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COMPOUNDS & ADVANCED SILICON

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CMOS and GaAs
power amplifiers

Auger blamed for LED
efficiency droop

Spectrolab expands to
150mm wafers

Avago buys Javelin; CyOptics • GaN templates from Hitachi
Toshiba buys Bridgelux's GaN-on-Si assets • CDFP MSA formed

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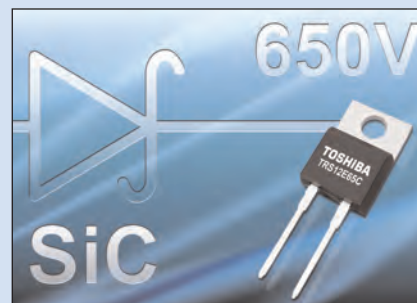
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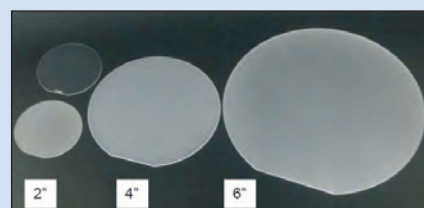
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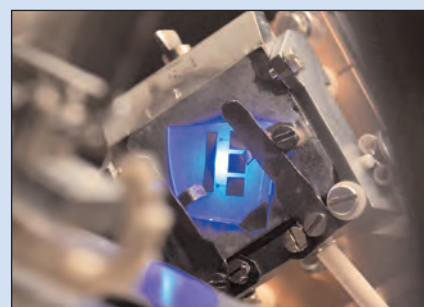
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p18 Toshiba has started volume production of SiC power devices, starting with a 650V Schottky diode.



p44 Hitachi Cable has launched HVPE-grown GaN templates on either flat sapphire or PSS of 2–6" diameter, with 8"-diameter templates planned.



p90 UCSB and École Polytechnique have identified Auger recombination as the cause of the droop in luminous efficiency at high drive current in nitride LEDs.



Cover: Wafer manufacturing supervisor Ali Glaser examines 150mm wafers during the final step of the solar cell manufacturing process at Spectrolab. Spectrolab has expanded its production from 100mm-diameter germanium wafers to 150mm-diameter wafers. **p73**

CMOS silicon to complement GaAs in cellular RF front-ends?

On page 14 of this issue we report how Avago Technologies (which focuses on making III-V-based components) has acquired Javelin Semiconductor of Austin, Texas, which claims to have been one of the first firms to develop 3G wireless communications power amplifiers (PAs) based on CMOS silicon. The start-up's investors said the firm had grown to where it would either have to expand its sales, marketing and administration spending or find a buyer.

This follows November's news of the acquisition by GaAs-based PA maker RF Micro Devices of Silicon Valley-based fabless firm Amalfi Semiconductor for \$47.5m. RFMD reckons its customer relationships, in-house manufacturing scale and global supply chain will help to speed market adoption of Amalfi's RF CMOS and mixed-signal ICs, which are targeted at the rapidly growing cost-driven entry-level smartphone market. Previously, in mid-2009, rival GaAs PA maker Skyworks Solutions acquired California-based fabless RF CMOS PA supplier Axiom Microdevices.

In the meantime, at the 2013 Mobile World Congress in Barcelona, Spain in February, San Diego-based Qualcomm, the fabless provider of silicon-based chipsets for wireless applications, unveiled its RF360 front-end, a system-level solution enabling for the first time, it is claimed, a single, global 4G LTE design for mobile devices (see page 92). This includes a chip that is claimed to be the first featuring an integrated CMOS PA and antenna switch with multi-band support across 2G, 3G and 4G LTE cellular modes. For Qualcomm (which dominates the base-band chipset market) this marks its entry into the RF front-end component market.

According to market research firm Strategy Analytics, Qualcomm is the first firm to launch a CMOS PA alternative to GaAs-based multi-band, multi-mode (MMMB) PAs for mid- to high-tier 3G/4G smartphones (a phone segment formerly the exclusive domain of GaAs PAs). "Envelope tracking (ET) power management enables this, and we expect adoption of CMOS PAs from Qualcomm and others to accelerate in mobile phones as a result," the firm adds (see page 93). Indeed, in February RFMD expanded its portfolio of envelope tracking power management and MMMB PA products. "GaAs PA suppliers will have to continue to innovate to maintain an edge over CMOS, and they may also need to consider offering their own CMOS PAs for the most cost-sensitive phones, as Skyworks and RFMD now do," notes Strategy Analytics' Eric Higham (who will host the panel session 'The Death of GaAs(?)' at June's IEEE International Microwave Symposium).

While the likes of Qualcomm may not threaten GaAs-based firms like RFMD, Skyworks and now Avago that can compete in the silicon PA sector, whether GaAs-based firms without silicon technology are threatened depends on how GaAs and silicon compete in the PA market. At the moment, CMOS PAs best suit the cost-driven entry-level smartphone market (e.g. high-volume, low-end markets such as China). It remains to be seen whether they will ultimately be able to challenge GaAs (and hence GaAs-focused firms, especially those without RF CMOS silicon technology) on the performance levels that are demanded in higher-end products.

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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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- feature articles (technology, markets, regional profiles);
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- event calendar and event previews;
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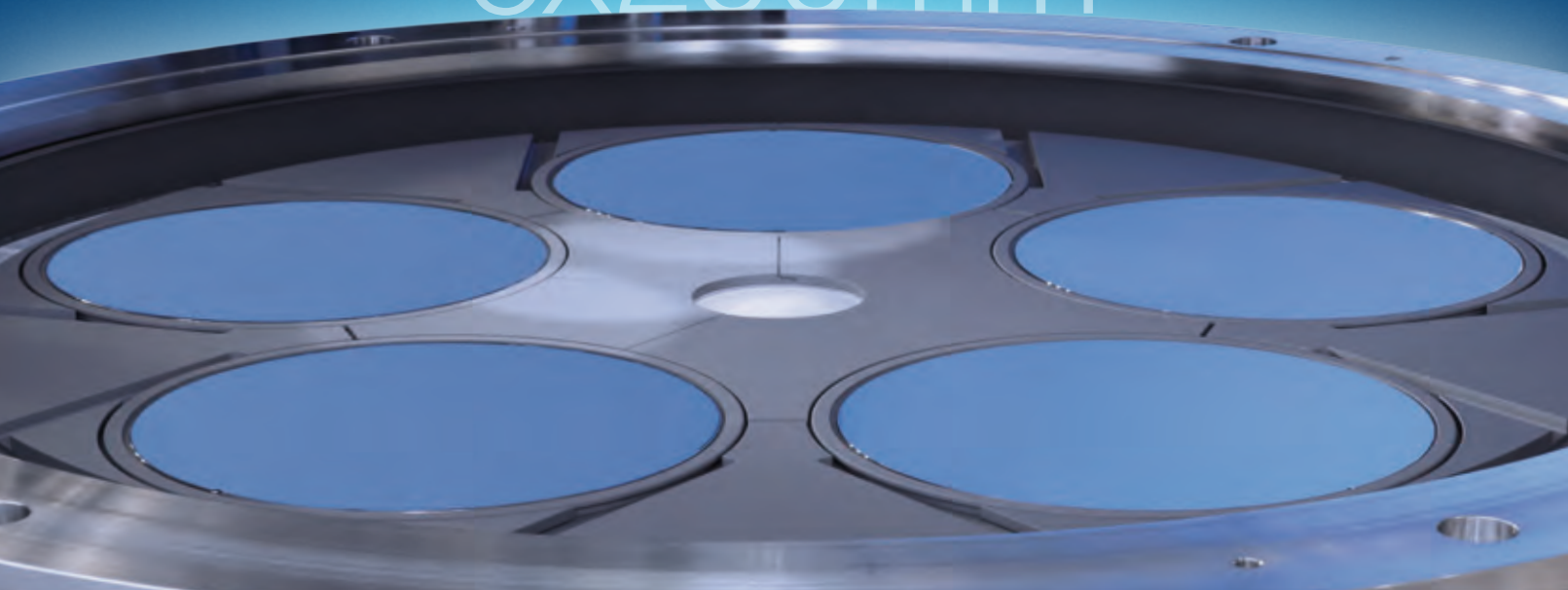
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LED lighting market consolidation to continue

LED lamp revenue to grow from \$1.5bn to over \$8.5bn in 2021

The lighting industry is in the early stages of shifting away from established technologies — fluorescent, incandescent, and high-intensity discharge (HID) lighting — toward light-emitting diodes (LEDs). Hence adoption rates of LED lighting are expected to grow in the coming years as the efficacy and quality of LEDs surpass those of competing technologies and as prices fall to enable reasonable payback periods, according to the new research brief 'LED Supply Chain Dynamics' from Navigant Research.

The transition has been widely expected for a number of years, leading to the launch of new LED-focused companies and to the repositioning of existing lighting firms to take advantage of LED sales. Now that the rise of the LED has begun, the repercussions are rippling up and down the LED supply chain, says Navigant.

The total number of vendors involved in the LED supply chain will shrink over the remainder of this decade, the firm forecasts.

"Driven by a desire for vertical integration among the larger lighting companies — fueled, in turn, by the relentless demand for lower prices and higher quality — consolidation in this sector is likely to continue," says research analyst Jesse Foote. "Other factors, including the expiration of existing patents, new interchangeability standards, new technologies, and an expected upsurge in creative product designs, will create opportunities for new entrants at each level of the supply chain."

Navigant Research forecasts that annual revenue from LED lamps will grow from just over \$1.5bn in 2013 to more than \$8.5bn in 2021.

LED makers in China have attempted to master the process of epi deposition of GaN... they have had only limited success with high-quality wafers needed for high lumen output

While LED makers in China have attempted to master the process of epitaxial deposition of gallium nitride (GaN), they have had only limited success with the high-quality wafers needed for the high-lumen-output LEDs used for lighting, according to Navigant's report. The market is hence led by US, German, Japanese and Taiwanese firms such as Cree, Osram, Nichia and Epistar.

The report examines the specific trends that affect the manufacture of the primary components of an LED light, as well as the broad trends reshaping the industry. Regional influences and applicable international standards are detailed, and an industry map shows how some of the larger vendors fit within the supply chain. Recommendations for how industry players can best take advantage of the global opportunity presented by the shift toward LED lighting are also included.

www.navigantresearch.com/research/led-supply-chain-dynamics

LED lamp shipments to grow at 44.3% from 68 million to nearly 1.3 billion units by 2021

...but lamp and luminaire revenue to begin decline in 2017

Unit shipments of LED lamps worldwide will grow from 68 million in 2013 to 1.28 billion annually by 2021, according to the report 'Energy Efficient Lighting for Commercial Markets' from Navigant Research, as falling prices and improving quality are driving widespread adoption of LEDs and affecting every part of the commercial lighting industry. The markets for every other lighting technology will contract over 2013-2021, while LED technology appears likely to surpass all others in nearly every metric of

quality and efficiency, the firm adds.

"LED lighting has already begun to enter the commercial market in significant volume, and will grow rapidly over the remainder of the decade," says research analyst Jesse Foote. "Specific applications, such as cold storage, have already seen widespread LED adoption, while spaces that are currently lit by efficient linear fluorescent lamps await further LED price declines," he adds. "The industry has entered a period of rapid upheaval, as established and startup companies

scramble to position themselves to benefit from the rise of LED lighting."

Although shipments of LED products will expand at a compound annual growth rate (CAGR) of 44.3% through 2021, they will be insufficient to compensate for the overall fall in commercial lighting revenue as the industry moves toward much more long-lasting lamps, says the report. Lamp and luminaire revenue will both grow for the next few years, before beginning an inexorable decline in 2017, the study concludes.

www.navigantresearch.com

LEDs to account for quarter of lighting market by 2016

Due to significant expansion in manufacturing capacity, falling prices, environmental concerns and government incentives, the LED lighting market will double from 16 million units in 2012 to 33 million in 2013 and nearly triple by 2016, forecasts the NPD DisplaySearch 'LED Lighting Market and Forecast Report'.

Demand for all LED lighting products (e.g. spot lights, LED luminaires, street lights, LED light bulbs and fluorescent tubes) will reach 90 million in 2016, boosting global penetration for LED lighting from only 5% in 2012 to 26% in 2016, due largely to continued growth in commercial applications, government incentive programs, and consumer demand for energy-saving technology. Greatest growth will be in LED-based tubes that replace fluorescent (FL) tubes in commercial applications, LED-based street lights, and LED luminaires — innovative designs producing light across various shapes and sizes, says NPD DisplaySearch.

"LEDs are playing a leading role in the lighting industry, driven primarily by government incentive policies and consumer demand for more efficient light sources with advanced technologies such as wireless and color control," notes analyst Steven Sher. "This increased demand will manifest over the next three years, as consumers look to replace their traditional light bulbs with more efficient LED lighting options."

Japan and China lead demand

Japan has been the largest market for LED lighting applications since 2011, and NPD DisplaySearch projects this dominance will continue through 2016, driven by the adoption of LED bulbs, spot lights, fluorescent tubes, and luminaires. LED lighting growth in China will be higher than other regions from 2012 to 2016 due to government policies such as the 12th Five-Year Plan, which is already driving demand for LED street lights. North America and Europe are also experiencing increased demand for LED lighting

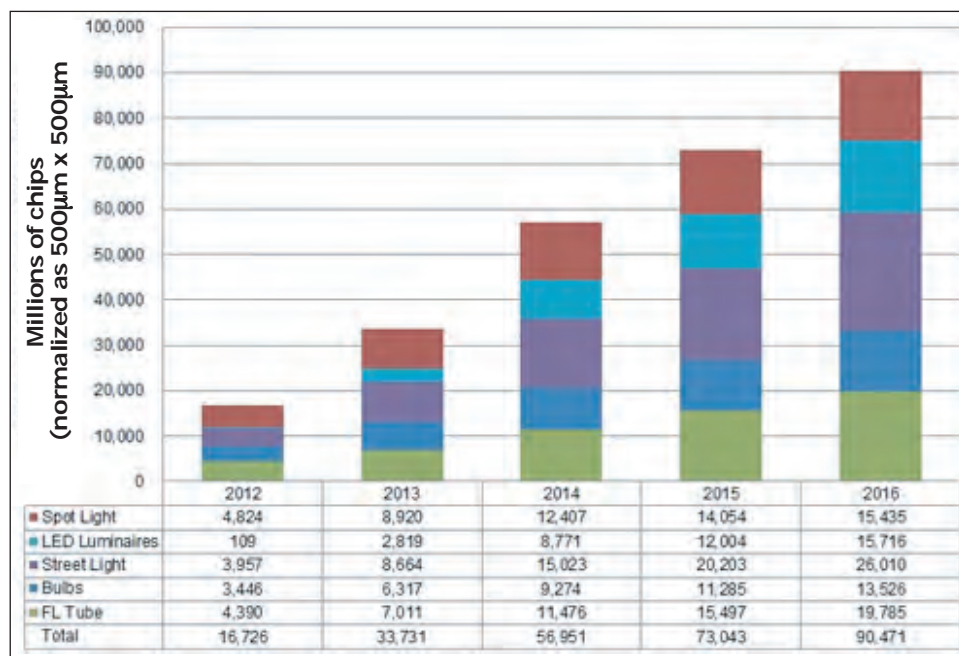


Figure 1: Demand in LED lighting applications.

applications through 2016, particularly for LED fluorescent tubes.

LED lighting is playing out in the context of a stagnant market for LEDs in LCD backlighting (currently the largest application for LEDs). In 2014, general illumination will pass display backlighting as the largest application, forecasts the firm.

In addition, the market for LED chips has been in oversupply as LED makers have invested heavily in MOCVD equipment, particularly in China. The surplus has caused competition to intensify and prices to

drop dramatically, leading to higher LED penetration in lighting, but lower profits for LED makers. This has led many LED makers to pursue vertical integration, with LED chip makers integrating the chip, phosphor, and control circuits to make lighting engines, and LED package makers integrating the lamp assembly. Success in the lighting market requires technical integration, but also optical design and the development of brand and channel strategies, concludes NPD DisplaySearch.

www.displaysearch.com

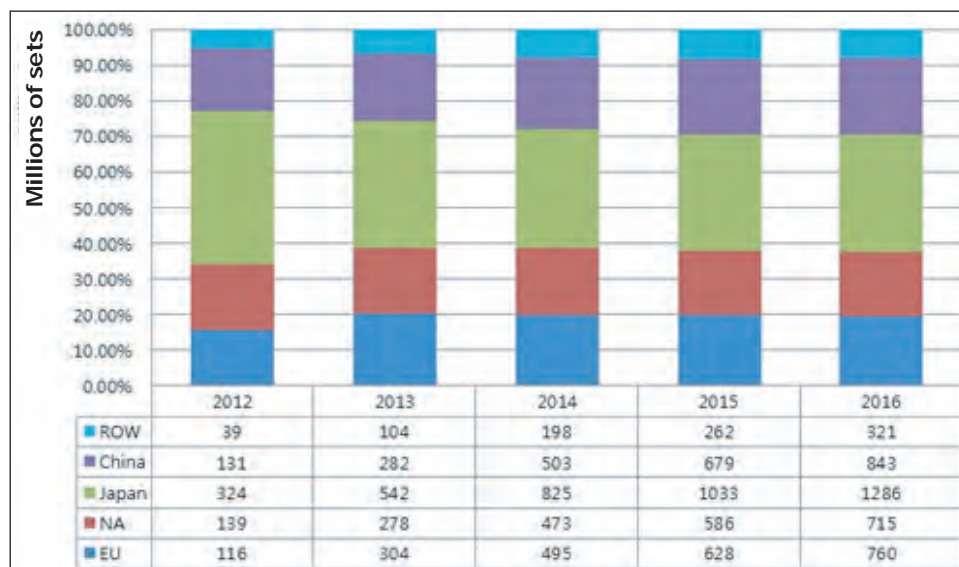


Figure 2: LED lighting demand by region.

China's LED lighting market to reach \$10bn in 2015, then \$22bn in 2020

Ban on 100W incandescents boosting adoption

The Chinese government passed a series of domestic policies in 2012 that have served to not only stimulate LED lighting demand but also to strengthen the entire business momentum within the LED lighting market, according to the 'Chinese Lighting Market Report (2013 version)' released by LEDinside (a research division of TrendForce). Key policies worth noting include the proposed spending of RMB2.2bn on the promotion of CFL and LED lights. Bans on the sales of 100W-and-above incandescent light bulbs — along with halogen lamps whose efficiency falls below required standards — took effect on 1 October 2012.

With the general demand for traditional lighting replacement, both LED-based and energy-saving lighting items are expected to gain

significant momentum. LEDinside has attempted to quantify the Chinese LED lighting market by formulating a model based on the original demand for general luminous flux and the replacement demand for LED-based lighting. To maximize accuracy, factors such as China's domestic economic growth and factors increasing the penetration of LED lighting in China were also taken into account. LEDinside forecasts that, by 2015, Chinese LED lighting demand will rise to as much as US\$10bn. Assuming that the country is successful in maintaining its economic growth and increasing the popularity of LED lighting, demand is likely to more than double from 2015 to US\$22bn in 2020, says LEDinside.

Despite the large scale of China's LED lighting market, different mar-

keting channels are expected to exert different impacts on the various production life-cycles of LED lighting products, says the market research firm. While China's LED industry development is at present still known to be dependent on engineering projects and bidding projects, the situation is expected to change for the better if more LED lighting manufacturers develop their business channels and traditional lighting manufacturers generally use LED luminaires. Via online and physical sales channels, the popularity of LED lighting products will ultimately rise, says LEDinside. In time, LED lighting is expected to break away from the confines of its segmented market and reach a broader audience in China, the firm adds.

www.LEDinside.com

LED lighting demand in Taiwan to take off in second-half 2013

LED bulb power rising from 8W to 10–12W

Driven by the mainstream power rating of LED light bulbs rising from 8W currently to 10–12W, demand for LED lighting in Taiwan is expected to take off in second-half 2013, with sales reaching 10 million bulbs for full-year 2013, according to Taiwan-based LED chip packaging house Everlight Electronics, reports Digitimes.

Everlight is cooperating with Tsann Kuen, a large IT and consumer electronics retail chain in Taiwan, for marketing its own-brand LED light bulbs. Tsann Kuen sold over 1 million LED bulbs in 2012, far exceeding the originally expected 200,000–300,000 units and representing huge growth from the 50,000–100,000 units sold in 2011. Tsann Kuen aims to sell

2.5–3.0 million LED bulbs in 2013.

While 8W LED bulbs account for 50% of Everlight's LED bulb shipments currently, 10W will become the mainstream power as soon as the end of June due to the increasing luminous efficiency and brightness of LED chips. Models of above 10W in power output will comprise more than 50% of LED bulbs sold by the end of 2013, Everlight reckons.

While 8W LED bulbs account for 50% of Everlight's LED bulb shipments currently, 10W will become the mainstream power as soon as the end of June

The availability of LED bulbs is expected to rise to 60% of all light bulbs for retail sale in Taiwan at the end of 2013, Everlight indicates. LED bulb prices in Taiwan and China are generally lower than other markets. Average prices for models replacing 60W incandescent bulbs are expected to drop further, from about US\$13.90 now to US\$10 in 2013, Everlight notes.

Everlight expects to remain the largest LED bulb vendor in Taiwan in 2013, with a market share of 30%. The firm has obtained 1000 Taiwan-issued patents related to LED lighting (much more than Taiwan-based fellow makers Lite-On Technology, Lextar Electronics and Unity Opto Technology, it is claimed).

www.digitimes.com

GaN and SiC power semiconductor market to rise 18-fold from 2012 to 2022

Price and performance parity with silicon devices by 2019 to drive GaN power market past \$1bn in 2022

Energized by demand from power supplies, photovoltaic (PV) inverters and industrial motor drives, the emerging market for silicon carbide (SiC) and gallium nitride (GaN) power semiconductors is forecast to grow a remarkable factor of 18 over 10 years, from just \$143m in 2012 to \$2.8bn in 2022, according to the report 'The World Market for SiC & GaN Power Semiconductors — 2013 Edition' from IMS Research (now part of HIS). Market revenue is expected to rise by double digits annually for the next decade.

