel: +1 412 261 3200
Fax: +1 412 471 9427
www.ansoft.com

Crosslight Software Inc

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Canada
Tel: +1 604 320 1704
Fax: +1 604 320 1734
www.crosslight.com

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Fax: +1 804 740 3814
www.semitech.us

22 Used equipment

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24 Consulting

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25 Resources

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Optical Fiber Communication Conference
and Exhibition/National Fiber Optic
Engineers Conference**

Los Angeles Convention Center, CA, USA

E-mail: info@ofcconference.org

www.ofcnfoec.org

18–19 March 2012

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Kerry Hotel Pudong, Shanghai, China

E-mail: cstic@semi.org.cn

http://semiconchina.semi.org/cstic

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**Oxford Instruments 'Nanoscale Plasma
Processing' one-day workshop**

Shanghai, China

E-mail: process.news@oxinst.com

www.oxford-instruments.com

19–22 March 2012

**GOMACTech-12:
37th Annual Government Microcircuit
Applications & Critical Technology
Conference)**

Las Vegas, NV, USA

www.gomactech.net

20–22 March 2012

SEMICON China 2012

Shanghai New International Expo Centre (SNIEC), China

www.semiconchina.org

20–22 March 2012

LASER World of PHOTONICS CHINA

Shanghai New International Expo Centre (SNIEC), China

E-mail: laser@mmi-shanghai.com

www.world-of-photonics.net/en/laser-china/start

21–23 March 2012

7th Asia Solar Photovoltaic Industry Exhibition

Shanghai Expo Theme Pavilion, China

E-mail: info@aiexpo.com.cn

www.asiasolar.cc/en

25–30 March 2012

**8th conference on Porous Semiconductors —
Science and Technology (PSST-2012)**

Hotel Monte Malaga, Spain

E-mail: info@the-psst.com

www.the-psst.com

2–4 April 2012

**Semiconductor and Integrated Opto-
Electronics Conference (SIOE'12)**

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www.astro.cardiff.ac.uk/research/pm/events/?page=sioe

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Evatec	49	Temescal	51
III/V-Reclaim	30	Veeco Instruments — MBE	9
IQE	27	Veeco Instruments — MOCVD	2
k-Space	57	Wafer Technology	29
LayTec	35	Wafer World	31

9–13 April 2012**2012 MRS Spring Meeting**

San Francisco, CA, USA

E-mail: info@mrs.org**www.mrs.org/spring2012**

15–17 April 2012**13th Annual IEEE Wireless and Microwave Technology Conference (WAMICON 2012)**

Hilton Cocoa Beach Oceanfront hotel, FL, USA

E-mail: ryan_baker@cree.com**www.wamicon.org**

15–19 April 2012**IEEE International Reliability Physics Symposium (IRPS-2012)**

Hyatt Regency Orange County, Anaheim, CA, USA

E-mail: yuan.chen@nasa.gov**www.irps.org**

15–20 April 2012**Light+Building 2012**

Frankfurt am Main, Germany

http://light-building.messefrankfurt.com

16–17 April 2012**WAMICON 2012 (13th Annual IEEE Wireless and Microwave Technology Conference)**

Hilton Cocoa Beach Oceanfront Hotel, FL, USA

E-mail: mumcu@usf.edu**www.wamicon.org**

16–18 April 2012**12th European Advanced Process Control and Manufacturing Conference (APCM 2012)**

MINATEC, Grenoble - France

E-mail: weber@apcm-europe.eu**www.apcm-europe.eu**

16–18 April 2012**CPV-8 International Conference on Concentrating Photovoltaic Systems**

Toledo, Spain

E-mail: iinfo@cpv-8.org**www.cpv-8.org/cms**

16–20 April 2012**SPIE Photonics Europe 2012**

The Square Conference Center, Brussels, Belgium

http://spie.org/photonics-europe.xml

17–19 April 2012**7th Annual Photovoltaics Summit**

The Westin Hotel, San Diego, CA, USA

E-mail: info@pira-international.com**www.photovoltaicssummit.com**

18–20 April 2012**16th European Conference on Integrated Optics (ECIO 2012)**

Hotel Melia Sitges, Barcelona, Spain

E-mail: ecio2012@icfo.es**www.ecio2012.com**

19–20 April 2012**4th Photovoltaics Thin-Film Week, including:****4th Thin-Film Industry Forum (TIF 2012)**

Berlin, Germany

E-mail: info@solarpraxis.de**www.solarpraxis.de/en/conferences**

23 April 2012**JEDEC's 27th Annual ROCS (Reliability of Compound Semiconductors) Workshop**

The Boston Park Plaza Hotel, Boston, MA, USA

E-mail: ptanner@jedec.org**www.jedec.org/home/gaas**

23–26 April 2012**2012 CS MANTECH:****International Conference on Compound Semiconductor Manufacturing Technology**

The Boston Park Plaza Hotel, Boston, MA, USA

E-mail: csmantech@csmantech.org**www.csmantech.org**

23–27 April 2012**SPIE Defense, Security, and Sensing 2012**

Baltimore, MD, USA

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28 April – 3 May 2012**2012 SVC TechCon:****55th Society of Vacuum Coaters****Annual Technical Conference**

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E-mail: svcinfo@svc.org**www.svc.org/ConferencesExhibits/Future-Meetings.cfm**

6–11 May 2012**221st Electrochemical Society (ECS) Meeting**

Seattle, Washington

E-mail: meetings@electrochem.org**www.electrochem.org/meetings/biannual/fut_mtgs.htm**

14–18 May 2012**E-MRS 2012 Spring Meeting**

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