SiC Schottky diodes have been around for more than 10 years, with SiC metal-oxide semiconductor field-effect transistors (MOSFET), junction-gate field-effect transistors (JFET) and bipolar junction transistors (BJT) appearing in recent years. In contrast, GaN power semiconductors are only just appearing on the market.

The wide-bandgap material GaN offers similar performance benefits to SiC but has greater cost-reduction potential, says IMS. This price/performance advantage is possible because GaN power devices can be grown on silicon substrates that are larger and lower-cost compared to SiC.

"The key factor determining market growth will be how quickly

GaN-on-silicon (Si) devices can achieve price parity and equivalent performance as silicon MOSFETs, insulated-gate bipolar transistors (IGBT) or rectifiers," says Richard Eden, senior market analyst for power semiconductor discretes and modules. "IHS expects this will be achieved in 2019, driving the GaN power market to pass the \$1bn mark in 2022."

SiC Schottky diode revenue exceeded \$100m in 2012, making it the best-selling SiC or GaN device currently. But, even though SiC Schottky diode revenue is forecast to grow until 2015, it will decline when lower-priced 600V GaN diodes become available. Still, revenue will recover to approach \$200m by 2022, with sales concentrated at voltage ratings of 1200V and above.

By then, SiC MOSFETs are forecast to generate revenue approaching \$400m, overtaking Schottky diodes to become the best-selling SiC discrete power device type. Mean-

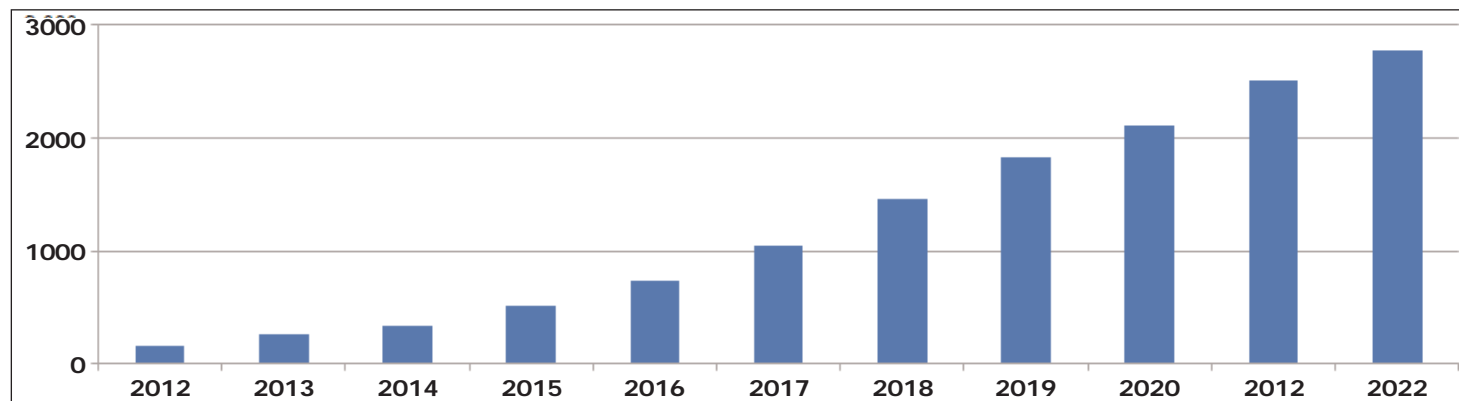
while, SiC JFETs and SiC BJTs are each forecast to generate less than half of SiC MOSFET revenues at that time, despite their likelihood of achieving good reliability, price and performance. End-users now strongly prefer SiC MOSFETs, so vendors of SiC JFETs and BJTs have a major task ahead in educating their potential customers on the benefits of these technologies, believes the market research firm.

While IHS predicts strong growth for the SiC and GaN power semiconductor market in the years ahead, the forecast has been significantly reduced compared to the outlook from one year ago.

The main reason for the change is the reduced forecasts for shipments of equipment that use power components, resulting from today's gloomier view of the global economy. SiC adoption forecasts have also been slashed because device prices are not falling as fast as originally assumed a year ago.

In contrast, industry confidence in GaN technology has increased, with more semiconductor firms announcing GaN development projects. For instance, Transphorm has become the first company to achieve JEDEC qualification for its GaN-on-Si devices, the report notes.

www.imsresearch.com



Global market forecast for SiC and GaN power semiconductor devices (revenue in millions of US\$).

Samsung takes 30% share of global smartphone market in first-quarter 2013 as iPhone loses ground

Q2 shipments to be hit by component shortages

Smartphone shipments grew steadily worldwide in Q1/2013, by 9.4% quarter-on-quarter to 216.4 million units in total, according to global research firm TrendForce. Since the beginning of 2012, smartphone shipment figures have risen each quarter despite seasonality, indicating the electronic device is here to stay.

In terms of first-tier manufacturers' shipment volumes, Samsung continues to take the lead in Q1, leveraging its vertically integrated supply chain, global marketing, and various sales channels. Samsung's smartphone series is expected to see 65 million units shipped this quarter, accounting for 30% of the global market.

As for Apple, iPhone 5 has been unable to satisfy consumers' desire for innovation, says TrendForce, and shipments were unsatisfactory as Android manufacturers stepped up to the plate. The firm shipped just

37.5 million units in Q1, representing a 17.3% market share (1.2 percentage points less than the previous quarter). Currently, circumstances surrounding

the announcement of Apple's new device are unclear, while Samsung, HTC, Sony, and other global corporations are planning product unveilings for Q2, which will likely lead to another dip in Apple's shipments, expects TrendForce.

Samsung takes all in China as Lenovo's results disappoint

Regarding China's smartphone market, Samsung is the leading brand in terms of both reputation and image, says TrendForce, as reflected in the manufacturer's sales figures. Initial estimates place

Manufacturers are facing problems with component supply (e.g. a shortage of memory products)

Samsung's smartphone shipments in China at 11.7 million units, giving the Korean maker a wide lead over other brands with a share of about 17% of China's smartphone market.

Other leading brands in China such as Huawei, ZTE and Lenovo were all affected in varying degrees, but on average China's domestic brands saw a 5–15% decrease in sales in Q1. Lenovo, which had nearly caught up to Samsung in market share in second-half 2012, saw sales of just 7.6 million units in Q1 (15% less than projected).

In Q2/2013, manufacturers are facing problems with component supply (e.g. a shortage of memory products like eMCP), notes TrendForce. Smartphone makers' relationships with their suppliers will hence determine how strong their shipment volumes will be in Q2, forecasts the market research firm.

www.trendforce.com

Low-cost smartphones to rise from 28% of smartphone shipments in 2012 to 46% by 2018

Sub-\$250 shipments to grow from 259 million in 2013 to 788 million

In many parts of the world, smartphone shipments account for a larger percentage of mobile handset shipments than feature phones and low-cost handsets, yet among smartphones segmentation is increasing to three price tiers (low, mid, and high). Shipments of sub-\$250 low-cost smartphones will grow from 259 million in 2013 to 788 million in 2018, while mid (sub-\$400) and high (\$400+)-cost smartphone shipments are expected to grow from 635 million to 925 million, according to recent findings in ABI Research's Mobile Handset Markets Database.

"As the feature-phone segment continues to lose its battle for rele-

vance, the low-cost smartphone has become the tool for operators seeking to drive increased data revenues," says senior analyst Michael Morgan. The growth of smartphones in pre-paid and emerging markets will be the primary driver of low-cost smartphone growth. Developed and subsidized markets are also finding that low-cost smartphones can capture the remaining consumers that have yet to convert to a smartphone while minimizing the margin impacts stemming from subsidizing high-cost smartphones, ABI notes.

However, mid- and high-cost smartphones will continue to play an important role for operators looking to seed their customer base

with the most advanced smartphones, adds the market research firm. Premium smartphones tend to carry the most advanced wireless connectivity and operators that are upgrading their network want to ensure that the handsets running on their network can deliver the best possible experience and customer satisfaction. "As smartphone penetration moves from early adopters to mass-market and laggard consumer segments, the smartphone as a product will be less dependent on technical superiority, and more dependent on reliability and value," says senior practice director Jeff Orr.

www.abiresearch.com/research/service/mobile-devices



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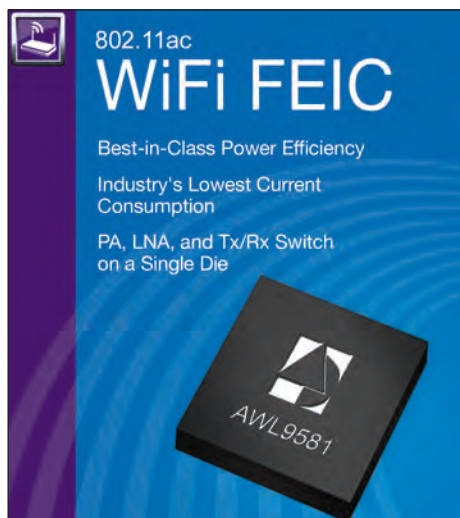
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Murata selects Anadigics' 5GHz 802.11ac front-end IC

GaAs-based broadband wireless and wireline communications component maker Anadigics Inc of Warren, NJ, USA says its AWL9581 front-end integrated circuit (FEIC) is being used in the latest WiFi module of Murata Manufacturing Co Ltd of Kyoto, Japan, which is now in mass production in support of high-volume smartphones equipped with 802.11ac WiFi technology. Murata's new WiFi module is optimized for mobile applications by providing complete high-performance WiFi connectivity in a compact package.

To meet the increasing demand for high-performance WiFi functionality, the wireless mobile device industry is rapidly transitioning to the new IEEE 802.11ac standard, says Anadigics. According to market research firm Strategy Analytics, 802.11ac will lead WiFi handset sales by 2016. In support of these trends, the AWL9581 delivers performance and integration to enable 802.11ac mobile devices with longer battery-life, greater range and higher data throughput, while minimizing space requirements.



Anadigics' AWL9581 front-end IC.

Anadigics says that its WiFi FEICs provide a combination of integration, power efficiency and linearity to accelerate time to market, increase battery life, and maximize throughput for mobile devices such as smartphones, tablets, netbooks, notebooks and gaming systems. The FEICs use the firm's exclusive InGaP-Plus technology and patented design architectures to combine a power amplifier (PA),

low-noise amplifier (LNA), and RF switch on a single die. This level of integration reduces valuable PCB space requirements and simplifies RF front-end design. Anadigics' WiFi FEICs also deliver ultra-low error vector magnitude (EVM) and noise figure performance in the toughest 802.11ac modulation formats, enabling extremely high data throughput and connectivity over greater range.

Specifically, the 5GHz AWL9581 also combines a high-accuracy integrated power detector and RF ports internally matched to 50Ω in its compact, low-profile 2.5mm x 2.5mm x 0.4mm QFN package.

"It is a perfect fit for applications that demand highly integrated, high-performance front-end functionality that is easy to use," reckons Dave Cresci, Anadigics' VP of WiFi Products. "With outstanding linearity and noise-figure performance, our new 802.11ac FEICs enable maximum throughput and range in mobile devices," he adds.

www.murata.com

www.anadigics.com

TriQuint launches packaged GaAs RF power amplifiers with high gain and efficiency

At the 14th annual IEEE Wireless and Microwave Technology Conference (WAMICON 2013) in Orlando, FL (7–9 April), RF front-end component maker and foundry services provider TriQuint Semiconductor Inc of Hillsboro, OR, USA launched three packaged gallium arsenide (GaAs) RF power amplifiers that deliver high output, gain and efficiency for commercial and defense applications including point-to-point microwave radio, radar, and VSAT.

The TGA2501-GSG is a 3.2W (35dBm), 6–18GHz RF power amplifier with 26dB small-signal gain, 19dB large-signal gain, 23% efficiency, and 8V/1.2A DC bias.

TGA2536-FL is a 5.5W (37.4dBm), 13.5–16GHz RF power amplifier



TriQuint's new RF power amplifiers.

with 25dB small-signal gain, 19dB large-signal gain, 20% efficiency, and 8V/2.6A DC bias.

The TGA2517-GSG is a 14W (41.6dBm), 7.5–11.5GHz RF power amplifier with 30dB small-signal gain, 22dB large-signal gain, 25% efficiency, and 12V/3A DC bias. The device is ITAR controlled (contact

TriQuint for license requirements).

All of the new power amplifiers incorporate integrated DC blocking capacitors, and are housed in a 14-pin 11.38mm x 17.32mm flange package.

The new amplifiers feature low-loss, ground-signal-ground (GSG) RF transitions designed to interface with a coplanar waveguide multi-layer PC circuit board for superior grounding. The packaging enables the amplifiers to serve on either side of a PCB board, facilitating a greater variety of component layout alternatives.

Samples and evaluation fixtures are available for all three of the new amplifiers.

www.triquint.com

Infineon launches SiGe transceiver family for millimeter-wave wireless backhaul; single-chip ICs simplify design of small-cell backhaul links

Germany's Infineon Technologies AG has introduced a silicon germanium (SiGe) based transceiver family to address the market for wireless data links with data rates of more than 1Gbps between LTE/4G base stations and core networks.

Devices in the BGTx0 product family come in a standard plastic package and replace more than 10 discrete devices used in current system designs with a single chip, simplifying system design and production logistics. Due to their low power consumption, the single-chip high-integration transceivers also help to reduce fixed expenses in high-data-rate millimeter-wave wireless backhaul communication systems. Customers' assembly processes can be simplified dramatically as they can continue to use a standard SMT assembly flow, says Infineon.

The BGTx0 family provides a complete RF front-end for wireless communication in 57–64GHz, 71–76GHz or 81–86GHz millimeter-wave bands. Paired with a baseband/modem, the system solution requires less space, and offers improved reliability and lower cost for the critical wireless backhaul links needed in mobile base stations that support LTE/4G networks, says the firm.

"The V- and E-band microwave frequencies available for LTE/4G backhaul support data rates three times higher than in earlier-generation networks. Correspondingly, they need superior RF performance to meet operating requirements," says Philipp von Schierstaedt, VP & general manager of the Business Line RF & Protection Devices at Infineon. "With this new transceiver family, Infineon leverages its process technology and RF design leadership to help system designers reduce complexity, simplify their

production logistics, and ultimately improve quality and field reliability of their backhaul connectivity solutions."

The BGTx0 transceivers integrate all of the RF building blocks – I/Q modulator, voltage-controlled oscillator (VCO), power amplifier (PA), low-noise amplifier (LNA), programmable gain amplifier (PGA), SPI control interface and more – on a single chip in a plastic eWLB package (embedded wafer-level ball grid array). Validation and calibration of RF performance occurs in production using built-in self-test (BIST), which contributes to the simplicity of integrating the chip into a device builder's production flow.

In terms of RF performance, SiGe technology offers output power of up to 18dBm of PA, a low noise figure of 6dB of the LNA and VCO phase noise better than –85dBc/Hz at 100kHz offset. The technology allows system designers to implement high modulation schemes up to QAM64 with a sample rate of 500Msamples/sec and QAM32 with 1Gsamples/sec at a 10^{-6} BER (bit error rate). ESD (electrostatic discharge) performance of more than 1kV increases robustness and eases system design, says the firm.

The low power consumption of less than 2W for this backhaul transceiver family also allows network operators to reduce related fixed expenses. Due to the direct conversion architecture of the transceiver, the interface between RF and baseband is simplified significantly compared to currently available discrete millimeter-wave systems.

Engineering samples of the BTGx0 family will be available in September, with production ramp planned for late this year.

www.infineon.com/backhaul

Skyworks supports Samsung's GALAXY S 4 smartphones

Skyworks Solutions Inc of Woburn, MA, USA is supporting Samsung's Galaxy S 4 smartphone platforms with multiple analog and front-end solutions.

"Given our broad product portfolio and system-level expertise, we have expanded our partnership with Samsung beyond delivering traditional power amplifiers to providing an entire suite of solutions for an unprecedented level of analog and RF integration," says executive VP & corporate general manager Liam K. Griffin.

Skyworks' content in the Galaxy S 4 platforms includes multi-mode, multi-band front-end solutions, LTE power amplifiers, 2.4 and 5GHz WiFi front-end modules (FEMs), DC/DC converters and diversity switches.

Skyworks' analog and front-end solutions include:

- SKY13415-485 LF, a 0.1–3.0GHz, single-pole, five-throw antenna switch with internal 50Ω termination;
- SKY85303-11, a complete 802.11b/g/n WLAN RF FEM with a Bluetooth port;
- SKY85707-21, a 5GHz FEM incorporating a single-pole, double-throw transmit/receive switch, a low-noise amplifier with bypass, and a PA;
- SKY87000-13, a step-down regulator with auto-bypass LDO for multi-band and multi-mode RF PAs;
- AAT1171, a 600mA voltage-scaling, step-down DC/DC converter for controlling the operating voltage of a WCDMA or CDMA PA inside single lithium-ion battery-powered systems;
- SKY77615, a hybrid, multi-mode, multi-band power amplifier module (PAM);
- SKY77619, a multi-band, multi-mode PAM for quad-band GSM/EDGE and penta-band WCDMA, HSDPA, HSUPA, HSPA+ and LTE;
- SKY77737 is a fully matched, surface-mount PAM developed for LTE application bands 12/17.

www.skyworksinc.com

IN BRIEF

Avago's Wireless Semiconductor Division's general manager made COO

Avago Technologies Ltd of San Jose, CA, USA and Singapore (a designer, developer and supplier of III-V-based analog interface components for communications, industrial and consumer applications) has appointed Bryan Ingram, senior VP & general manager of its Wireless Semiconductor Division, to serve as the firm's senior VP & chief operating officer.

Ingram was VP & general manager of the Wireless Semiconductor Division from Avago's formation out of Agilent's Semiconductor Products Group in 2005 until being promoted to senior VP in 2007. He joined Hewlett-Packard in 1990 and held various positions at Hewlett-Packard and then Agilent. Ingram has a BSEE from the University of Illinois and an MSEE from The Johns Hopkins University.

"Bryan is a proven operator with decades of experience growing the Avago wireless franchise into a highly profitable technology leader," says president & CEO Hock Tan. "I see a lot of value in leveraging Bryan's talent across all of our businesses."

www.avagotech.com

Javelin sold by Silverton Partners and Sevin Rosen Funds to Avago Expansion of sales, marketing and admin required to continue growth

Investors Silverton Partners and Sevin Rosen Funds have sold their stakes in Javelin Semiconductor Inc of Austin, TX, USA, which was one of the first firms to develop 3G wireless communications power amplifiers (PAs) based on industry-standard CMOS silicon, to Avago Technologies Ltd of San Jose, CA, USA and Singapore (a designer and supplier of III-V-based analog components for communications, industrial and consumer applications).

Founded in 2007, in less than five years of operation Javelin had raised over \$21m in venture capital funding led by Austin-based Silverton Partners and Dallas-based Sevin Rosen Funds, including a \$6.3m Series A round of funding, followed by a \$6.2m Series B round involving 14 investors in February 2010, a \$4m Series C round involving 17 investors in May 2011, and a \$5m Series D round involving 16 investors in February 2012. Since then, Javelin has shipped several power amplifiers developed for cellphones made by Korea's Samsung Electronics Co Ltd.

According to the Austin American-Statesman publication, CEO Brad Fluke (formerly of Austin-based cell-phone PA developer Silicon Laboratories Inc) said last fall that Javelin had grown to 29 staff and

was shipping about 1 million chips per month. However, Sevin Rosen Fund's Jon Bayless told the Wall Street Journal that the firm had grown to where it would either have to expand its sales, marketing and administration spending or find a buyer.

Morgan Flager of Silverton Partners says that other firms (in addition to Avago) took an interest in Javelin late last year, after Qualcomm Inc (the world's largest cell-phone IC maker) announced its plans to develop a CMOS silicon-based power amplifier.

Avago began as part of Hewlett-Packard Co in 1961, and in 1999 became the semiconductor products group of spin-off Agilent Technologies Inc. In 2005 it was acquired for \$2.66bn in a leveraged buy-out by private-equity firms Kohlberg Kravis Roberts and Co (KKR) and Silver Lake Partners, becoming Avago. In 2008, the firm raised \$400m in an initial public offering of stock on NASDAQ. With staffing of about 3600, revenue in 2012 was \$2.4bn.

The acquisition of Javelin follows Avago's purchase earlier in April of CyOptics of Lehigh Valley, PA, USA, which makes indium phosphide-based optical chips and components, for about \$400m in cash.

www.javelinsemi.com

RF Micro Devices adds VP, Foundry Services

RF Micro Devices Inc of Greensboro, NC, USA has appointed James A. Clifford as VP, Foundry Services.

Clifford has broad experience in technology, procurement, supply chain, operations, quality, and program management. From 1994 to 2012, he was at Qualcomm Corp, most recently as senior VP & general manager Operations. Previously, he spent 21 years at Unisys Corp,

in positions of increasing responsibility covering manufacturing, engineering and procurement. Clifford also holds a BS in Physics from San Diego State University.

In his newly created position at RFMD, Clifford will report to James D. Stilson, corporate VP of Operations, with responsibility for relationships with external foundry partners.

"Jim is extremely well respected throughout the technology industry," says president & CEO Bob Bruggeworth. "Given Jim's broad knowledge of all areas of the semiconductor industry, we expect him to contribute immediately to our ability to deliver the industry's highest-performance and most innovative technologies and RF solutions."

www.rfmd.com

AWR showcases 2013 release of Design Environment

At the IEEE MTT-S International Wireless Symposium (IWS2013) in Beijing, China (16–18 April), AWR Corp of El Segundo, CA, USA, which supplies electronic design automation (EDA) software for designing RF and high-frequency components and systems, showcased its first new release in 2013 of the AWR Design Environment, inclusive of Microwave Office/Analog Office circuit design software and Visual System Simulator (VSS)

system design software, as well as AXIEM 3D planar electromagnetic (EM) software and Analyst 3D finite element method (FEM) EM software. The firm also demonstrated joint hardware/software solutions with parent company National Instruments.

AWR also presented the following papers at the Industrial Forum:

- 'A Novel Design Methodology for MMIC Applications', by AWR's Dr Milton Lien;

- 'Design and Simulation of Modern Radar Systems', by AWR's Peter Xu;
- 'Linking RF Design and Test — Connecting RF Design Software to LabVIEW & Modular Instruments', by National Instruments' Yuan Yao and AWR's Yufu Li.

AWR (a silver sponsor at the event) also awarded both cash and in-kind software contribution prizes to the winning teams of the IWS Student Paper Competition.

www.awrcorp.com

M/A-COM adds finance expert

M/A-COM Technology Solutions Inc of Lowell, MA, USA (which makes analog semiconductors, components and subassemblies for RF, microwave and millimeter-wave applications) says Mark Edelstone will join its board as an independent director.

Edelstone has 23 years of experience in evaluating and providing strategic and financial advice to publicly traded semiconductor companies. He will also serve on M/A-COM's Audit Committee and as chairman of the Nominating and Governance Committee.

"Mark's deep insight into the semiconductor industry will strengthen our board of directors' ability to identify and evaluate the merits and risks of strategic and financial opportunities," says president & CEO John Croteau. "Additionally, Mark's experience in the financial industry will assist the board's oversight of our financial reporting, treasury functions and internal financial controls."

Edelstone is a managing director at Morgan Stanley. He has an undergraduate degree in Political Economics from the University of California, Berkeley, and an MBA in Finance (with a concentration in Investments) from Golden Gate University. Also, Edelstone holds the Chartered Financial Analyst and Chartered Market Technician designations.

www.macomtech.com



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Peregrine files additional patent lawsuit against RFMD

Peregrine Semiconductor Corp of San Diego, CA, USA, a fabless provider of RFICs based on silicon-on-sapphire (SOS), has filed a new lawsuit alleging infringement of its intellectual property relating to RFICs and switching technology by RF Micro Devices of Greensboro, NC.

Filed in US District Court for the Southern District of California, the suit claims that certain RFMD products infringe a newly issued Peregrine patent relating to silicon-on-insulator (SOI) technology for RFICs. In addition to damages, Peregrine seeks to permanently enjoin RFMD from further infringement. This new legal action is in addition to an existing lawsuit filed against RFMD in February 2012 and currently pending in US District Court.

The new patent (US Patent 8,405,147) concerns Peregrine's HaRP invention, which is claimed to significantly improve the linearity and circuit performance of RF SOI devices. Peregrine believes that the HaRP invention is instrumental for RF SOI devices to successfully meet the demanding RF requirements of advanced mobile wireless applications such as 4G LTE.

"Peregrine has enabled significant advancement in the RF front-end architectures of mobile wireless devices with our high-performance products and technology," claims president & CEO Jim Cable. "Our innovative products are used extensively in the latest generation of mobile devices," he adds. "Peregrine's proprietary UltraCMOS

process and design technologies are the result of more than 20 years of intensive research and development activity and the investment of approximately \$200m. Peregrine is committed to a vigorous defense of its intellectual property and continuing advancements in the field."

Peregrine has been awarded numerous US and foreign patents based on its work in developing and manufacturing high-performance products using CMOS-based semiconductor manufacturing processes. Such patented innovations allow RFICs to deliver what is claimed to be a unique combination of high levels of monolithic integration and performance, small size and low power consumption.

www.psemi.com

AEC-Q100-certified SPDT RF switch for automotive designs

Peregrine has launched an Automotive Electronics Council (AEC) Q100-certified SPDT RF switch.

The HaRP technology-enhanced PE42359 RF switch is certified to AEC-Q100 Grade 2. The switch is available in a miniature 6-lead SC-70 package and is suitable for automotive applications such as Remote Keyless Entry (RKE), emergency communication systems, Tire Pressure Monitoring Systems (TPMS), automotive multimode compensator modules, and automatic toll systems, says the firm.

The AEC-Q100 certification was developed to provide automotive manufacturers and suppliers with industry-wide methods and procedures for obtaining the best, most robust device for the application. AEC-Q100-certified products are graded by temperature range, with Grade 2 certification putting the IC through reliability stress tests over the extended temperature range of -40°C to +105°C. To be certified, several thousand samples of the IC must withstand the stress tests for an extended period of time. Previously, a year ago, Peregrine



Peregrine's PE42359 SPDT RF switch.

achieved ISO/TS 16949 quality system certification.

"The launch of the PE42359 RF switch reaffirms our commitment to expanding our product portfolio to reach new markets and customers," said Gene Lyons, VP of quality assurance. "We now have a proven ability to manufacture products that meet the rigorous quality and performance requirements of the automotive market," he adds.

"The growing trend toward more telematics and infotainment in today's automobiles is creating demand for high-performance RFICs that meet the stringent reliability

standards of the AEC-Q100 stress test qualification," says Mark Schrepferman, director of the communications and industrial product line for Peregrine's High-Performance Solutions business unit. "UltraCMOS is an advanced form of

silicon-on-insulator process utilizing a highly insulating sapphire substrate, which enables our products to operate reliably at elevated temperatures. This, along with the repeatability of a CMOS manufacturing process, makes our products well suited for automotive applications."

The PE42359 switch is available for \$0.39 each in 10k-unit quantities. The firm has also announced availability of an Evaluation Kit (part number EK42359-01, costing \$70), enabling designers to demonstrate the switch in their applications.

www.psemi.com

Peregrine's UltraCMOS RFICs designed into six Globalstar mobile communication satellites

Peregrine Semiconductor Corp of San Diego, CA, USA, a fabless provider of radio-frequency integrated circuits (RFICs) based on silicon-on-sapphire (SOS), says that its UltraCMOS phase-locked loop (PLL) frequency synthesizer and prescaler devices are designed into six Globalstar mobile communication satellites that were launched into orbit on 6 February. Built by Thales Alenia Space, France, the low-Earth orbit satellites transmit audio and data communications for Globalstar's mobile voice and data customers.

Peregrine's PLL and prescaler enable communication in 16 C- and S-band transponders in the system, which connects end-users with terrestrial communication networks via vehicle-mounted mobile devices, as well as fixed terminals, such as those used for rural telephony. The devices feature extremely

low phase noise and single-event effect (SEE) immunity, enabled by the insulating properties of UltraCMOS process technology, as well as low power, small form factor, and light weight, says the firm.

"Our products have nearly 20 years of commercial space flight heritage in some of the most high-profile missions, and we've considered Thales Alenia Space an important partner in our endeavor to provide market-leading RF performance in the most demanding radiation-rich environments," says Dave Shepard, VP of Peregrine's High-Performance Solutions business unit. "UltraCMOS, with its inherent radiation-induced latchup immunity, continues to be the technology of choice for this, or any, space application," he reckons.

Single-event effects (SEEs) are errors that are caused by naturally occurring space-based radiation. There are two primary types:

single-event upsets (SEUs) are non-destructive and can be corrected, and single-event latchups (SELs), which are often catastrophic and result in permanent damage (requiring at least a power-down to recover). SELs can occur when a high-energy particle strikes a semiconductor device, causing a short circuit from power to ground within the device. RFICs manufactured using UltraCMOS technology do not contain the bulk parasitics found in regular CMOS devices, making latchup impossible.

Peregrine's UltraCMOS technology is an RF silicon-on-insulator (SOI) process that uses a synthetic sapphire substrate, which enables low parasitic capacitance, high signal isolation, broadband linearity, and inherent SEL immunity (suited for high-reliability applications such as commercial satellites), says the firm.

www.psemi.com

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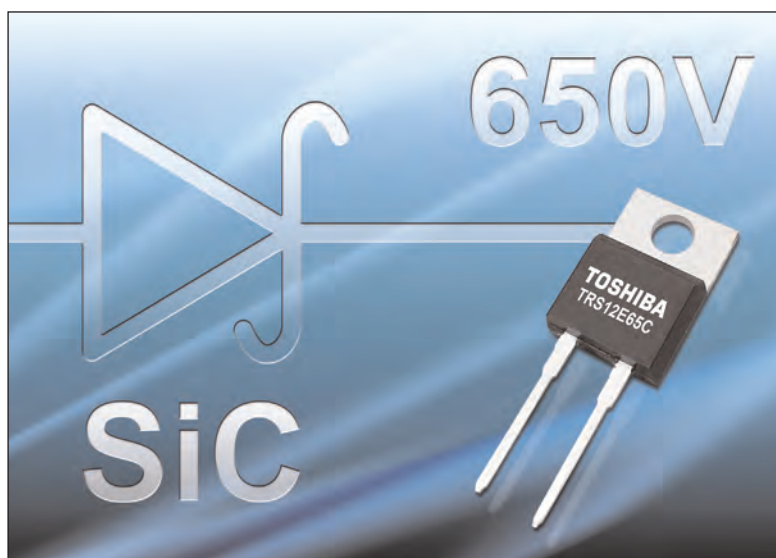
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Toshiba starts volume production of SiC power devices with 650V Schottky barrier diode

In anticipation of growing demand for industrial and automotive applications, Japan's Toshiba Corp has started volume production of silicon carbide (SiC) power devices at its Himeji Operations-Semiconductor plant in Hyogo Prefecture.

As the first of its new line-up of SiC products, Toshiba will manufacture the 650V TRS12E65C Schottky barrier diode (SBD). Operating at a current of 12A and a forward voltage of 1.7V maximum, the SBD is suited to applications including power conditioners for photovoltaic power generation systems. SBDs can also act as replacements for silicon diodes in switching power supplies, where they are about 50% more efficient.

SiC power devices offer more stable operation than current silicon devices - even at high voltages and currents - as they significantly



Toshiba's TRS12E65C 650V Schottky barrier diode.

reduce heat dissipation during operation, says Toshiba. They meet diverse industry needs for smaller, more effective communications devices and suit industrial appli-

cations ranging from servers to inverters and trains to automotive systems, the firm adds.

Analysts estimate that the SiC power device market will grow to about 10 times the current scale by 2020.

Toshiba aims to secure 30% market share in 2020 by strengthening its product line-up, starting with the launch of the new SBD.

www.toshiba.co.jp/index.htm

Cree's 1200V SiC MOSFETs enable Delta Energy Systems' next-generation solar inverters

Delta Energy Systems, a subsidiary of Delta Electronics Group (one of the world's largest providers of power management solutions), has launched a new generation of solar photovoltaic (PV) power inverters that use SiC power MOSFETs made by Cree Inc of Durham, NC, USA.

"The next-generation PV inverters from Delta are designed to set a new milestone of power density by utilizing SiC MOSFETs," says Klaus Gremmelspacher, head of R&D for PV inverters at Delta Energy Systems. "The SiC MOSFETs from Cree were essential for us to realize our goals for new, high-power inverters that are lightweight and have industry-leading efficiency," he adds.

Cree released the first SiC MOSFETs (used for their ability to cut losses and allow PV inverters to run at higher efficiencies and higher power densities) in 2011, followed



Cree's SiC MOSFET and Delta's inverter.

by a much improved, second-generation SiC MOSFET in 2013.

Now, using 1200V SiC MOSFETs from Cree in an 11kW PV inverter, Delta has been able to extend the DC input voltage range while maintaining and even increasing the maximum efficiency of its previous products. The Delta 11kW booster,

which now has 1kV DC input instead of 900V, is targeted for release before the end of second-quarter 2013.

"Delta Energy Systems is utilizing the 1200V, 160mΩ MOSFET, which has matured rapidly since its release in 2011," says Dr Scott Allen, senior director of marketing, Cree Power. "Advanced technology customers like Delta are now moving aggressively forward with our SiC MOSFET technology, which enables reduced size, weight and cost for PV inverters, from 20% to 50% when compared with silicon, while at the same time maintaining or increasing efficiency," he adds.

Packaged SiC MOSFETs from Cree are available from DigiKey and Mouser, and die are available from SemiDice.

www.cree.com/power

www.deltaenergysystems.com

Mitsubishi Electric delivers first SiC-based auxiliary power supply systems for railcars

Tokyo-based Mitsubishi Electric Corp has commercialized and delivered railcar auxiliary power supply systems that incorporate what it claims are the first silicon carbide (SiC) power modules for use in operating trains. The systems are now being installed for test purposes in the new Type 1000 railcars of Tokyo Metro's Ginza Line subway, which are scheduled to enter commercial operation in June.

Compared to Mitsubishi Electric's existing system incorporating silicon (Si) power modules, the new system achieves 30% less power loss, is 20% smaller and 15% lighter, says the firm. It also reduces transformer noise by 4dB due to a 35% improvement in the distortion rate of output voltage waveforms.

Compared to Si, SiC helps to reduce size and weight through lowered power loss and higher energy efficiency, as well as smaller

power module radiators. Mitsubishi Electric has developed a variety of SiC power module applications, including the first large-voltage SiC railcar inverters for DC600V/750V power lines (launched in October 2011 and incorporated in Tokyo Metro's Ginza Line Type 01 railcars in February 2012). Also, SiC railcar inverters developed for DC1500V power lines were launched in November 2012 and installed in Tokyo Metro's Tozai Line Type 15000 railcars beginning in January 2013.

The new SiC auxiliary power supply system incorporate technologies Mitsubishi Electric developed for SiC inverters.

Mitsubishi Electric is developing total railway energy solutions for enhanced energy management of railcars, including the new SiC auxiliary power supply systems, as well as stations, rail yards and train lines.

www.MitsubishiElectric.com

IN BRIEF

Richardson launches GaN website

Richardson RFPD has launched a new website resource focused exclusively on gallium nitride.

Several manufacturers are driving innovation in GaN discrete devices and modules, says the firm, and the site's new GaN technology section offers a range of power transistors, power amplifiers and switches from Empower RF Systems, M/A-COM Technology Solutions, Microsemi, Nitronex, TriQuint, and United Monolithic Semiconductors (UMS).

The featured GaN products suit broadcast transmission, aerospace and defense, commercial and military avionics and radar, communications, test & measurement, small-cell, and wireless infrastructure applications.

The GaN website also has links to technical resources, from applications notes to brochures, selector guides, videos and white papers.

www.richardsonrfpd.com

Plextek selects Agilent's Momentum simulation software for high-frequency IC and MMIC design

Agilent Technologies Inc of Santa Clara, CA, USA says that Plextek RF Integration, a UK-based company that designs and develops RFICs, MMICs and microwave/millimeter-wave modules, has selected Agilent's Momentum software to simulate its new high-frequency circuit and MMIC designs.

After an evaluation of available 3D planar electromagnetic software tools, Plextek RF Integration chose Momentum software for its performance and flexibility, says Agilent. Momentum is integrated with Agilent's Advanced Design System and Genesys RF and microwave design software.

In its evaluation, Plextek RFI used Momentum to simulate the per-

formance of a 57–64GHz amplifier IC. The firm also used Momentum to develop a number of Ka-band ICs. In all cases, the software provided excellent agreement between measured and modeled data. Additionally, Momentum's tight integration with ADS provided Plextek RFI with greater ease of use, making its EM simulation of RFICs and MMICs quick and straightforward.

"Designing advanced, high-frequency circuits and MMICs requires access to the industry's most advanced modeling and simulation tools," says Plextek RFI's CEO Liam Devlin. "The performance and flexible features of Agilent's Momentum software provides us the functionality we need to maintain a leading

edge in the highly competitive wireless, microwave and millimeter-wave markets in which we compete," he added. "Because of this, we plan to leverage this solution on future design projects, including our current development of an LNA covering the full 71–86GHz range of E-band."

"We are pleased Plextek RFI selected Momentum for its amplifier IC and MMIC development," says Joe Civello, ADS product planner at Agilent EESof EDA. "The accuracy, speed and capacity of our software are enabling Plextek RFI to produce high-quality designs that can stand apart from their competition."

www.agilent.com/find/eesof

GaN amplifier to be launched on ESA's Proba-V earth observation mini-satellite

Fraunhofer-IAF's GaN HEMTs enable faster, lighter and more compact X-band communication electronics

The launch by the European Space Agency (ESA) of its Proba-V earth observation mini-satellite in the coming weeks will represent the first time that a European-made device based on gallium nitride (GaN) will be sent into space. This follows an intensive test series that has qualified the amplifier — developed by Fraunhofer Institute for Applied Solid State Physics IAF in Freiburg, Germany — for launch into space.

The satellite weighs about 140kg and is just about the size of a washing machine. The mini-satellite Proba-V is covered in solar cells and will be observing the vegetation on earth. Every other day, the environmental satellite will send pictures from a distance of about 820km. Rain forest destruction, pollution of the seas and soil erosion will be made visible by pictures taken in various spectral ranges.

Being more robust, more compact and lighter than traditional solutions, the new GaN technology promises to significantly improve communication electronics in space. "We expect signal strength and data transmission to improve five- or tenfold," says Andrew Barnes, who is responsible for the project at ESA. Based on GaN high-electron-mobility transistors (HEMTs), the amplifier circuit operates in the 8–8.5GHz (X-band) frequency range for Proba-V's communication system. Tesat-Spacecom GmbH of Backnang, Germany, in cooperation with SCHOTT Electronic Packaging, packaged the amplifier together with further components into a hermetically sealed housing suitable for operation in space. "We are eagerly awaiting the results of the first practical test in space," says Barnes.



The Proba-V mini-satellite. © ESA.

Robust and reliable in stress tests

GaN devices can be operated under much higher voltages and temperatures than traditional silicon or gallium arsenide components. The circuits are more compact, smaller and lighter than other solutions, and may replace electron tubes currently used for amplification. This would greatly cut weight and transport costs, which can amount to €30,000/kg of payload. Due to the long lifetime and radiation hardness of the material, such electronic devices are suited to the extreme conditions of aerospace.

However, before being authorized for space travel, the GaN device had to prove its resilience. It was exposed to cold and heat, strong vibration and motion as well as radiation. "Accelerated lifetime tests, conducted together with Tesat-Spacecom, have shown that our gallium nitride amplifier will live for at least 20 years," says Dr Patrick Waltereit, project leader at Fraunhofer IAF. "The approval of our device for the flight into space is an important milestone for the further development of gallium nitride technology, also for other areas of application," he adds.

Pushing the limits of silicon technology

Due to its exceptional physical properties, GaN is suited to applications in power electronics, says Fraunhofer IAF. Compared with semiconductors such as silicon and GaAs, GaN has a larger bandgap (3.4eV) and higher breakdown field strength (3.3MV/cm). Higher dielectric strength and current density result in a fivefold increase in power density. Moreover, the usable frequency range is larger in GaN, allowing several functions to be integrated on one chip. Also, GaN's thermal robustness results in a considerable decrease in cooling effort, which is both energy- and cost-efficient. This makes compact and energy-efficient GaN devices interesting not only for applications in aeronautics but also for voltage converters for the batteries of electric cars, solar panels or household appliances. Fraunhofer IAF says that the devices hence offer great potential especially for applications that demand high performance and long lifetime even in harsh environmental conditions (where silicon technology meets its limits).

The project is part of the initiative Great² ('GaN Reliability Enhancement and Technology Transfer Initiative'), which ESA established to exploit the potential of GaN technology for aeronautics. Together with industrial partners, research institutes involved in III-V semiconductors such as Fraunhofer IAF develop high-quality GaN-based devices under the project leadership of Tesat-Spacecom, with the aim of strengthening the competitiveness of the European aerospace industry.

www.iaf.fraunhofer.de

<http://great2-project.com>

www.tesat.de

UK's EPSRC funds R&D project on high-thermal-conductivity substrates for GaN electronics at two universities £430,597 to Bath and £393,218 to Bristol

The UK's Engineering and Physical Sciences Research Council (EPSRC) has awarded funding totaling more than £823,800m to two universities for the project 'Novel High Thermal Conductivity Substrates for GaN Electronics: Thermal Innovation' (from 1 May 2013 to 30 April 2016).

A £430,597 grant (EPSRC reference EP/K024337/1) goes to the University of Bath's Department of Electronic and Electrical Engineering, with principal investigator Dr DWE Allsopp joined by professor W Wang as the other investigator.

A £393,218 grant (EPSRC reference EP/K024345/1) goes to the University of Bristol's Department of Physics, with principal investigator professor M Kuball joined by professor D Cherns as the other investigator. Bristol's project partners are IQE Silicon Compounds Ltd, NXP Semiconductors UK Ltd and Plessey Semiconductors Ltd.

In their grant application, the researchers say that AlGaIn/GaN high-electron-mobility transistors (HEMTs) are a key enabling technology for future power conditioning applications in the low-carbon economy, as well as for both high-efficiency military and civilian microwave and RF systems.

Although the performance of AlGaIn/GaN HEMTs currently reaches RF powers of up to 40W/mm at frequencies exceeding 300GHz, their long-term reliability, which is often thermally limited, is still a serious issue, not only in the UK and Europe but also in the USA and Japan. Corresponding challenges exist for power conditioning applications.

To mitigate the existing thermal device challenges, the aim of the project is innovation and step change in thermal management of AlGaIn/GaN HEMT devices by devel-

oping novel substrates, in particular (1) high-value substrates that have higher heat extraction capability than high-cost silicon carbide (SiC) substrates commonly used for GaN RF applications, and (2) low-cost substrates that have improved heat extraction capability to gallium nitride on silicon (GaN-on-Si) substrates for more cost-sensitive power electronics markets. The resulting step-change in improvement in heat spreading should improve reliability, circuit efficiency and ease system constraints of GaN electronics, it is reckoned. To enable optimization of thermal substrate properties, key enabling new thermal analysis technologies will be developed.

The UK has roadmaps for employing RF and microwave GaN electronics in defence as well as satellite communication. Key UK industrial players in this field include Selex, MBDA, and Astrium, all requiring reliable and efficient GaN RF and microwave electronics, which the project aims to enable via the new heat-extracting substrate technologies and improved thermal characterization methods. IQE UK, which is supporting the project, is a key component in the supply chain for RF GaN applications.

The corresponding roadmap for power electronics requires cost-effective GaN power devices on silicon substrates, with UK-based manufacture at project partner NXP as well as International Rectifier (IR).

Further business opportunities are expected to emerge through development of the substrate itself (e.g. via Element-6), at IQE through the development of III-nitride epitaxial growth for optimum heat extraction, or through spin-out companies.

www.bath.ac.uk

www.bris.ac.uk

IN BRIEF

Solid-state GaN RF amplifier for electronic warfare and radar offered by Comtech PST

Comtech PST Corp in Melville, NY, USA is introducing the BME69189-20 high-power-density solid-state RF module for electronic warfare, radar transmitters, and communications applications where space, cooling, and power are limited.

The integrated RF gallium nitride (GaN) 6-18GHz RF amplifier for RF and microwave applications has an output power at 1dB compression (P1dB) of more than 20W; gain at 20W of more than 41dB; maximum RF input overdrive of 10dBm; and built-in test that includes composite fault indication, over-current, and over-voltage.

The RF GaN amplifier has a seven-pin DC control interface; DC input of 28V DC; standby power of 35W; DC-to-RF efficiency of 14%; operates in temperatures from -50°C to +55°C at the baseplate; and meets MIL-STD-810F for shock and vibration.

The GaN RF amplifier weighs five pounds and measures 6.56 by 3.5 by 0.84 inches.

Comtech PST supplies broadband, high-power, high-performance RF microwave amplifiers and switches using gallium nitride (GaN) transistor technology for applications including defense, medical, satellite communications systems and instrumentation. Parent company Comtech Telecommunications conducts business through three complementary segments: telecommunications transmission, RF microwave amplifiers and mobile data communications.

www.comtechpst.com

IN BRIEF

EPC development board for eGaN FETs upgraded with gate driver from TI

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA says its EPC9005 development board featuring the firm's 40V EPC2014 enhancement-mode gallium nitride (eGaN) field-effect transistors (FETs) — launched in August 2011 — is now available in upgraded form using a dedicated GaN FET gate driver from (TI) Texas Instruments. The board demonstrates how IC gate drivers, optimized for eGaN FETs, make the task of transitioning from silicon to eGaN technology simple and cost effective, says the firm.

The EPC9005 development board is a half-bridge configuration containing two 40V EPC2014 eGaN FETs with a 7A maximum output current using TI's LM5113 gate driver (optimized for GaN devices). The LM5113 used on the board is housed in a 2x2 BGA package, allowing for a very compact power stage with the driver and two eGaN FETs. The EPC2014 is designed for use in applications such as high-speed DC-DC power supplies, point-of-load converters, wireless charging, and high-frequency circuits.

EPC says that the EPC9005 simplifies the evaluation process of eGaN FETs by including all the critical components on single 2" x 1.5" boards that can be easily connected into any existing converter. There are also various probe points on the board to facilitate simple waveform measurement and efficiency calculation. A Quick Start Guide is included for reference and ease of use.

The EPC9005 development board is \$99.18, available from Digi-Key. http://epc-co.com/epc/documents/guides/EPC9005_qsg.pdf

Panasonic develops 600V GaN power transistor with 'failure-free' stable switching operation

Panasonic Corp of Osaka, Japan has announced the development of a gallium nitride (GaN)-based power transistor with a blocking voltage of 600V that enables stable switching operations. Shipment of evaluation samples began in March.

The firm claims that its design will for the first time ensure 'failure-free operation' by 600V GaN power transistors. The GaN transistors, housed in a small-size package, are also said to contribute to saving energy in a variety of power switching systems for both industrial and consumer applications.

The new GaN transistor has the following three key technical features:

● Normally-off gate injection transistor on 6-inch silicon substrate

Power switching systems require normally-off operation of such transistors for safe operation. Lowering the cost of the substrate for growing GaN-based films is also required for GaN transistors to be cost-effective. Panasonic claims that it has solved these issues through its novel design of normally-off gate injection transistors (GITs) developed on cost-effective silicon substrates.

Proprietary technologies for the epitaxial growth of GaN by metal-organic chemical vapor deposition (MOCVD) enable the fabrication of GaN transistors on a 6-inch silicon substrate. The p-type gate of the GIT reduces on-state resistance by taking advantage of conductivity modulation by the hole injection from it.

● Stable switching operation free from current collapse

Up to now, the increase in on-state resistance after the application of high-voltage current collapse has been a serious problem for commercializing GaN transistors. This increase is the greatest obstacle to achieving stable operation.

The origin of current collapse is believed to be trapped electrons under a high electric field. Panasonic says that, through its novel processing technologies and new device structures that relieve the electric field, it has reduced the number of traps. The gate injection transistor fabricated on silicon enables stable 600V operation free from current collapse.

● Highly efficient switching at high frequencies

The lateral structure of the gate injection transistor is advantageous for high-speed switching due to lower parasitic capacitance than is typical of conventional silicon-based power transistors with their vertical structures. Here, $R_{on}Q_g$ (where R_{on} is on-state resistance and Q_g is gate charge) is a figure-of-merit for high-speed switching. The newly fabricated gate injection transistor exhibits a low $R_{on}Q_g$ of 715mΩnC, which is 7.5% lower than that achieved by 'state-of-the-art' silicon MOS transistors.

Also, by using the gate injection transistors on silicon, Panasonic has demonstrated 1MHz operation of resonant LLC DC-DC converters at an efficiency above 96%.

Panasonic says this demonstration indicates that the transistor can be used for practical systems free from operational failure. Applications for 130 domestic and 112 overseas patents have been filed.

The research results were presented at the Applied Power Electronics Conference (APEC 2013) in Long Beach, CA, USA (17–21 March). The work has been partially supported by the New Energy and Industrial Technology Development Organization (NEDO), Japan, under the Strategic Development of Energy Conservation Technology Project.

<http://panasonic.net>

Matthew Peach, Contributing Editor

Nitronex recruits former RF Micro Devices' director of High Power Engineering VP of engineering

Nitronex LLC of Durham, NC, USA, which designs and makes gallium nitride (GaN)-based RF power transistors for the defense, communications, broadband, and industrial & scientific markets, has named David W. Runton as its new VP of engineering.

Runton has almost 20 years of RF power semiconductor experience, with six years in GaN-specific product development, including design, assembly, qualification and packaging.

"Nitronex has very compelling technology that I feel has advantages for numerous market applications," says Runton. Founded in 1999, the firm provides gallium nitride on silicon (GaN-on-Si) semiconductor solutions using its proprietary SIGANTIC manufacturing process, which combines the



David W. Runton.

power, efficiency and bandwidth performance of GaN with the reliability, ease of use and low-cost advantages of industry-standard silicon substrates. "I am joining Nitronex at an exciting time with a new owner, management team, and significant growth plans for the future," he adds.

Nitronex was acquired last June by Silicon Valley-based Gaas Labs LLC, a private investment fund targeting communications semiconductors.

Runton was most recently director of High Power Engineering for RF Micro Devices Inc of Greensboro, NC, USA, where he led an engi-

neering product release team and developed long-term product strategy. He has also held engineering leadership positions at Freescale and Motorola Semiconductor.

"I'm confident he will help us leverage our core technology in the RF power market," says president & CEO Greg Baker. "He has an extensive background developing LDMOS and GaN power devices and a proven track record leading engineering teams to develop new products and technologies."

Runton holds both a Bachelor Degree and a Master of Science degree in Electrical Engineering from the Georgia Institute of Technology as well as a Masters in Business Administration, High Technology Program from Arizona State University.

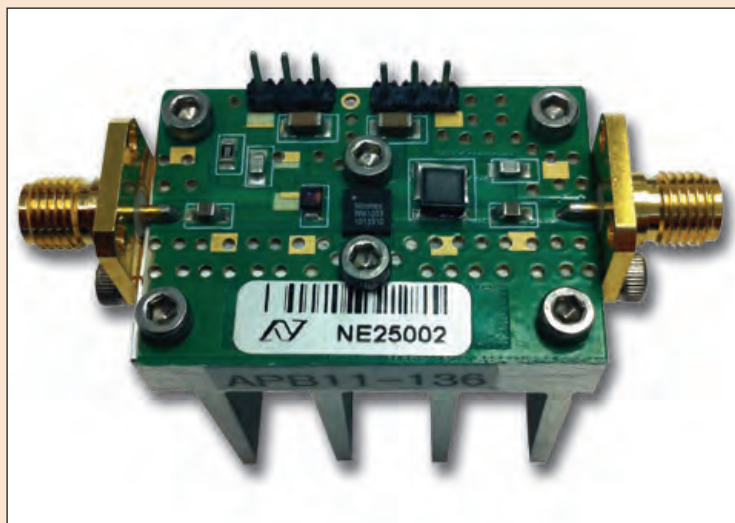
www.nitronex.com

Richardson RFPD introduces evaluation kit for smallest 5W gallium nitride MMIC power amplifier

Electronic component distributor Richardson RFPD Inc (an Arrow Electronics Company) of LaFox, IL, USA has announced availability and full design support capabilities for a new evaluation kit for a 5W gallium nitride monolithic microwave integrated circuit (MMIC) power amplifier made by Nitronex LLC of Durham, NC, USA, which provides gallium nitride on silicon (GaN-on-Si) solutions using its proprietary SIGANTIC manufacturing process.

The NPA1003QA-EVK evaluation kit includes: a test fixture tuned for 20–1000MHz broadband performance; two device loose samples; and a USB memory stick containing the NPA1003 datasheet, test data, and full drawings and documentation.

The evaluation board arrives ready for testing. It is a full, 50Ω circuit, with input and output connectors, and DC supplies for



Nitronex's NPA1003QA-EVK evaluation board.

both drain and gain voltage. The unit can be immediately connected to any network analyzer to test small-signal gain, or to any power measurement system.

Nitronex's NPA1003 5W GaN MMIC PA (which was launched in mid-2011) is optimized for

broadband operation from DC to 1500MHz, and offers an integrated 50Ω I/O match, in a small, 4mm x 4mm QFN package. The device is suited to avionics and L-band radar applications, as well as applications in

communications bands under 1GHz. A video is available with information about the evaluation kit and the device at www.youtube.com/watch?v=K19eYnsCFXI.

www.richardsonrfpd.com/Pages/Product-Details.aspx?productId=1091015

IQE grows revenue 45% year-on-year in second-half 2012

Risk mitigation via acquisition counteracts wireless customer destocking in Q1/12

For 2012, epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK has reported record full-year revenue of £88m, consisting of £69m (79%) from Wireless, £18m (20%) from Photonics, and £0.95m (1%) from Electronics. This is up 17% on 2011's £75.3m, which consisted of £55.2m (73%) from Wireless, £18.6m (25%) from Photonics, and £1.6m (2%) from Electronics.

However, sales and profits were much more heavily skewed to the second half than normal, reflecting the impact of destocking in first-quarter 2012 related to market share swings at two major wireless customers (leading to poor sales) and a £20m boost since June from the acquisition of RF Micro Device's epiwafer manufacturing unit. Second-half revenue was £53.7m, up 56% on £34.3m in the first half and up 45% on £37m in H2/2011. EBITDA (earnings before interest, taxes, depreciation, amortization, share-based payments and exceptional items) was £12.2m, up 56% year-on-year on H2/2011's £7.8m, and comprising most of the record full-year EBITDA of £16.4m (up 18% on 2011's £14m).

For full-year 2012, gross profit rose from £18.2m to £18.5m and contribution margins have remained stable. However, the benefit of the sales growth has been partly offset by higher depreciation and the overhead associated with the facility acquired from RFMD. Nevertheless, adjusted operating profit rose from £7.4m to £7.6m (excluding one-off transaction costs of £0.6m), of which £7.2m came in H2/2012.

Capital expenditure (CapEx) was £13.1m (down from 2011's £17.4m), marking the completion of a two-year capacity expansion program (CapEx should now return to maintenance levels).

Assuming cash settlement of acquisition, pro-forma cash gener-

ated from operating activities was £13.2m, up 27% from £10.3m for 2011 (though down 54% to £4.8m on a statutory basis, after deducting £8.4m used in investing activities).

In the prior 14 months, IQE completed three strategic transactions. In February 2012, IQE invested in a 9% stake in concentrated photovoltaic (CPV) cell manufacturer Solar Junction Corp (as well as announcing an exclusive wafer supply agreement), accelerating IQE's strategy to become a global supplier of CPV wafers for the solar power markets.

In June, IQE acquired the in-house MBE epiwafer manufacturing unit of RF Micro Devices Inc of Greensboro, NC, USA, involving a seven-year supply agreement for the provision of all of RFMD's MBE wafers and most of its MOCVD wafer requirements (under a discounted pricing arrangement, but with a minimum purchase commitment of \$55m over the first two years).

This January, IQE acquired the Kopin Wireless MOCVD-based heterojunction bipolar transistor (HBT) epiwafer manufacturing business of Kopin Corp of Taunton, MA, USA — plus its 90.2% controlling interest in subsidiary Kopin Taiwan Corp (KTC) in Hsinchu — for \$75m (with \$15m payable in January 2016). The transaction extends IQE's global manufacturing footprint, providing access to growing Asian semiconductor markets.

The acquisition of Kopin Wireless at the beginning of the current financial year has brought with it a significant share of business with Skyworks Solutions, which has filled the gap in the risk mitigation strategy

It also increases IQE's wireless market share, including adding Skyworks as a major customer (via a contract that continues until the end of 2013), acting as part of IQE's risk mitigation strategy. The expanded global footprint and the increase in the scale of IQE's wireless business is expected to yield cost synergies from 2014 onwards of at least £7m per annum.

IQE says that the three strategic transactions provide a platform for continued strong growth, reduce market risk and short-term volatility through the diversification of markets and customers, strengthen IQE's position in compound semiconductor manufacturing and supply, and provide further economies of scale and opportunities for cost savings.

The strategic value of the RFMD acquisition was demonstrated in fourth-quarter 2012, says IQE. "It protected the group from further swings in market share between chip companies. In particular, higher-than-anticipated volumes with RFMD mitigated the impact of a destocking elsewhere, which was similar to that experienced a year earlier," the firm adds. "The acquisition of Kopin Wireless at the beginning of the current financial year has brought with it a significant share of business with Skyworks Solutions, which has filled the gap in the risk mitigation strategy."

IQE says that it is beginning to see the rewards of its investment program in advanced wireless technology over the last two years. Progress on qualification programs includes entering production with five chip companies on advanced BiHEMT products. IQE reckons that it now has a 50-60% share of the wireless epiwafer market.

Also, several photonics (optoelectronics) R&D programs are transitioning into volume production. In particular, IQE has started to

► ship vertical-cavity surface-emitting laser (VCSEL) materials for optical communications applications (including multiple customers for data-center applications).

In addition, concentrated photovoltaic (CPV) solar milestones for 2012 (set out at the time of the Solar Junction investment last February) were achieved on schedule (with two dedicated tools installed and commissioned, and process transfer technology completed in Q4/2012) and end-customer qualifications are on track to allow transition into volume production in H2/2013.

"IQE has been transformed over the last 14 months," comments chief executive Dr Drew Nelson. "Three major transactions, the completion of our capacity expansion program and the achievement of a number of significant qualifications in both wireless and photonics (optoelectronics) have laid the foundations for accelerated growth in 2013 and beyond," he adds.

"Our record second-half performance in 2012 has provided a glimpse of what's to come," Nelson believes. "Furthermore, the strengthening of our risk mitigation strategy reduces the potential for short-term customer demand volatility," he continues.

"The advanced properties of compound semiconductors are central to addressing the challenges and performance expectations facing the electronics industry," notes Nelson. "This is a matter of fundamental physics as the next wave of growth for the electronics industry will be enabled by combining the properties of advanced compound semiconductors with the cost advantages of silicon. This is already beginning to happen and will accelerate in the next few years," he adds.

"We are increasingly confident that the group is well positioned for strong growth in 2013 and beyond. Therefore our focus now is on delivery... The momentum seen in the second half of 2012 is continuing."

www.iqep.com

IN BRIEF

ESTNet honors IQE as 'Company of the Year'

At a gala ceremony at the Wales Millennium Centre in Cardiff in late March, Cardiff-based epiwafer foundry and substrate maker IQE plc was awarded the 'Company of the Year' title at the inaugural awards of ESTNet (a network for organizations in the electronics and software technologies sector).

"It is a great honour to receive this prestigious title at the inaugural ESTNet awards, celebrating the Welsh technology sector," said IQE Group's president & CEO Dr Drew Nelson. "From its headquarters in Wales, IQE has established a global presence and a clear leadership position in advanced semiconductor wafer technology."

<http://estnet-awards.co.uk>

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5N Plus reports quarterly revenue down 14% year-on-year

Focus on recycling and Asia while commodity pricing recovers

For fourth-quarter 2012, 5N Plus Inc of Montreal, Quebec, Canada, a producer of specialty metal and chemical products, has reported revenue of \$128.6m, up 6.5% on \$120.7m last quarter but down 13.9% on \$149.4m a year ago. Revenue for full-year 2012 was \$551.7m, up 40.8% on \$391.7m for '2011' (although the latter comprised just seven months, since on 24 August 2011 5N Plus changed its financial year-end date from end-May to end-December).

In April 2011, 5N Plus paid \$317m to acquire MCP Group SA of Tilly, Belgium, a producer and distributor of bismuth and bismuth chemicals (with a 50% global market share) as well as other specialty metals (including gallium, indium, selenium and tellurium). 5N Plus already focused on specialty high-purity metals such as tellurium, cadmium, selenium, germanium, indium and antimony and also produces related II-VI semiconducting compounds such as cadmium telluride (CdTe), cadmium sulphide (CdS) and indium antimonide (InSb) as precursors for the growth of crystals for electronic applications, including solar photovoltaic, radiation detector and infrared markets.

For Q4/2012, adjusted EBITDA (earnings before interest, taxes, depreciation and amortization) was \$6.4m, down on \$7.1m a year ago. However, goodwill and other non-current asset impairment charges were \$204.8m due to longer-than-expected pricing softness in minor metals and a significant reduction in the market capitalization of the firm. This yielded a net loss of \$212m in Q4 and \$227.9m for full-year 2012 versus \$37.2m and \$22.5m for Q4/2011 and the seven-month period to end-December 2011, respectively. Excluding impairment charges and reversals, restructuring costs and acquisition costs net of the related income tax, adjusted net earnings yielded a loss of \$6.9m in Q4/2012 versus \$0.1m in Q4/2011.

"Despite a very challenging business environment, we managed to maintain market share and generate significant cash flow, enabling a sizeable reduction in debt," says president & CEO Jacques L'Ecuyer. Cash flow from operating activities was \$101.8m in full-year 2012. Net debt fell from \$260.6m to \$136.6m, including falling by \$4m in Q4. Total debt fell from \$341.9m to \$148.4m, including falling by \$1.4m in Q4.

"We also achieved commercial, technical and operational milestones including the completion of our Malaysian facility, breakthroughs at our Sylarus subsidiary, relocation of our Fairfield US operations to Wisconsin and further penetration of the Asian market," L'Ecuyer adds.

As at end-December 2012, the backlog of orders expected to translate into sales over the following 12 months stood at \$165.8m, up from \$162.3m at the end of September but down on \$223.2m a year ago.

"Revenues, backlog and profitability were negatively impacted in the quarter and the year by low underlying commodity prices, resulting in significant write-downs in the value of our inventories, non-current assets and goodwill, the latter having now been completely written off," L'Ecuyer notes. "Headwinds related to continuing concerns over European demand, the slowdown in the global economy and the structural changes in the solar industry continued to weigh on our performance. This was further exacerbated by the difficulties encountered with the integration of the former MCP activities, leading to the departure of some senior executives from the former management team and the dispute which followed related to some of the seller's representations and warranties made at the time of the purchase," he adds.

5N Plus has also amended its senior secured multi-currency revolving credit facility, under which the facility will be reduced to \$100m starting end-March 2013 and could, at any time, be expanded to \$140m at the firm's request through the exercise of an additional \$40m accordion feature (subject to review and approval by the lenders).

"The amendment to our credit facility provides us with the required financing flexibility for 2013 and better fits our current financing needs," says L'Ecuyer. "We are now better aligned and we intend to gradually redeploy capital into higher-value opportunities and recycling, with a strong focus on increasing commercial dealings in Asia. We also intend to leverage our dominant market share and take advantage of what we believe will be a much more favorable underlying commodity pricing environment in the coming year," he adds.

"Recognizing that 2013 will be a year of transition, we have established a plan for improving efficiency which includes the closure of the Trail operations [the former Firebird Semiconductors Ltd indium antimonide manufacturing plant in Trail, BC, Canada] and the relocation of all corresponding activities, and more generally significant cost-reduction efforts throughout the group," continues L'Ecuyer. "We also intend to further develop our Asian footprint in Korea, as previously announced [a gallium chemicals plant set up in conjunction with Hong Kong-based primary gallium producer Golden Harvest]. These measures, together with the continuing support from our financial institutions, should enable us to be very well positioned to take advantage of growth opportunities beyond the current year," he reckons.

"We therefore continue to remain cautiously optimistic and are confident in our ability to weather the current challenges," L'Ecuyer concludes.

www.5nplus.com

Gelest bolsters product, facilities & business management

Gelest Inc of Morrisville, PA, USA has announced new appointments and promotions to drive and support its growth as a manufacturer and supplier of silane, silicone and metal-organic compounds.

Greg Hertenberger has joined as product manager, silanes and metal-organics. Responsibilities include the development of new business for Gelest's functional and non-functional alkyl silane compounds and for its expanded range of metal-organic compounds for materials, polymers and synthesis.

Hertenberger has over 30 years' experience in additives for coatings and construction products (including silanes), gained from technical, commercial and management roles with Petrarch Systems, Huls America, Degussa, International Specialty Products, and Ashland Specialty Ingredients. He has a BA in Chemistry from Ursinus College and an MBA from Rider University.

Matthew Suits has joined as facili-

ties manager, with responsibilities including managing new construction as well as the maintenance department. Previously, he was an engineering and process manager at PB Leiner Gelatins in Davenport, Iowa, after promotion from maintenance and project engineer. Prior to that, he served in engineering positions at Dow Corning, General Electric, and Louisville Gas and Electric. Suits has a Master of Chemical Engineering degree from the University of Louisville.

Sean Nichols has joined as purchasing manager, responsible for the procurement of raw materials for manufacturing operations. This follows five years as operations manager in the manufacturing division of Haas Group International, based in West Chester, PA. Prior to that, he was an R&D chemist and a purchasing manager at Haas. He achieved Certified Purchasing Manager status in 2001, and completed the Dale Carnegie Leadership Train-


ing for Managers program in 2004. Nichols also has a BSc in chemistry from the University of Bridgeport.

Adrien Salomon has been promoted to production manager, responsible for managing day-to-day production activities and staff. He joined Gelest in 2004 as a chemist after earning a BSc in chemical engineering from the University of Delaware. He later assumed roles of increasing responsibility, ranging from process engineer to process and development engineering manager.

William Fry, who joined in 2010 as assistant controller, has been promoted to controller. Prior to Gelest, he gained experience in the auditing of manufacturing, distribution, construction, and not-for-profit organizations as a senior accountant for several accounting firms. A graduate of West Chester University with a BSc in accounting, Fry holds a Certified Public Accounting license from the State of Pennsylvania.


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Wafer World, Inc. is a privately held company founded by Sean Quinn in 1997. The 12,000 sq ft facility is situated in Palm Beach County, FL. Wafer World, Inc. is an ISO 9001:2008 and AS9100:2004 certified manufacturing facility for Silicon, Gallium Arsenide, Germanium, Indium Phosphide, Sapphire and Quartz.

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Customers who need 25 wafers once a year and customers who require 1000 wafers/week receive the same high quality service.

[Download the Wafer World Presentation](#)

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IN BRIEF

Samco relocates and expands Silicon Valley office

Etch, CVD and cleaning system supplier Samco Inc of Kyoto, Japan has expanded its OPTO Films Research Laboratory in California's Silicon Valley in order to strengthen its research structure and after-sale process support. The new facility is about twice as large as the one it replaces.

Samco is expanding activities at its three global R&D centers: the Kyoto Research and Development Center; the OPTO Films Research Laboratory in Silicon Valley; and Cambridge Research Center at the UK's University of Cambridge.

The OPTO Films R&D Center was established in 1987 as Samco's first overseas R&D center. It has since led research on carbon-type materials such as diamond thin films, diamond-like carbon (DLC) and materials for electrodes etc, as well as the development of thin-film deposition systems. The facility also plays a key role in joint research with universities.

The new lab is equipped with Samco CVD systems, dry etching systems, cleaning systems, and a suite of thin-film measurement systems. Research will continue on thin films of carbon-based materials, and new research will begin on MEMS fabrication for the bio-medical industries. Recruitment of local researchers is also progressing, with plans for up to ten researchers to be based at the facility (currently six).

SAMCO has also increased sales personnel in its East Coast Sales and Service Office, located in North Carolina's 'Research Triangle Park'. The new OPTO films Laboratory will play a key role, as a demonstration laboratory, in supporting the expansion of North American sales.

www.samcointl.com

Johnson Matthey closing down Gas Purification Technology business

Operations to be wound down at Pennsylvania plant due to LED & semiconductor slowdown

Johnson Matthey announced on 28 March that, due to the "continued downturn in the LED and semiconductor markets", it has decided to exit the gas purification market.

The decision relates to gas purification for bulk gases using palladium membrane, heated getter or regenerable catalytic purifying technology. The result will be the

closure of the firm's manufacturing facility in West Chester, PA, USA.

As a consequence, it will begin to wind down operations at its Gas Purification Technology (GPT) business with immediate effect.

Johnson Matthey assures customers that it continues to stand behind its warranty obligations for previously purchased products.

www.pureguard.net

Power+Energy sells hydrogen purifier business to SAES Pure Gas

P+E to focus on advanced hydrogen generation, separation and analysis

Power+Energy Inc (P+E) of Ivyland, PA, USA has sold the intellectual property and all other rights to manufacture and market its palladium micro-channel purifiers to SAES Pure Gas Inc of San Luis Obispo, CA, USA.

P+E says that its future business focus will be on providing products and technologies to the growing markets for syn-gas and hydrogen generation, separation and analysis.

"We are looking forward to fully supporting the transition of the palladium hydrogen purifiers from Power + Energy to SAES Pure Gas," says P+E's CEO Peter Bossard.

SAES Pure Gas will expand its manufacturing facility at its San Luis Obispo plant to build the palladium micro-channel purifiers for ultra-high-purity hydrogen applications. P+E will continue to build purifiers for SAES Pure Gas at its Ivyland plant until the SAES Pure Gas facility has been completed and will continue to provide warranty support for its existing purifier customers.

"The palladium membrane technology fits perfectly within the

purification portfolio of SAES Pure Gas," believes SAES Pure Gas' CEO Tim Johnson, "in conjunction with our other ultra-high-purity technologies for hydrogen (adsorber, heated getters) and other bulk

The palladium membrane technology fits perfectly within the purification portfolio of SAES Pure Gas, in conjunction with our other ultra-high-purity technologies for hydrogen (adsorber, heated getters) and other bulk gases

gases which include nitrogen, argon, helium, ammonia, CDA and oxygen", he adds. "This acquisition comes at a crucial moment for palladium membrane technology, with

the increased use of hydrogen within the electronics industry."

www.powerandenergy.com

www.saespuregas.com

Riber's income halved in 2012 as Sources & Cells sales drop counteracts Systems growth

Order book rises from €12.1m to €15.5m in January–February,

For full-year 2012, Riber S.A. of Bezons, France, which manufactures molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells, has now reported its earnings, after reporting revenue in late January.

Revenue was €27.4m, down 5% on 2011's €29m but up on 2010's €20.7m.

Full-year Systems revenue was €19.4m, up 68% on 2011's €11.5m. This reflects "the dynamic level of commercial development with compound semiconductor firms and research centers" as sales of Systems rose from 10 invoiced and delivered in 2011 to 17 in 2012 (including a record 15 systems delivered to research laboratories). Riber hence achieved its strategic revenue target for MBE, with strong growth in the research sector. Specifically, it has seen accelerating growth in emerging markets where Riber has a long-standing presence (e.g. China, Russia, Turkey etc).

The growth in MBE system business has offset a decline in sales of Evaporation Sources & Cells of 83%, from €12m in 2011 to just €2.1m in 2012. However, 2011 had been exceptional, marked by the delivery of major equipment orders for organic light-emitting diode (OLED) screen production lines in Asia, and this market is still buoyant, says Riber.

Revenue from Services & Acces-

sories has returned to growth, up 9% from €5.4m in 2011 to €5.9m in 2012, confirming the upturn in business during second-half 2012, despite the difficult economic climate. The Services and Accessories business has benefited from work carried out at the end of 2011 to further strengthen the firm's commercial and technical organization, says Riber.

Due to a less favorable product mix than in 2011, gross margin fell from 42.9% in 2011 to 33.2% in 2012. Riber still achieved an operating profit of €2m (an operating margin of 7.2% of revenue), though down from €4.3m (15% margin) for 2011. As well as the downturn in overall revenue and the change in product mix, profitability was also affected by the year-on-year change concerning the reversal of provisions for inventories (€0.6m in 2012 versus €1.7m in 2011). Net income fell from €4.3m in 2011 (14.8% of revenue) to €1.9m (7% of revenue) in 2012.

During the year, cash reserves have fallen from €6.8m to €5.3m, factoring in the impact of seasonality in deliveries on working capital requirements, in addition to the dividend paid out for 2011, the increase in investments and the significant ramping up of R&D efforts. Riber's management board will be submitting a proposal at the

firm's general meeting on 31 May for a dividend of €0.04 per share.

Riber says that its order book has risen from €12.1m at end-2012 to €15.5m at the end of February, confirming the healthy market for MBE research systems, in which Riber reckons it is particularly well positioned (with orders for 13 machines to be delivered in 2013).

In 2013 Riber is moving forward with deploying its growth strategy of:

- continuing to further strengthen its place in the MBE reactor market;
- capitalizing on its installed base and growing sales of epitaxy equipment, spare parts and accessories, as well as the corresponding services;
- launching a range of equipment and services for high-growth applications (OLED lighting and screens, thin-layer solar cells, etc); and
- longer term, integrating MBE into the silicon manufacturing chain.

To support the growth strategy, the supervisory board has appointed the following new members:

Dominique Pons, director at III-V Lab (the joint Thales, Alcatel-Lucent and CEA-Leti industrial research laboratory); and Gildas Sorin, CEO of German firm Novalis (which develops materials for OLED production). The appointments will be submitted for approval at the general meeting on 31 May.

www.riber.com

Video drivers for deposition controller

UK-based Henniker Scientific Ltd says its TMC13 deposition rate controller, a multi-channel device (launched last May) for control of film thickness and rate in vacuum-based thin-film deposition processes, is now available with a new video driver facility, allowing original equipment manufacturers (OEMs) to upload service and

maintenance procedures as video files for easy access and viewing direct from the device display.

The TMC13's feature-rich touchscreen interface can be customized to suit operator preference and operated in both automatic and manual modes, providing a direct display and control of film thickness, deposition rate and frequency

value for up to six independent deposition sources.

The device also includes shutter relays for each channel, two trip inputs for connection of pressure gauges, and two re-transmission analogue outputs as standard, as well as an extensive and fully editable materials library.

www.henniker-scientific.com

Challenged Veeco sees MOCVD orders fall 42% in Q1 ...but recovery in LED customers' utilization leading to first rush purchase orders in two years; Q2 recovery expected

Epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA has reported selected financial metrics and business highlights for first-quarter 2013 (excluding revenue and earnings, due to the firm's ongoing review of revenue recognition, announced last November).

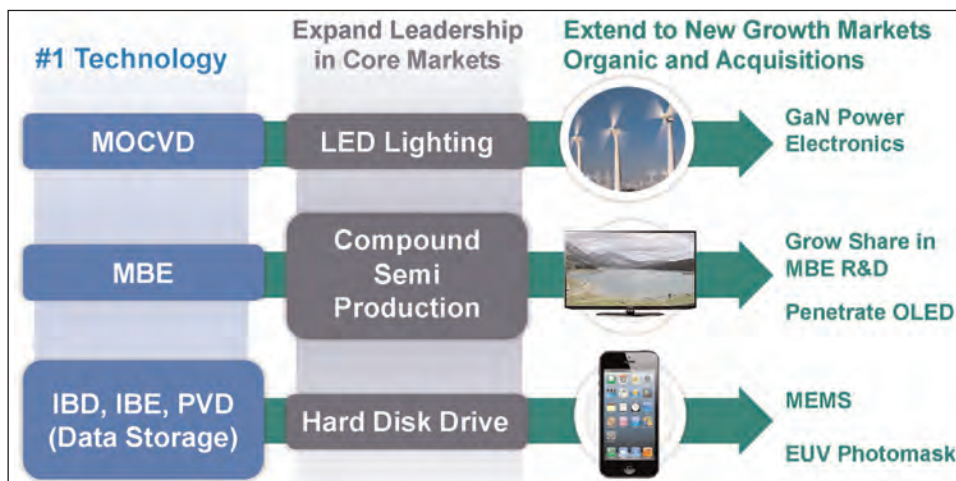
Order bookings totalled \$70m (down 24% on \$92.3m for Q4/2012). This included: \$37m from MOCVD (down 42% on \$62.8m) and \$6m from MBE (down 51% on \$12.6m); hence LED and solar market orders together totalled \$43m (down 43% on \$75.4m). Data Storage orders totalled \$27m (up 64% on \$15.9m).

Other notable financial statements by the firm were that first-quarter system shipments had "declined sharply, on a sequential basis, in both MOCVD and data storage". Also, with few MOCVD deals available, Veeco continues to experience "significant competitive pricing pressure".

"First-quarter business conditions remained extremely challenging, with system shipments at very low levels and bookings the weakest we have seen since early 2009... this downturn has persisted longer than anyone predicted," says chairman & CEO John R. Peeler. "We are pleased that Veeco continues to weather this business downturn with our strong cash position," he adds. During the quarter, the unaudited cash balance rose by 1.6% from \$579m to \$588m.

Market trends seen by Veeco.

"Looking ahead, the end-market signals in MOCVD activities are mixed but they appear to be trending in a positive direction. Some key LED customers are operating at close to full utilization rates, and we are now booking some rush purchase orders – the first we have seen in two years," says Peeler.



Veeco's growth strategy.

"In particular, some Chinese customers with committed funding for MOCVD equipment are planning fab expansions. In data storage, customers are making technology buys and we are seeing an increase in quotations for MBE systems for research applications. While visibility remains limited, we anticipate meaningfully higher bookings in the second quarter," Peeler adds.

Veeco also states that its "focus on service growth continues", with four key objectives: new service products; expanding Veeco-certified equipment across more product lines; designed-in services for new products; and, for MOCVD, post-warranty parts and services, local depots, consumables, performance upgrades (aiming to boost MOCVD services by about 70% between 2011 and 2013).

"It is a top priority to conclude our accounting review as soon as possible," Peeler noted. "Veeco's other key focus areas for 2013 are our plans to fortify and build on our leadership positions in our core markets, especially in LED lighting which we believe is a huge market opportunity in front of us, and to leverage our technologies into adjacent markets like power electronics, organic LEDs (OLEDs), MEMS and extreme UV (EUV)."

Analysts' conference

"Q1/2013 was another challenging quarter for Veeco," executive VP & chief financial officer David D. Glass told market analysts. "Bookings came in at just \$70m, remaining at trough levels for MOCVD and MBE. Data storage was up versus Q4, but not enough to counter the very weak MOCVD trend. Bookings were at the lowest level we've seen since 2009," he added.

"We do expect to see a recovery in bookings during Q2. However, there are positive signs such as some of our top-end MOCVD customers operating close to full utilization, and in some case they're even talking about fab expansions," Glass continued.

"System shipments declined sharply in MOCVD and data storage, reflecting the weak overall environment we're still operating under. There are a few sizable MOCVD deals that were not shippable in Q1. Shipments continue to be lumpy because of issues such as fab readiness in China," Glass noted.

"Our advanced planning in areas like inventory and supply-chain management, cost containment and flexible manufacturing have all paid off for us. We have also completed a 10% reduction in workforce and significantly cut our operating

► expenses since peak level in 2011. We have installed strong inventory and working capital disciplines that have helped us to continue to fund R&D at high levels."

Commenting on the lack of announcement of full results for Q1, Glass added, "The accounting review concerns technical accounting issues related to multiple arrangements for MOCVD transactions originating in 2009 and 2010. This concerns some of our deals that include systems as well as upgrades, parts credits and other add-ins we might sell as part of our deals with the customers. These systems were delivered, accepted and paid for in full."

Peeler further commented to analysts: "We intend firstly to fortify and build our leadership position in our core markets, especially in LED lighting, which has a huge market opportunity and which also allows us to grow our services business. Second, we want to leverage our core technologies into adjacent markets like power, electronics, OLED, MEMS and EUV. Third, we want to acquire other businesses that have synergy with our business.

Veeco's strategy for growth.

"Considering MOCVD, services accounts for less than 15% of revenues at this point, but it's growing rapidly. Our customers are coming back to us for upgrades, consumables, parts that improve the performance of their systems and increase their profitability. If we achieve our internal goals, Veeco's 2013 MOCVD services revenue will be 70% higher than it was two years ago," Peeler added.

"In the MBE R&D market our share is well below the 75% share that we have in the production market, but that should change: we are launching a new R&D tool in the coming

Late in March we started to experience what looks like a meaningful inflection in MOCVD business... Some customers are operating at close to full utilization rates. We had the first rush orders we've had in a long time

months and we expect to substantially increase our R&D market share."

Outlook

"Our first-quarter bookings levels were the worst we've seen since early 2009. But late in March we started to experience what looks like a meaningful inflection in MOCVD business conditions," commented Peeler on the firm's outlook. "It included reports that some customers are operating at close to full utilization rates. We had the first rush orders we've had in a long time and we are negotiating orders at several Chinese customers who have committed expansion plans," he added.

"Talking to customers worldwide, what I hear is that they all see lighting ramping; some are optimistic in moving to increase their capacity, while others are holding out and waiting before committing more capital. It's a tough market to predict at this point, but we do anticipate meaningfully higher bookings in Q2," Peeler concludes.

www.veeco.com

Matthew Peach, Contributing Editor

Veeco's K465i MOCVD system chosen for CEA-Leti and nanowire-LED spin-off Aledia

Epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA says that the research lab CEA-Leti in Grenoble, France, has selected Veeco's TurboDisc K465i metal-organic chemical vapor deposition (MOCVD) system for its program with its partner Aledia S.A. which develops LEDs based on nanowire GaN-on-silicon technology.

Aledia was spun out of CEA-Leti in 2011 and is based at the CEA site. Its three founders include two former CEA researchers, Xavier Hugon and Philippe Gilet. Aledia's goal is to manufacture 3D nanowire-based LEDs for solid-state lighting applications on thin silicon wafer substrates, of 8 inches or greater in diameter, at

a cost significantly below that of conventional planar LEDs.

When electrically charged, thin crystalline nanowires can emit a broader spectrum of light than conventional LEDs, and can be grown on industry-standard silicon substrates. Aledia's nanowire technology was originally developed at CEA-Leti, and Aledia and CEA-Leti continue to develop nanowire technology in close cooperation.

"We are confident that Veeco's MOCVD system is the right equipment to help make this technology successful," comments Fabrice Geiger, head of CEA-Leti's Silicon Technology Division.

"The TurboDisc reactor will be an important element of our strategy to take this potentially

game-changing technology towards the commercialization phase," believes Aledia's president & CEO Giorgio Anania. "In partnership with CEA-Leti, we selected Veeco because our analysis indicated that at this time their MOCVD systems showed the best financial returns for 8-inch wafer production on the market," he adds.

"We are looking forward to working with CEA-Leti and Aledia on their efforts to commercialize nanowire LED technology, which shows promise to accelerate the industry's roadmap towards cheaper and more efficient LEDs," says William J. Miller Ph.D., executive VP, Veeco Process Equipment.

www.aledia.com

www.leti.fr

MOCVD shipments to fall 46% to 148 systems in 2013

Veeco, Aixtron cut prices in China market as local competitors gear up

Global shipments of metal-organic chemical vapour deposition (MOCVD) systems will fall by 46% year-on-year to a total of 148 units in 2013, forecasts a report by Digitimes Research, as LED chipmakers have sufficient capacity and the number of LED chips used in LED TV backlighting has been decreasing.

US-based Veeco Instruments is predicted to continue dominating the MOCVD system market, with 60.2% market share in 2013, due mainly to orders from China-based firms. Germany-based Aixtron is expected to rank second, with 35.8% market share. Some China-based MOCVD system makers have begun shipments of multi-wafer MOCVD systems.

As China's 12th Five-year Plan promotes domestic supply of LED production equipment, the government has been supporting China-based makers developing MOCVD

equipment since 2011. Consequently, four China-based firms — Tang Optoelectronics Equipment, Advanced Micro-Fabrication Equipment Inc, Brilliant Light Technologies and Ideal Energy Equipment — are gearing up for production of MOCVD systems. In particular, Tang claims that its MOCVD equipment can produce LED chips with luminous efficacy of 155lm/W.

Although these firms have yet to pose a threat to the top-two players, a few China-based LED chipmakers have begun to adopt locally made equipment, notes Digitimes.

Since local governments have ended subsidies for China-based LED makers procuring MOCVD systems, and total LED production capacity is 20–30% in excess of demand in China, the MOCVD market has been in favor of buyers, says Digitimes Research. As a result, Veeco and Aixtron have faced bottlenecks

in marketing MOCVD equipment due to shrinking demand and less price competitiveness, the market research firm adds.

Mainly because of the slump in demand and new competition, Veeco and Aixtron are said to have lowered quotes in the China market from about US\$2m to about US\$1.4m for a single-wafer MOCVD system and by 30–40% for a multi-wafer model, says Digitimes Research, citing industry sources.

Nevertheless, China is expected to account for as much as 62% of global demand for MOCVD equipment in 2013, because some firms have applied for subsidies but have yet to use them (hence these subsidies have extended into 2013). In addition, tier-two chipmakers in China are expected to continue expanding capacities in 2013, notes Digitimes Research.

www.digitimes.com

Aixtron leads 'Production' workpackage of European Union's Graphene flagship project

Germany's Aixtron is participating as a key partner in the recently announced European Union (EU) Future Emerging Technology (FET) flagship project 'Graphene'. As part of the consortium, Aixtron will bring its expertise in deposition processes for graphene and shall lead the production work package of the project.

"Our key contribution is to enable high-quality large-scale graphene growth through the development of next-generation deposition equipment," says Dr Ken Teo, director of Nanoinstruments at Aixtron. "Working with graphene thin-film producers, bulk graphene manufacturers and associated partners, graphene will be produced for a variety of applications ranging from wireless communications to display, sensing and energy storage. This is a unique opportunity for us to interact with and



A 300mm wafer of graphene, shown by professor Jari Kinaret, director of the Graphene Flagship, and Neelie Kroes, EU Digital Agenda Commissioner.

understand the requirements of R&D and industrial end-users," he adds.

"For a disruptive new material such as graphene, long-term investment is required to create the entire value chain and end-market applications," comments Aixtron's chief operating officer Dr Bernd Schulte. "Support

for the Graphene Flagship over the next decade by the EU is indeed a significant commitment that makes this possible," he adds. "The development furthermore confirms Aixtron's long-term strategy in enabling the deposition of new electronic materials such as graphene.

Chalmers University of Technology in Sweden, with professor Jari Kinaret as the flagship director, will coordinate 126 academic and industrial research groups in 17 European countries. The EU funding for the academic-industrial consortium starts with an initial 30-month EU budget of €54m, which will be extended up to 10 years with €1bn total project cost, with further contributions coming from the Horizon 2020 program and local programs from various EU countries.

www.graphene-flagship.eu

Peking University orders CCS system for LED and laser research

Aixtron SE of Herzogenrath, Germany says that in Q2/2012 China's Peking University ordered a further Aixtron Close Coupled Showerhead (CCS) reactor with capacity for three 2" substrates in a single run, for delivery in Q1/2013.

"We already have an Aixtron CCS system in use, and we are very satisfied with it. We now needed a system to improve our UV LED and laser research," says Peking University's Professor Shen Bo. "The aluminium gallium nitride (AlGaIn) material growth

needed for this is very challenging due to the very high temperatures of more than 1200°C required," he adds. "Also, AlGaIn is very difficult to dope, particularly with magnesium that is used to create the p-type regions needed for hole injection."



Aixtron Close Coupled Showerhead (CCS) reactor.

University of Cambridge installs second CCS system for 6" GaN-on-Si

The UK's University of Cambridge has commissioned another Aixtron multi-wafer Close Coupled Showerhead (CCS) MOCVD reactor at its new facility at the Department of Material Science and Metallurgy. The CCS 6x2" system will be configured to handle a single 150mm wafer (1x6").

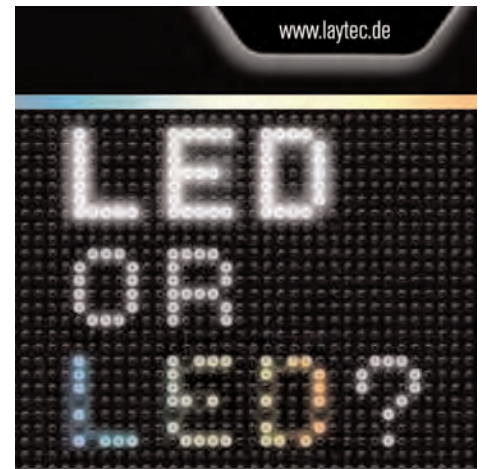
"We will be using the systems to expand our research efforts for LED and electronic devices based on gallium nitride (GaN) epitaxy on 6-inch silicon wafers," says professor Sir Colin Humphreys, director of research in the Department of Materials Science and Metallurgy. "We already use one CCS 6x2" system in our work, but the gathering pace of GaN-on-Si development means that we need an extra system with

large-diameter wafer handling," he adds.

"Aixtron is proud to continue its long-standing collaboration with the University of Cambridge and to supply another state-of-the-art CCS research system to complement the university's existing reactor," says Tony Pearce, managing director at Aixtron Ltd. "The Cambridge group has developed world-leading GaN-on-Si processes and we look forward to further supporting this work with this new system," he adds.

"Using silicon substrates for power electronics and LED applications, this technology should gain a big share from the existing market," believes Dr Frank Schulte, vice president Aixtron Europe.

www.aixtron.com



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Knowledge is key

Aixtron's revenue and orders continue to struggle in Q1

Operations generate cash despite incurring restructuring costs and inventory write-downs of €49.1m

For first-quarter 2013, deposition equipment maker Aixtron SE, Aachen, Germany has reported revenue of €40.2m, down 4% on €42m a year ago and 48% on last quarter's €77.5m.

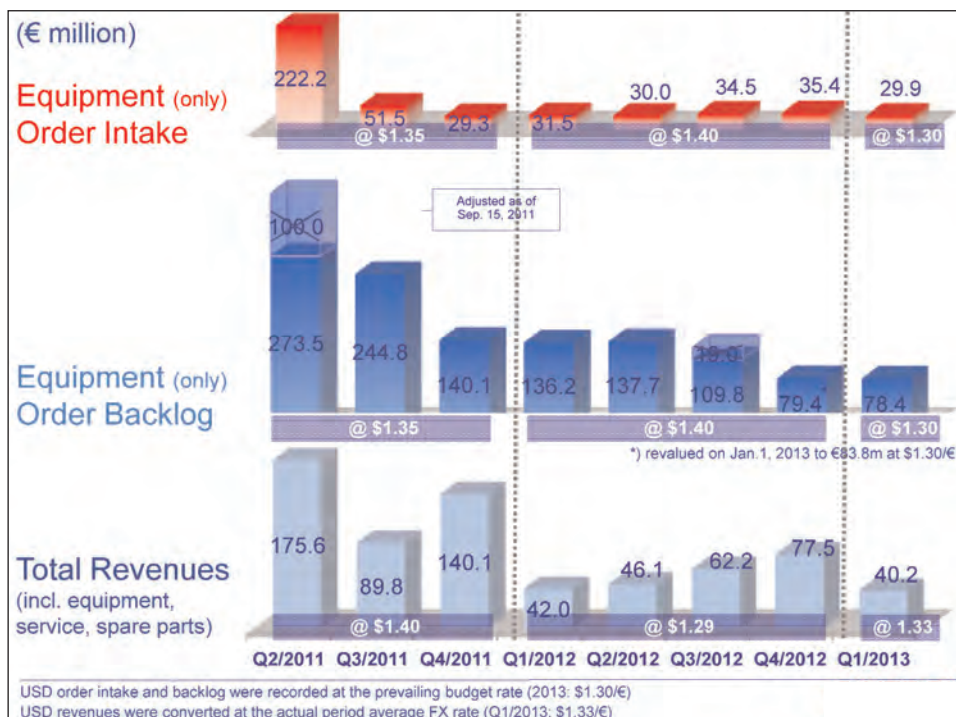
Against the backdrop of uncertain demand and considering the firm's technological progress, Aixtron's management has executed a further review of all inventories during the quarter and consequently decided on additional write-downs of about €43m.

Moreover, management has recorded restructuring expenses of €6.1m in conjunction with staff reductions in Germany that were initiated in co-operation with employee representatives. Between end-March 2012 and end-March 2013, Aixtron's staffing has fallen by 66 (7%) from 984 to 918, including Sales staffing down by 15 (17%) and Manufacturing & Services down by 44 (10%). Despite this, R&D staffing is level on a year ago.

Aixtron commented that it "considers a strong R&D competence to be an important strategic factor in pursuing our technological leadership in MOCVD systems and securing leading positions in other future technologies". In Q1/2013, investments in R&D were stable at €16.6m (compared with €16.4m a year ago), while improvements in process efficiency have been initiated.

Aixtron said the restructuring measures are part of the recently initiated programs for cost optimization and efficiency improvement, especially in the areas of procurement, supply chain as well as product development. In addition, measures for product and process optimization have been initiated in conjunction with customers.

Due to the unusual items (i.e. restructuring costs and inventory write-downs totaling €49.1m), gross profit has fallen significantly



Aixtron's 24-month business development, showing recovery in revenue from Q2/2011 to Q1/2013.

from €10.3m a year ago and €17.7m last quarter to a loss of €47.7m. Consequently, net earnings before interest and taxes (EBIT) has worsened, from –€12.3m a year ago and –€43.2m last quarter to –€76m.

Due largely to new payments received from customers, cash flow from operating activities was €10.1m, compared with €7m last quarter and –€0.1m a year ago.

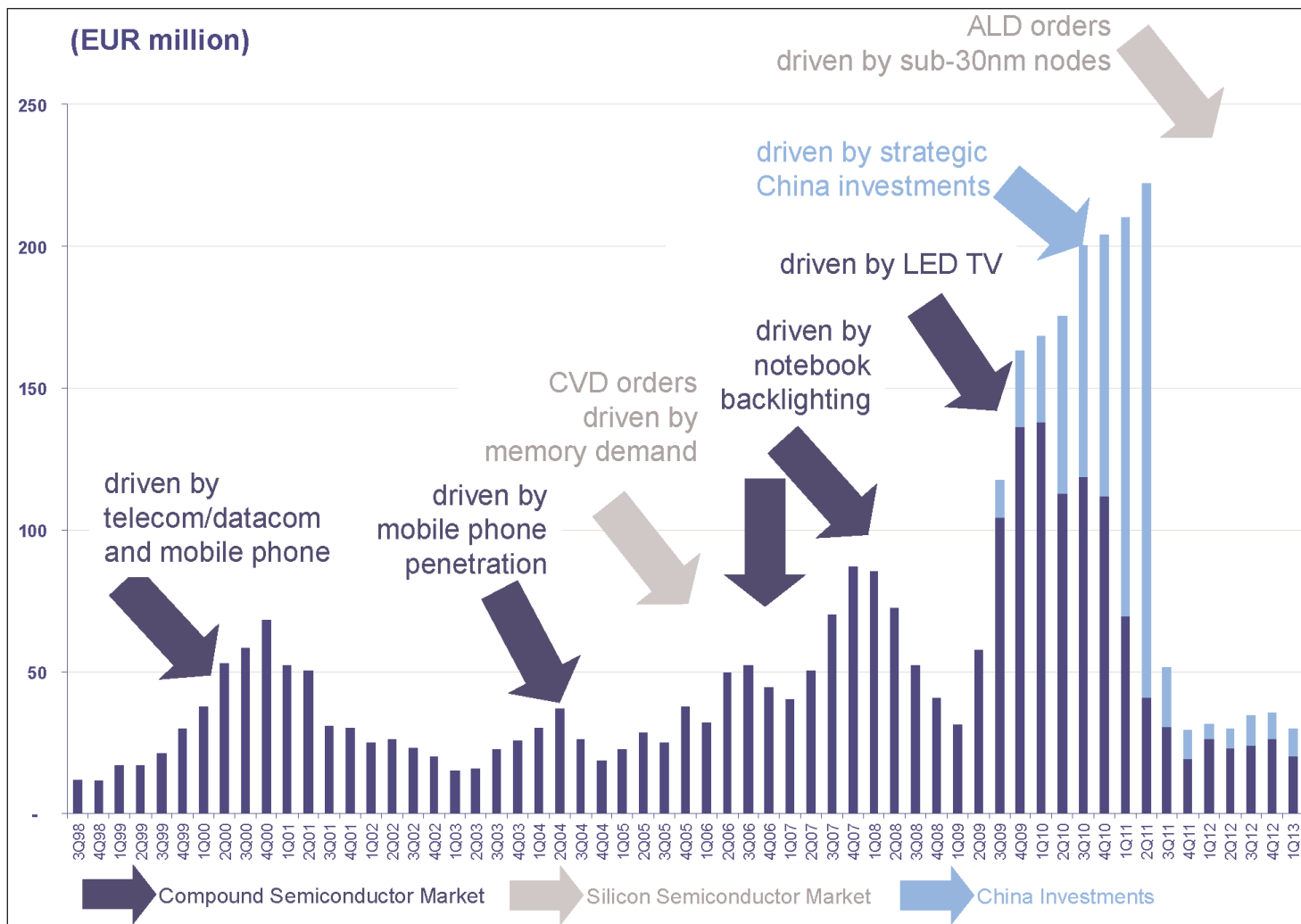
Consequently, free cash flow was €9.3m, compared with just €1.8m last quarter and cash burn of €5.6m a year ago. Cash and cash equivalents hence rose during the quarter from €209.5m to €219.9m.

Against the backdrop of the subdued demand, Aixtron's equipment order intake remained low at

€29.9m, down 5% on €31.5m a year ago and 16% on €35.5m last quarter (extending the 'trough level' of about €30m to six quarters now). As of end-March, total order backlog was €78.4m — only slightly below the backlog of €79.4m as of end-December 2012, but down 42% on €136.2m a year ago.

In its previous-quarter outlook statement (Q4/2012), Aixtron had warned that there remained "a high degree of uncertainty" about a possible order recovery. At that point, in February 2013, the firm was unable to give "precise revenue and EBIT margin guidance for the rest of 2013, due to the prevailing low visibility."

Aixtron now comments that, "The continued low level of order intake in the latest quarter is mainly attributable to the subdued demand for semiconductor deposition equipment," adding that, "despite further increases in capacity utilization rates at leading Taiwanese and Korean LED manufacturers, amongst others



Aixtron's quarterly equipment orders, showing flat levels since the end of 2011.

► [to 75–90%], Aixtron has not seen higher capacity investments in the first quarter of 2013."

Although the firm said it is currently experiencing an increase in customer

inquiries, order development for 2013 remains difficult to predict. Given this ongoing low degree of visibility, Aixtron's executive board repeated that it is currently unable

to issue any precise forecast for the company's revenues and EBIT margin in the current financial year.

www.aixtron.com

Matthew Peach, Contributing Editor

Candidates proposed for Aixtron's Supervisory Board; Holger Jürgensen appointed honorary chairman

Dr Andreas Biagosch and Dr Martin Komischke have been proposed as candidates for election to the Supervisory Board of deposition equipment maker Aixtron SE of Herzogenrath, Germany at the firm's annual general meeting on 23 May.

Biagosch worked for 28 years as an engineer for international consulting firm McKinsey & Co on various international projects for high-tech and other industries and was part of McKinsey's global Shareholder Council. Biagosch is currently an independent

entrepreneur.

Komischke, also an engineer, is chairman of the executive board at Hoerbiger Holding AG, a manufacturer of components for mechanical engineering in Switzerland.

Aixtron says that the experience demonstrated by both candidates in sectors relevant to the firm, as well as their international experience in consultancy and industry, were important factors in the Nomination Committee's decision. The Supervisory Board is following its recommendation in proposing

both candidates to shareholders for election at the AGM.

Dr Holger Jürgensen has been appointed honorary chairman of the Supervisory Board. After co-founding Aixtron in 1983, Jürgensen ran the firm and served on its board of directors until 2002. Between 2002 and 2013, he was the Supervisory Board's deputy chairman. He resigned in January for personal reasons. In recognition of his work over the last 30 years, the Supervisory Board has made him honorary chairman.

SPTS ships etch systems to European R&D organizations

Plasma etch, deposition and thermal processing equipment maker SPTS Technologies Ltd of Newport, Wales, UK has received multiple orders from several European R&D institutions, including the Delft Institute of Microsystems & Nanoelectronics (DIMES), Ecole Polytechnique Fédérale de Lausanne (EPFL), Institut FEMTO-ST (Franche-Comté Electronique Mécanique Thermique et Optique – Sciences et Technologies) and IEF (Institut d'Electronique Fondamentale).

Dimes is a research institute within the Delft University of Technology with cleanroom facilities where submicron electronics and MEMS technologies are combined to fabricate micro systems. Applications are medical (flexible chips in catheters), nano-instrumentation (integrated microfluidic jet systems, sensors), infrastructure (integrated radars) and energy (smart lighting). SPTS' Omega i2L Rapier system will be used for wafer-deep etching of micromechanical structures and through-silicon vias (TSVs) with vertical or tapered sidewalls. The

selection of this system was driven by the need for a reliable DRIE system, able to fulfill the stringent process requirements, says SPTS.

Swiss research institute EPFL chose SPTS' advanced physical source (APS) to focus on dielectric etching. Of particular interest is controlling sidewall quality for shallow optical waveguides in silicon nitride and also etching 40µm deep trenches into fused silica glass. The APS is characterized by a plasma density that is typically ten times higher than conventional inductively coupled plasma (ICP) reactors, making the module well suited to etch strongly bonded materials such as glass, and even tougher materials like silicon carbide (SiC) and sapphire.

France's IEF will use its etch system for two dissimilar silicon processes. The first application involves fabricating nano trenches 80nm wide at >5:1 aspect ratio and with super-smooth sidewalls (with a roughness of <6nm), with the second, a 50µm feature at 400µm deep. IEF awarded the business to SPTS following a demonstration that saw its Pegasus

Rapier process module perform to these rigorous requirements using a single hardware set-up.

The French research organization Institut Femto-ST chose the Pegasus Rapier for its optics, sensor and actuator device development. During the evaluation process, SPTS satisfied stringent process specifications to win the business.

Both Femto-ST and IEF are members of RENATECH, the French national network of large technological facilities.

"Our customers each carried out extensive testing activities across multiple competing vendors, running demonstrations on critical applications and bench-marking technical capabilities, system functionality, and cost," said Dr Dave Thomas, SPTS' marketing director for etch products. "These wins demonstrate SPTS is meeting its commitment to satisfy the demanding requirements of the world's most prolific R&D organizations. It is through this type of collaboration that new production applications will emerge".

www.spts.com

IN BRIEF

CVD Equipment completes sale of former corporate HQ

CVD Equipment Corp of Central Islip, NY, USA (which designs and makes equipment for developing and manufacturing electronic components, materials and coatings) says that on 5 April it completed the sale of its 50,000ft² facility at 1860 Smithtown Avenue, Ronkonkoma, NY, where its former corporate headquarters had been located. The sale price was \$3,875,000, representing an estimated profit of about \$900,000. The firm's new HQ covers 130,000ft².

www.cvdequipment.com

H-Square appoints northwest sales representative

H-Square Corp of Santa Clara, CA, USA, which makes wafer and substrate fabrication handling tools and equipment, has appointed Rick O'Malley as sales representative of the firm's Oregon and Washington territories.

"We were aware of Rick O'Malley's excellent reputation from his years in Silicon Valley, as well as his extensive knowledge of the semiconductor industry," says H-Square's VP of sales Brett Hofmann. "When we began our search for a new sales executive to represent H-Square products in the Northwest, Rick stood out as the highly qualified candidate with a long-standing reputation in our

industry."

O'Malley will take on the new territory in addition to his acting role as head & founder of Innerskil Group, a consulting firm specializing in sales evaluation and training for organizations operating in highly technical industries.

"Innerskil Group was born out of my passion for sales and working with sales professionals' selling and sales management skills," says O'Malley. "The new partnership with H-Square will allow me to focus on the leading technology companies in the Northwest by providing high quality products and handling solutions."

www.innerskil.com



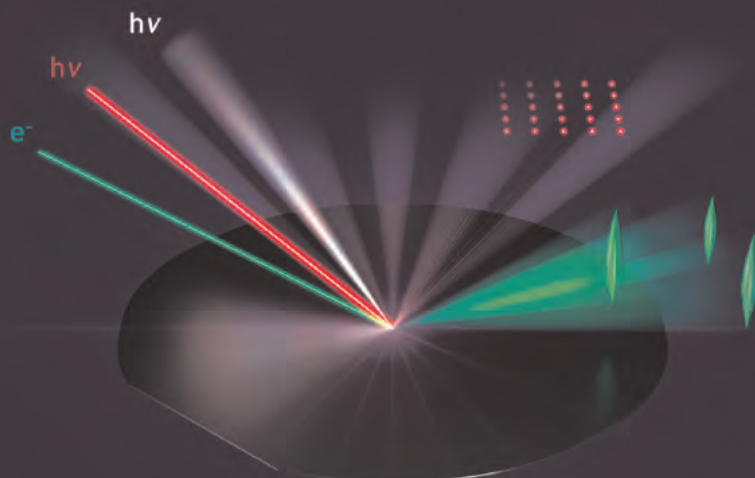
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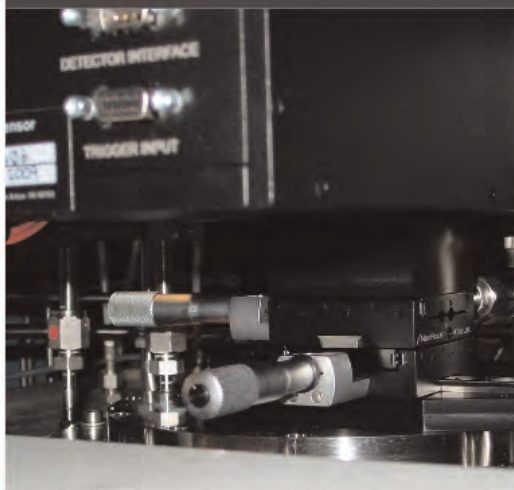
Real-Time Process Monitoring for MOCVD, MBE, Sputtering, and Thin-Film PV Deposition



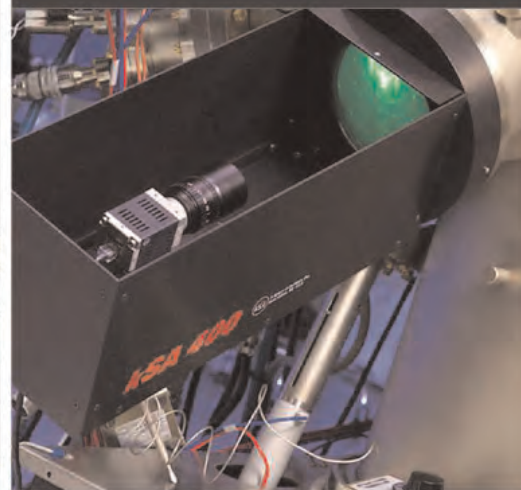
kSA BandiT Wafer Temperature



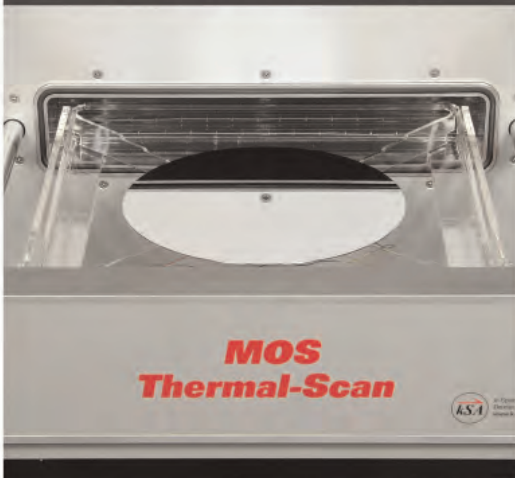
kSA MOS and kSA Mini-MOS Thin-Film Stress



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



IN BRIEF

Oxford Instruments Nanoscale Plasma Processing seminars in Beijing and Taiwan

After its program of Chinese seminars attracted over 200 participants, UK-based etch & deposition system maker Oxford Instruments is holding two further one-day seminars in Asia focusing on Nanoscale Plasma Processing, on 14 May (Beijing) and 16 May (ITRI, Hsinchu, Taiwan).

Talks are by invited guest speakers and specialists from China, Taiwan and Europe, as well as process and applications experts from Oxford Instruments Plasma Technology (OIPT). Topics include: atomic-layer deposition (ALD), photovoltaics (PV), deep silicon etch, power devices, HB-LEDs and ion beam technologies.

www.oxford-instruments.com

Plasma-Therm VERSALINE DSE for Southampton Nanofabrication Centre

Plasma process equipment maker Plasma-Therm LLC of St Petersburg, FL, USA has been selected by the UK's University of Southampton to provide deep silicon etching capability for the Southampton Nanofabrication Centre (SNC), located in the Zepler Institute's new cleanroom facility, which also houses the Optoelectronics Research Centre (ORC).

Together they provide research facilities for users from universities and industry, locally and internationally, from a wide range of disciplines. In addition to serving a key role in their academic mission, the centers encourage commercialization of internal and external research efforts managed by a dedicated university business unit.

SNC's new Plasma-Therm VERSALINE DSE etching system will be used for diverse silicon-based applications including MEMS

and BioMEMS sensors, MOEMs, solar cells, and optical component devices.

"The VERSALINE's array of capabilities was an important part of the decision criteria," says SNC cleanroom manager Iain Anteney. "In addition to having broad process latitude to successfully etch many structures using an operating system that offered superior control, we were interested in process stability. The uniquely heated source and substrate temperature management strongly influenced our assessment."

"We look forward to a closely connected on-going relationship with another leading research institution," says Dr David Lishan, Plasma-Therm's principal scientist and director for Technical Marketing.

www.plasmatherm.com

www.soton.ac.uk

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SPTS shortlisted for two BVCA Management Team Awards

Plasma etch, deposition and thermal processing equipment maker SPTS Technologies Ltd of Newport, Wales, UK, has been shortlisted for the annual Management Team Awards organized by British Private Equity and Venture Capital Association (BVCA). SPTS is in the running for 'Large Buyout Management Team of the Year' and 'International Impact Management Team of the Year'.

The Large Buyout Management Team award recognizes outstanding management of a firm backed by a large private equity firm (>£100m deal size). The International Impact Management Team award honours business leaders who have achieved commercial success on a global scale. Regional finalists were announced in April. National winners will be announced in July.

"BVCA Management Team Awards, in partnership with Clearwater Corporate Finance, recognize the achievements of British companies that are backed by private equity and venture capital," says BVCA's deputy chief executive Tim Hames.

International private equity group Bridgepoint backed a management buyout of SPTS in June 2011. The firm has grown by strategically investing in organic and inorganic projects that focus on emerging market sectors in the semiconductor industry. SPTS says that this focus on technical innovation, coupled with an emphasis on comprehensive global customer support, has allowed it to gain market share and deliver strong financial performance.

www.bvca-mta.com

www.spts.com

IN BRIEF

Queen's Award

SPTS has won a Queen's Award for Enterprise in International Trade, recognizing outstanding growth in global business during the past three years. The judging panel also assessed SPTS' relationships with staff, customers and suppliers, and its impact on the environment and society.

The Queen's Awards for Enterprise were introduced in 1966 to acknowledge businesses with outstanding performance in three categories: International Trade, Innovation and Sustainable Development. The awards are open to any company operating in the UK and are announced annually on Queen Elizabeth II's birthday (21 April).

www.gov.uk/the-queen-s-awards-for-enterprise-international-trade



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Temescal launches fast-cycle electron-beam metallization system for more efficient lift-off

Temescal of Livermore, CA, USA (a division of Ferrotec Corp) has introduced its UEFC-5700, an ultra-high-efficiency electron-beam metallization system for lift-off compound semiconductor applications.

The UEFC-5700 is the first Temescal system to incorporate the Auratus deposition process enhancement methodology (launched last December), a patent-pending proprietary optimization methodology for lift-off e-beam evaporative coating. This offers what is claimed to be near-perfect uniformity while delivering up to 40% increases in material collection efficiency, resulting in significant cost savings on process materials like gold and platinum compared to traditional box coaters, says the firm.

UEFC-5700 is designed for compound semiconductor production environments that use lift-off electron-beam evaporation processes. It features a unique conical-shaped vacuum chamber that reduces volume and surface area, significantly reducing pump-

down time, adds the firm. The system also features a patent-pending High-Uniformity Lift-off Assembly (HULA) design that uses a dual-axis motion to optimize collection efficiency.

"With the UEFC-5700, we have significantly improved the throughput efficiency of traditional lift-off coating processes," says Gregg Wallace, managing director of Ferrotec's Temescal division.

"From the unique chamber design to the HULA carrier system, the UEFC-5700 improves pumping and batch capacity with excellent uniformity across all evaporated materials, enabling the system to run more wafers and

The UEFC-5700 improves pumping and batch capacity with excellent uniformity across all evaporated materials, enabling the system to run more wafers and more batches per day

more batches per day than any conventional box coater," he claims. "The biggest benefit to users of this system is the improvement in uniformity and collection efficiency of all materials being evaporated. For IDMs and foundries, this equates to improved yields of better devices that cost much less to produce."

The UEFC-5700 offers increased wafer production capacity, up to 42 150mm wafers in a batch, without a significant change in raw material or energy consumption, the firm says. In terms of footprint and power consumption, the system is virtually identical to Temescal's largest production system, the FC-4400.

With its conical-shaped load-locked chamber and 44,000 liters/second of installed cryogenic pumping capacity, the UEFC-5700 reaches process pressures faster than most conventional box coaters, the firm claims. Systems have reached 5×10^{-7} Torr in under 10 minutes, improving production cycle times and the number of batches that can be run per shift or day.

www.temescal.net

EVG deploys data acceleration software from Silver Peak to streamline global workflow processes

EV Group (EVG) of St Florian, Austria, a supplier of wafer bonding and lithography equipment, has deployed data acceleration software from Silver Peak Systems Inc of Santa Clara, CA, USA to accelerate data and applications cost-effectively between its global offices. EVG constantly sends data between its head office in Austria and remote sites in the US, Japan, South Korea and Taiwan. In addition to transferring large files and backing up data from these remote sites, the firm relies on a variety of 10, 20 and 50Mbps WAN connections for business-critical

applications that include SAP, Siebel, Web and e-mail.

"We were constantly encountering delays with our data transfers, which interfered with our workflows," says Alexander Olm, head of IT infrastructure for EVG. "Silver Peak was the solution-of-choice for a number of reasons. Their products provide outstanding performance, offer excellent support for linking our remote offices and data centers, and are easy to implement."

EVG selected Silver Peak because of its software-based approach that gives the company flexibility to deploy virtual or physical WAN

acceleration systems with equal performance, features and functionality. EVG currently uses a variety of Silver Peak NX physical appliances and VX virtual machines running on VMware.

Silver Peak partnered with sysob IT-Distribution GmbH & CoKG and Munich-based Data-Warehouse GmbH on testing and implementation in the EV Group environment. "Thanks to Silver Peak, centrally hosted applications accessed by staff at our remote sites run five-to-10 times faster," Olm notes.

www.silver-peak.com

www.EVGroup.com

CRAIC launches 20/30 PV microspectrophotometer for UV-visible-NIR, fluorescence and Raman microspectroscopy

UV-visible-NIR microscope and microspectrometer manufacturer CRAIC Technologies of San Dimas, CA, USA has launched its new flagship product, the 20/30 PV microspectrophotometer, designed to non-destructively analyze many types of microscopic samples from the deep ultraviolet (UV) to the near-infrared (NIR) using several different techniques.

Analysis of samples can be performed by absorbance, reflectance, Raman, luminescence and fluorescence using the same instrument. The system can also be configured to image microscopic samples in the UV and NIR regions in addition to color imaging.

Applications include materials science research and thin-film measurement on patterned semiconductors. Combined with CRAIC Technologies Traceable Standards, specifically designed for use with microspectrophotometers and calibrated using Standard Reference Materials from NIST, the 20/30 PV provides micro-analysis for laboratory or manufacturing facilities.

"With up to twice the sensitivity of previous models, an extended spectral range and all-new software, the 20/30 PV offers more power and capabilities than any previous model," says president Dr Paul Martin.

The 20/30 PV integrates spectrophotometers with a UV-visible-NIR-range microscope and easy-to-use software. The flexible instrument is designed to acquire data from microscopic samples by absorbance, reflectance, luminescence or even Raman spectroscopy. By including high-resolution digital imaging, the user can also use the instrument as an ultraviolet or infrared microscope. As well as touch-screen controls and software, innovations include calibrated variable apertures. With high sensitivity, durable design, ease-of-use, multiple imaging and spectroscopic techniques, automation and support from CRAIC, the 20/30 PV provides a comprehensive solution for analytical challenges, says the firm.

www.microspectra.com



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Rubicon granted patent for creating asymmetrical wafer configurations according to crystalline orientation

Rubicon Technology Inc of Bensenville, IL, USA, which makes monocrystalline sapphire substrates and products for the LED, RFIC, semiconductor and optical industries, says that the United States Patent and Trademark Office (USPTO) has granted it the patent 'Asymmetrical Wafer Configurations and Method for Creating the Same' (US Patent No. 8,389,099), which covers the creation of visual and tactile indicators to make sapphire wafers asymmetric according to their crystalline orientation, says the firm.

Sapphire wafers have specific orientation that is invisible to the naked eye. Rubicon has developed a process to make wafers appear asymmetrical via visual or tactile inspection. This is important as LED and semiconductor manufacturers process sapphire wafers using specific crystalline orientations. The patent helps manufacturers in the LED and SoS/RFIC industries eliminate costly and unnecessary steps to determine orientation of sapphire wafers during processing, such as x-ray crystallography.

"This new patent demonstrates our ongoing commitment to refine our products for our customers and

deliver innovations that deliver real value," says Raja M. Parvez, president & CEO of Rubicon Technology. "For Rubicon's customers in the LED and SoS/RFIC markets, the crystal orientation is a critical factor in their manufacturing processes. This patent provides a simple and elegant solution to eliminating costly mistakes in the processing of sapphire wafers," he adds.

"It underscores our dedication to not only provide high-quality sapphire wafers, but to provide our customers with added value to lower the total cost of LED and RF solutions."

For Rubicon's customers in the LED and SoS/RFIC markets, the crystal orientation is a critical factor in their manufacturing processes. This patent provides a simple and elegant solution to eliminating costly mistakes in the processing of sapphire wafers

Epitaxy-ready wafers have either an orientation flat or an orientation notch, but this provides insufficient information: the wafer could be flipped front-to-back and still look the same yet be unusable in that state crystallographically. Only through repeated x-ray inspections could the manufacturer ensure that no wafers are reversed. If the wafers are made asymmetrical, operators at each stage of production can verify surface orientation quickly and economically.

Rubicon's patent demonstrates several different solutions for making sapphire wafers asymmetric. In one solution, a rounded corner on the orientation flat or notch allows a user to determine that the wafer has not been reversed. In another solution, both corners of the flat are rounded to different radii. These differences are enough to determine orientation by touch or visual inspection. The technique can be applied to other substrates including silicon, silicon oxide, aluminum nitride, germanium, silicon carbide, gallium arsenide, gallium phosphide, gallium nitride, and amorphous analogs.

www.rubicon-es2.com.

ARC selects Elmet as preferred supplier of crucibles and components for sapphire growth furnaces

Advanced RenewableEnergy Company LLC (ARC Energy) of Nashua, NH, USA, a provider of c-axis sapphire growth technologies and turnkey solutions for the LED solid-state lighting market, has selected Elmet Technologies Inc of Lewiston, Maine, USA as a preferred supplier of crucibles and furnace components for its Controlled Heat Extraction System (CHES) furnaces.

ARC's CHES furnaces grow synthetic sapphire up to 260mm diameter. Synthetic sapphire is a critical building block for LED light manu-

facturing, high-performance glass for mobile devices, silicon-on-sapphire (SOS) semiconductor substrates, military-grade windows, and other applications.

"We strive to provide our customers with innovative, efficient furnaces for large-diameter 6" sapphire," says ARC Energy's co-founder & chief technology officer Dr Rick Schwerdtfeger. "By partnering with Elmet, we feel secure knowing our customers have access to quality crucibles and furnace components manufactured

to the highest standards in the industry."

"The market for synthetic sapphire is increasing rapidly, and Elmet is continually investing to support the growing demand for sapphire crucibles and precision-formed furnace components," says Elmet's senior VP of sales & marketing Sandeep Jain. "We have unique capabilities on which the sapphire industry can capitalize to keep up with the demand."

www.arc-energy.com

www.elmettechnologies.com

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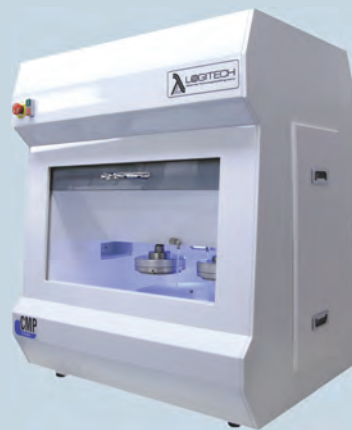
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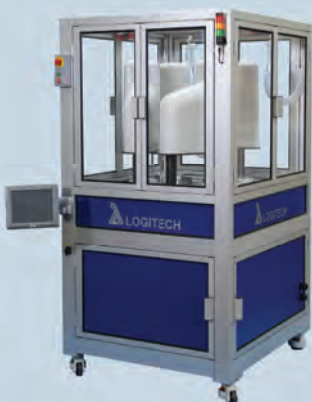
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Hitachi Cable launches HVPE-grown GaN templates

2–6" templates available on flat sapphire or PSS, with 8" planned

Tokyo-based Hitachi Cable Ltd has developed new mass-production technology for gallium nitride templates (see Figure 1), in which a high-quality GaN single-crystal thin film is grown on a sapphire substrate.

Using the template as a base substrate for an epitaxial wafer for white LEDs makes it possible to drastically improve the productivity of white LED epiwafers as well as the LED properties, claims the firm. The product is hence expected to become an effective solution for white LED makers to boost their position in the industry, where there is severe competition.

Demand for white LEDs is growing rapidly, used in recent years in backlight units (BLUs) in liquid-crystal displays (LCDs) as well as ordinary lighting devices due to their energy efficiency and long service life. The structure of a white LED epiwafer consists of a thin active layer and a p-type GaN layer with a total thickness of about $1\mu\text{m}$, on top of an n-type GaN layer with a thickness of about $10\mu\text{m}$, grown on a sapphire substrate (see Figure 1). In the usual manufacturing process, all these crystal layers are produced using the metal-organic vapor phase epitaxy (MOVPE) method. MOVPE is suitable for growing active layers that require atomic-level control of the film

thickness, but it takes a long time to grow a high-quality, thick n-type GaN layer, says Hitachi Cable. White LED epiwafers can therefore be grown only about once or twice a day at the most, thus there is a need for a high-efficiency production method, adds the firm.

Hitachi Cable had previously developed single-crystal free-standing GaN substrates (used to make blue-violet lasers) and also developed unique hydride vapor phase epitaxy (HVPE) growth technology and reactors (for mass producing GaN substrates). Based on this technology, Hitachi Cable has now developed new high-efficiency production technology and machines for mass producing high-quality GaN templates — consisting of an n-type GaN layer grown on sapphire — as a base substrate for MOVPE growth.

Using a GaN template means that LED makers do not need to grow an n-type GaN buffer layer, roughly halving their required growth time compared with conventional methods, it is reckoned. Hitachi Cable says that its GaN templates are also suitable for high-output LEDs, which require large currents because they allow both low resistance and high crystal formation.

Hitachi Cable lists the main characteristics of the GaN template as:

- high crystal quality and high surface quality (based on growth technology established in developing free-standing GaN substrates);
- a low-resistance n-type GaN buffer, suitable for high-output wafers and bonding-type LEDs (with electrodes on both the front and rear side, made by bonding an LED epiwafer on a highly heat dissipating supporting substrate and removing the sapphire — after which the surface should have a low resistance in order to achieve low contact resistance);
- templates on flat-surface sapphire substrates and various types of patterned sapphire substrate (PSS) are available;
- wafers with diameters of 2–6" in are available (an 8" version is planned for development).

Hitachi Cable says that, with the new GaN template now added to its range of GaN substrates and GaN epiwafers, it will strengthen and expand its GaN product group and offer compound semiconductor products catering for a variety of needs.

The firm is exhibiting the GaN templates at the International Conference on Compound Semiconductor Manufacturing Technology (CS MANTECH 2013) in New Orleans (13–16 May).

www.hitachi-cable.com

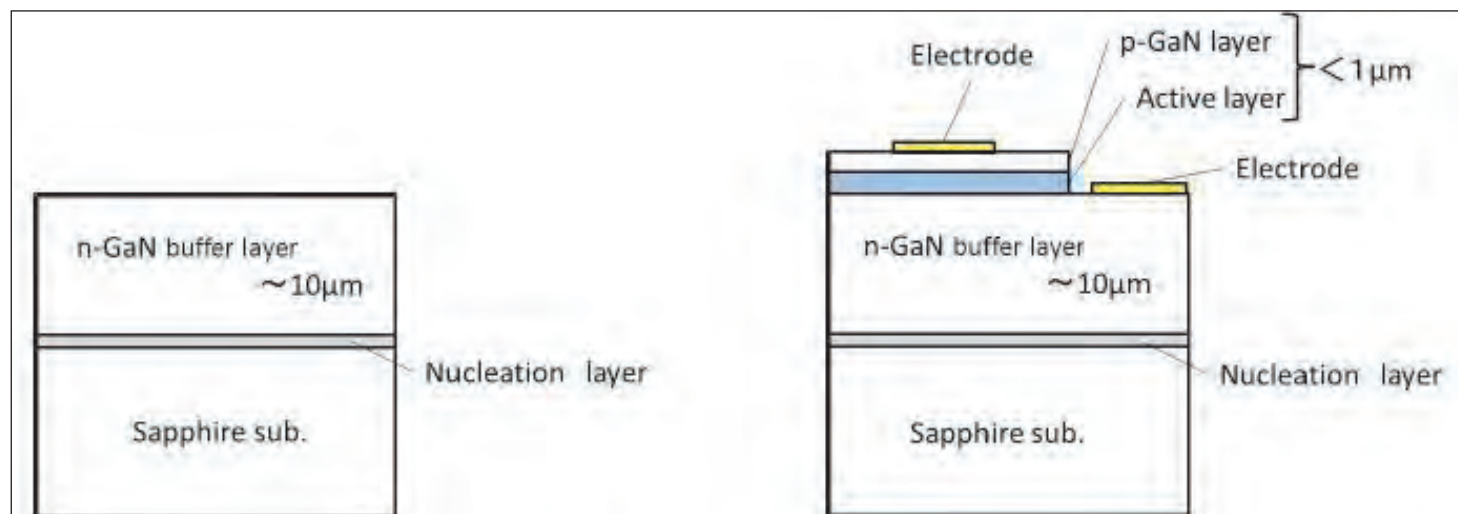


Fig.1 Cross-sections of GaN template (left) and epiwafer for white LEDs (right).



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Cambridge opens £1m GaN-on-Si growth facility

Research on energy-saving LED lighting and power electronics to be expanded and accelerated

The UK's University of Cambridge has opened a new £1m facility for growing gallium nitride that aims to enable researchers to expand and accelerate their work, which promises to further reduce the cost and improve the efficiency of LEDs.

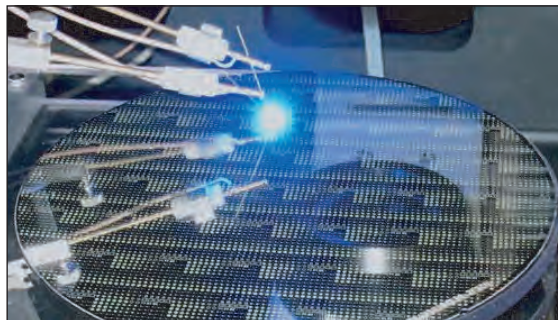
The new GaN growth reactor at Cambridge will allow researchers to further improve existing methods for growing low-cost LEDs on silicon substrates, reducing their cost by more than 50% and opening them up for more general use.

LED technology is already so energy-efficient that it is estimated that the overall demand for electricity would fall by at least 10% if every home and business in the UK switched to LED lighting. This could save the UK over £2bn annually in electricity costs, it is reckoned. Further developments planned in the new reactor could result in an extra £1bn in savings.

In addition, researchers are developing color-tunable LED lighting with the quality of natural sunlight, which would bring health benefits to users.

Funded by the UK's Engineering and Physical Sciences Research Council (EPSRC), the new reactor was opened by David Willetts MP, the Minister for Universities and Science, marking the latest chapter in a decade-long research project on LEDs for lighting applications led by professor Sir Colin Humphreys of the Department of Materials Science and Metallurgy.

In 2003, Humphreys and his team began experimenting with growing GaN on silicon instead of costly sapphire and silicon carbide (SiC). Last year, their process technology was picked up by UK-based manufacturer Plessey, which has since started manufacturing LEDs at its factory in Plymouth. Plessey also hired three of Humphreys' post-doctoral scientists to help transfer the process.



GaN LEDs grown on a silicon substrate.

Credit: University of Cambridge Department of Materials Science & Metallurgy.

"At the moment, a 48-watt LED lightbulb, made from GaN-on-sapphire LEDs, costs about £15," says Humphreys. "That's a cost that you make back several times, because the bulbs last for so long, but it is too much to convince most customers to buy them. The research we have already performed on GaN-on-silicon LEDs, plus that which we will carry out in this new reactor, will mean that soon people will be able to buy an LED bulb for just £3 instead," he reckons.

"LEDs are highly energy efficient but expensive to produce, meaning their domestic use is limited," commented Willetts. "This excellent new facility will enable researchers to look at more cost-efficient ways to produce LEDs."

Humphreys is also investigating 'smart lighting' systems, in which LED lights coupled to a sensor would be able to switch themselves on and off, or alter their brightness, relative to a user's presence or levels of natural daylight in a room.

Also, as their use increases, the beams from LEDs could be used to transmit information, for example from traffic lights to cars, it is forecast. "The two could be developed to talk to one another," Humphreys says. "Traffic reports, such as information about a road accident, could be sent to traffic light systems. They could then relay the details to drivers by transmitting it

through the headlamps."

In addition, since deep ultra-violet (UV) radiation kills bacteria and viruses, UV LEDs can be used to purify water supplies in the developing world. Placing a ring of UV LEDs around a water pipe at the point where it enters a home could kill off bacteria in the water as well as other undesirable organisms, such as mosquito larvae.

Humphreys and his team are also currently investigating the 'green gap' problem. With blue LEDs currently used to make white light, the color-changing phosphor coating is not completely energy efficient, so a better way of making white light could be by mixing together blue, red and green LEDs. However, this depends on resolving lower efficiency in green light compared with the other two colours. If this can be addressed, and LEDs made the standard for lighting, then there could be an extra electricity saving of 5%.

Cambridge researchers are also starting to investigate GaN's potential in electronics. Using GaN instead of silicon can improve energy efficiency in power electronics (devices, circuits and systems that manage electrical energy). Humphreys and colleagues from several other UK universities have just been awarded a grant by the EPSRC to develop and prototype highly efficient GaN power electronic devices that could underpin new applications in sectors such as the automotive, aerospace, consumer electronics, lighting, health-care and energy industries. "If we can replicate these devices with GaN electronics, we believe that we could make them 40% more efficient," Humphreys reckons. "That in itself would translate into a 9% electricity saving."

www.cam.ac.uk

Plessey samples LEDs grown on 6" GaN-on-silicon

Launch of firm's first LEDs marked by visit of UK Business Secretary

Plessey Semiconductors Ltd of Plymouth, UK says that samples of its PLW111010 gallium nitride (GaN)-on-silicon LED products are now available.

The entry-level products are claimed to be the first LEDs manufactured on 6-inch GaN-on-silicon substrates to be commercially available. Plessey is using its proprietary large-diameter GaN-on-Si process technology to manufacture the LEDs on its 6-inch MAGIC (Manufactured on GaN IC) line. Plessey says that the use of its MAGIC GaN line using standard semiconductor manufacturing processing enables yields of greater than 95% as well as fast processing times, providing what is reckoned to be a significant cost advantage over sapphire and silicon carbide (SiC)-based solutions for LEDs of similar quality.

The announcement of availability of Plessey's GaN-on-Si LEDs coincided with a visit to the Plessey Plymouth facility by the Rt. Hon. Dr Vince Cable MP, the UK government's Secretary of State for Business Innovation and Skills and president of the Board of Trade. "The government is supporting innovative companies like Plessey who are growing, creating jobs and exporting their products all over the world," commented Business Secretary Cable. "That's why we selected Plessey's £3.25m Regional Growth Fund bid for Government support, which will create 100 new, high-tech and highly skilled jobs in the region," he added.

"The department of Business Innovation and Skills has been very supportive of our efforts to date and, with the launch of our first range of LEDs today, we are now looking towards aggressive growth in the solid-



Plessey's new MAGIC GaN-on-Si LED product.

state lighting markets," says Plessey's CEO Michael LeGoff.

"From acquiring our first MOCVD reactor [an Aixtron CRIUS II-XL] in August 2012 to having our first product in April 2013 is excellent progress," reckons Plessey's chief operating officer Barry Dennington. "These entry-level products will be used in indicating and accent lighting applications," he adds. "We will continue to make progress in output efficiency and are on plan to release further improvements in light output throughout this year and into next. The operating and unit costs are on plan and we are seeing a number of routes to enhance our cost advantage over competing technologies."

www.plesseysemiconductors.com/products/magic



Plessey Semiconductors' CEO Michael LeGoff (left) and UK Business Secretary Dr Vince Cable MP (right).

IN BRIEF

Samsung launches 145lm/W efficacy Zhaga-compliant LED linear modules

Samsung Electronics Co Ltd of Seoul, South Korea has introduced a new lineup of Zhaga-compliant LED H-Series linear modules with high efficacy and light quality, as well as color consistency for use in a wide range of LED lighting applications including ambient lighting and linear fixtures.

"Our new Zhaga-compliant H-Series is well suited to be used in a variety of high-performance light fixtures," says Jaap Schleggen, senior VP, LED lighting sales & marketing, at Samsung Electronics's Device Solutions Division. The new LED module series is one of several launches in a series of new LED modules with high light performance and efficacy, says the firm.

The H-Series features luminous efficacy of 145lm/W, which is claimed to be the industry's highest in the LED module product category. The new module's correlated color temperature (CCT) of 5000K provides an improvement of about 40% over a typical T5 fluorescent lamp and an improvement of 50% over a T8 fluorescent lamp, says the firm.

The H-Series consists of four types of LED module, each with a different form factor and luminous flux for various market needs. Fixture makers can connect multiple modules together for variations in luminous flux, without a gap between the modules.

Samsung featured its H-Series at LightFair International 2013 in Philadelphia, PA, USA (23–25 April), along with other LED modules, as well as new LED packages, lamps and LED tubes. The H-Series is available in May.

www.samsung.com

IN BRIEF

SNAP attachment of accessories to MR16

Soraa has unveiled SNAP, claimed to be the first magnetic-attach LED lamp and accessory system for lighting. Coupling its high-output PREMIUM 2 or VIVID 2 LED MR16 10° lamp with a prismatic lens and an array of magnetic filter and lens attachments, light can be customized directly on lamps rather than on fixtures.

Using accessories is a costly process that involves heavy glass or metal that can withstand the heat from halogen lamps, requiring expensive fixtures built for such purpose, adds the firm.

Due to its bright, single LED light source and prismatic optic, the LED MR16 10° lamp can accept a magnet in the center of the lens without any major effect on light output. This enables a simple attachment mechanism that can accept all kinds of accessories. Also, the lamp's relatively low operating temperature allows use of new accessory materials, such as advanced polymer films. Typical accessories include: beam spreads such as 25°, 36° and 60°; hex-louvers and snoots to reduce glare; grates to create linear light patterns; and filters for color temperature shifting and color tint effects. Soraa will also deliver a series of what it claims are previously unattainable beam distributions such as flat tops with even illumination for specialty markets.

"You can now adjust beam spreads, color temperature, and CCT," says Dave McCarroll, partner at Kaplan Gehring McCarroll Architectural Lighting. "The ability to retrofit into the millions of existing fixtures with a tight 10° lamp in a variety of color temperatures and beam distributions is just what the lighting marketplace needs," notes Paul Gregory, president of Focus Lighting.

Soraa launches full-spectrum 65W- & 75W-equivalent LED MR16 lamps

Soraa Inc of Fremont, CA, USA, which develops solid-state lighting technology built on 'GaN on GaN' (gallium nitride on gallium nitride) substrates, has launched its full-spectrum VIVID 2 and PREMIUM 2 LED MR16 lamp lines — claimed to be the first ultra-efficient replacements for 65-watt and 75-watt halogen lamps — available for both 12V and line voltages.

Enabled by the latest record performance (announced in February) of Soraa's GaN-on-GaN LEDs, the new LED MR16 lamps deliver what is claimed to be the industry's highest light output, while rendering vivid colors, richer reds and whiter whites.

"We now have 65W- to 75W-equivalent lamps that produce full visible spectrum light and consume 80-85% less energy," says CEO Eric Kim. "We have just scratched the surface in terms of performance gains from our GaN-on-GaN LED technology," he adds.

Most LED lamps currently available are based on LEDs made by depositing GaN on foreign substrates like sapphire, silicon carbide (SiC) or silicon. They consequently have high crystal defect densities that limit the current density they can handle, limiting the amount of light they emit per unit area. The high defect densities also constrain the LEDs to much lower temperatures in order to operate reliably. Both these limitations are amplified when the LEDs are used in a small form factor like an MR16 lamp, which is frequently installed in constrained or enclosed fixtures, and is used in applications that require very high light output. The lamps that use these LEDs require compensating design choices, says Soraa, such as using multiple LED light sources to generate the required amount of light, and active cooling mechanisms to keep the LEDs within their operating temperature range.



Soraa's LED MR16 lamp.

In contrast, the VIVID 2 and PREMIUM 2 lamps' GaN-on-GaN LED technology leverages the 1000x lower crystal defect density advantage of the native substrate, thus emitting much more light and allowing reliable operation at much higher temperatures, says Soraa. This enables a very simple and robust MR16 lamp design that uses a single LED light source and a simple heat-sink, while producing 65–75W halogen equivalent light output and operating reliably at lamp temperatures of up to 120°C (a requirement for use in the most constrained fixtures). "Smaller-form-factor, high-output LED MR16 lamps will now replace larger lamp types like PARs," believes Kim.

The VIVID 2 LED MR16 lamp has a color rendering index (CRI) of 95 and an R9 value of 95 and is available in a complete suite of beam angles, color temperatures and lumen outputs; the PREMIUM 2 LED MR16 lamp has a CRI of 80 and is available in multiple beam angles and color temperatures.

Both MR16 lamps will soon be available for line voltage fixtures. The 100V E11 lamp will be available in May through Soraa's Japanese distribution partner Ushio. The 120V GU10 lamp for the US market will be available in July, followed by the 230V GU10 lamp for international markets in September. The 120V E26 lamp for PAR lamp fixtures will be available in fourth-quarter 2014.

www.soraa.com

CEA-LETI spin-off Aledia makes its first LEDs on 8-inch silicon wafers using microwire technology

First-round funding of €10m to aid commercialization

Aledia S.A. of Grenoble, France, which develops LEDs based on microwire GaN-on-silicon technology, has made its first LEDs on 8" (200mm) silicon wafers. The firm says that the cost of its 3D LED chips based on microwires is expected to be four times less than traditional planar (2D) LEDs. Aledia also announced that its first-round financing (which was closed in 2012) raised a total of €10m (about \$13m) from US and European investors.

Aledia says that the continued integration of LEDs into new applications (such as general lighting) depends on LEDs becoming available at substantially lower prices than today. The firm reckons that its microwire technology — fabricated on large-size silicon wafers and with low materials cost — can enable the steep cost reduction that is vital for the further transition to LEDs. The new LED technology is also compatible with silicon CMOS technology and can be manufactured directly in existing high-volume silicon foundries, the firm adds.

Aledia's 3D GaN-on-silicon microwire technology was developed over a six year period at CEA-LETI in Grenoble. As part of its spin-out from CEA, Aledia received exclusive worldwide rights to all present and future CEA patents on microwire technology as applied to the area of lighting. Several additional patents have already been filed directly by Aledia.

"Since our financing last year, we have scaled up our microwire manufacturing process and transferred it to 8-inch (200mm) silicon wafers," says co-founder, president & CEO Giorgio Anania. "We can now push forward to optimize the performance of these products and bring them to market."

Anania was previously CEO of Bookham (now Oclaro, the second-largest manufacturer of optical components for telecoms networks), which he joined when it had 30 people and zero sales. He left the firm nine years later, having brought it to \$250m in sales, 2700 in staff, and public offerings on both the LSE and NASDAQ stock markets.

At Aledia, he is joined by chief operating officer Xavier Hugon and chief technology officer Philippe Gilet (both co-founders of Aledia and former CEA employees).

Investors in Aledia's first-round financing include Sofinnova Partners (a European venture capital fund and an active investor in energy); New-York based Braemar Energy Ventures (a US energy technology investor with investments in the LED and illumination sectors); Demeter Partners (the largest France-based cleantech investor); and CEA Investissement (the venture capital arm of CEA, France's Commissariat à l'Energie Atomique et aux Energies Alternatives).

"Braemar is committed to investing in companies like Aledia that have developed a breakthrough approach to LED lighting to accommodate a rapidly changing market," says Braemar Energy Ventures' partner Jiong Ma, who looks forward to the expansion of Aledia's market presence and product offerings.

www.leti.fr

www.minatec-entreprises.fr/HelioDEL

Soraa adds fixture, transformer and dimmer partners to LED lighting compatibility program

After launching the 'Works with Soraa' lamp and fixture validation program last December, Soraa Inc of Fremont, CA, USA has added nine new fixture makers: Excelsior Lighting, HK Lighting Group, Light Raze, Tegan Lighting, Intense Lighting, Lucifer Lighting, Nora Lighting, Liton Lighting, and Pure Edge Lighting join the four original partners — Tech Lighting, Focal Point, Hevi Lite, and Dreamscape Lighting — to form the largest coalition building validated LED lamp and fixture solutions for the lighting market. Soraa has also expanded the program to dimmer

and transformer manufacturers, with launch partners Crestron and Q-Tran.

"LED lighting interoperability is a vexing problem that the entire industry faces," says CEO Eric Kim. "We are pleased to see new manufacturers joining the program to eliminate this problem and create validated solutions for the market," he adds. "The program will benefit all stakeholders in the lighting industry — lighting designers, architects, contractors, installers, and end users — by providing certainty about LED lamp, fixture and lighting infrastructure compatibility."

The Works with Soraa program is designed to foster strong collaboration between Soraa and fixture, dimmer and transformer makers, so combinations of products can be rapidly validated for mechanical, thermal and electrical compatibility to create market-ready solutions. Validated product combinations are listed on Soraa's and the partner's websites and in catalogs, so specifiers can then specify, and customers can purchase and install, these solutions with confidence.

www.soraa.com

Philips claims first 200lm/W lamp with high-quality light

Advances in green-emitting phosphors and blue LEDs yield record-efficiency warm-white LED lamp

Philips claims it has created the world's most energy-efficient LED lamp for general lighting applications.

Philips researchers have developed a prototype 'TLED' lamp — designed as a replacement for fluorescent tube lighting (TL) in office and industry applications (which account for over half of all lighting) — that produces a record 200lm/W of high-quality warm-white light (compared with 100lm/W for fluorescent lighting and just 15lm/W for traditional incandescent light bulbs). With lighting accounting for more than 19% of the world's electricity consumption, Philips reckons this could drive massive energy and cost savings.

The firm says that, to break the 200lm/W barrier, the challenge is to achieve higher efficiency at the lamp/system level (demonstrated in an end-product prototype under real-world, normal conditions and ready to be incorporated into actual products). Until now, similar efficiencies have been achieved in a cool and controlled lab setting or at the component level, but when placing the LED in a lamp it could lose up to 50% of its efficiency, says Philips.

Also, to be suitable for real-world applications, the light produced by LEDs must fall within certain technical parameters. If it is too cool or too warm in color, or lacks a sufficient quantity of red, it will interfere with the way the human eye perceives color, and will give objects an unnatural tint. Yellow/green-emitting LEDs obtained by phosphor conversion, for example, are extremely energy efficient (providing more than 380lm/W), but practically useless for general lighting purposes, the firm reckons.

There are currently two ways to make white light with LEDs: (1) mixing multiple wavelengths of different LEDs to make white light (i.e. RGB), allowing lighting designers to tune the white light to a spe-



Rifat Hikmet of Philips Research with the first prototype TLED and an integrating sphere.

cific color temperature; or (2) using a blue indium gallium nitride (InGaN) LED with a phosphor coating to create white light, resulting in the more commonly seen 'white LED'.

Philips says that it is using a new approach, combining blue, green and red LEDs to create high-quality white light. Inside the tube, red, green and blue LEDs consuming just 7.5W emit as much as a 100W incandescent bulb (about 1500lm). The red LED — presumably made from aluminium indium gallium phosphide (AlInGaP) — and the blue LED (InGaN) are both native (direct) emitters, while the green is made from an InGaN blue LED coated with a green-emitting phosphor (rather than from an InGaN die with the In/Ga ratio tuned to emit green directly). The InGaN dies are made by Philips' LED making subsidiary Lumileds of San Jose, CA, USA. For the TLED, Lumileds has boosted the luminous efficiency of its InGaN LED compared with the earlier generation that was at the heart of Philips' 10W A-lamp LED bulb (which won the US Department of Energy's L Prize for 60W-replacement bulbs in 2011).

Philips reckons that its TLED prototype lamp marks the first time that lighting engineers have been able to reach 200lm/W efficiency without compromising light quality, with all parameters required to meet the stringent requirements

for office lighting. The firm notes that comfortable, workable general lighting requires a correlated color temperature (CCT) of 3000–4000K, a color rendering index (CRI) of at least 80, and an R9 saturated red level of no less than 20. The specification of the TLED prototype is 200lm/W without reducing the CRI (>80) while staying on the black-body line; the CCT is 3000–4500K and R9>20, says the firm.

Until now, the relatively high efficiency of fluorescent lighting (100lm/W) has seen it dominate in office and industrial environments. Conversion to the twice-as-efficient 200lm/W TLED lamps could halve energy consumption for lighting, making significant cost savings, the firm reckons. In the USA alone, for example, fluorescent lights consume about 200 terawatt-hours (TWh) annually. If these lights were all replaced with 200lm/W TLEDs, the USA would use about 100TWh less energy (equivalent to 50 medium-sized power plants), saving more than \$12bn and preventing about 60 million metric tons of CO₂ from being released into the atmosphere, it is reckoned.

The new LEDs also generate less heat, and can hence be made without heat sinks. They are hence less bulky, give greater design freedom, use less material and can be produced more cheaply, reckons Philips.

The 200lm/W TLED lamp is expected to hit the market in 2015 for office and industry applications. However, Philips reckons the TLED lamp will ultimately be used in the home. Homes and shops have tended to stick with the gentler, warmer light produced by conventional incandescent bulbs (operating at about 15lm/W) or halogen lights (25lm/W), but the firm reckons that the greater efficiency of its 200lm/W LED, combined with its light quality, can finally overcome this.

www.philipslumileds.com

Philips and Optogan JV begins production in St Petersburg

Saint Petersburg governor Georgy Poltavchenko and Anatoly Chubais, CEO & chairman of RUSNANO (Russian Corporation of Nanotechnologies, a sovereign investment corporation based in Moscow), visited the St Petersburg site of LED chip and luminaire maker Optogan, where the joint venture 'Philips and Optogan' has started production of the new 'Avenue' LED luminaire. The maximum capacity of the line is more than 50,000 LED luminaires per year.

Founded in Helsinki, Finland in 2004 by Russian entrepreneurs and scientists from Ioffe Institute in St Petersburg, Optogan is a vertically integrated manufacturer of LED chips, components, lamps and lighting equipment for applications including general lighting. In addition to having an R&D facility in Helsinki, since founding Optogan GmbH in Germany in 2005 it has established epitaxy and chip R&D plus a pilot line in Dortmund and its Fab1 chip fabrication plant in Landshut. Also, after founding JSC Optogan in Russia in 2009, in 2010 it acquired an industrial facility in St Petersburg, where it has set up LED component and luminaire production lines.

The new line is capable of producing



St Petersburg governor and RUSNANO CEO visiting Optogan's production site.

LED luminaries for street lighting according to the highest international quality standards, energy efficiency and reliability, claims Optogan. The visitors to the plant were shown the new developments of 'Philips and Optogan' for street and yard lighting, which allow a significant decrease in energy consumption without any loss in light quality, it is claimed.

The Avenue LED luminaire fulfills the entire range of economic and technical requirements of the Saint-Petersburg Energy Efficiency Program, the firm says, adding that 'Philips and Optogan' can offer the Avenue at a competitive price of 8000 rubles. Also, the firm's experience of interacting with design bureaus supports application of the JV's LED luminaires, it is reckoned.

In particular, the new LED luminaires perform well even on A1-class highways, with lighting poles 65m apart and about 20m high.

Royal Philips Electronics and Optogan signed the joint venture agreement only in April 2012, with the aim of becoming a strong player in Russia's fast-growing LED road-lighting market. It took less than a year to launch the production line in St Petersburg. The JV combines Philips' latest LED road-lighting solutions and international quality standards with Optogan's LED expertise, solutions and understanding of local market requirements in this field.

'Philips and Optogan' has improved and developed its product portfolio over the past year regarding both economics and technology. Compared with 2012, the price of the LED luminaires in 2013 has fallen by 30%, while energy efficiency has risen by more than 10%.

As part of the visit, a cooperation agreement between St-Petersburg Government and Rusnano was signed to stimulate the demand for innovative products, including nano-products. The parties also signed an action plan for 2013–2016.

www.optogan.com

LUXEON Z ES micro-LED launched with 1-step warm-white binning

Philips Lumileds of San Jose, CA, USA claims its newest high-power emitter, the LUXEON Z ES, offers industry-leading color consistency via a 1-step MacAdam ellipse in warm-white color options. With a micro-footprint (1.6mm x 2mm), undomed design and full spectrum availability, LUXEON Z ES enables high lumen density with precise optical control, adds the firm. In retail applications, where superior beam angles and high efficacy are vital, the illumination-grade emitters help to lower costs while offering best-in-class white light, it claims.

The LUXEON Z ES is available with below black-body binning (the

new 1-bin option), a key feature required for color perception in specialty retail and hospitality applications. The undomed design also offers 10–15% better color-over-angle (CoA) over standard domed emitters for higher quality of light needs in indoor applications, it is claimed, making it suitable for GU10, BR30 and A19 lamps, for example. In directional light sources such as an MR16 lamp, the undomed design allows better optical coupling for greater luminance at narrower beam angles and better color consistency.

The ES is the first LED platform that combines high luminance in a

1-step MacAdam Ellipse option offering optical control in the smallest available footprint, claims Raj Malhotra, product line manager of the LUXEON Z family. "Manufacturers can use optical solutions that are 25% smaller, yet offer the same light quality that larger, domed solutions can achieve."

The LUXEON Z and Z ES white emitters are offered over a CCT (correlated color temperature) range of 2700–6500K with 5-, 3- or 1-step MacAdam Ellipse binning, enabling high-efficiency tunable solutions with a combination of different colors, including white CCTs, lime, blue, PC amber and red.

Bridgelux sells GaN-on-Si LED technology/chip-related assets to Toshiba as it focuses on lighting products

LED chip and lighting array maker Bridgelux Inc of Livermore, CA, USA has agreed to sell its gallium nitride-on-silicon (GaN-on-Si) technology and related assets to Tokyo-based semiconductor manufacturer Toshiba Corp. The firms will also strengthen and extend their strategic technology collaboration through an expanded licensing and manufacturing relationship.

In January 2012, Bridgelux and Toshiba entered into a joint development and collaboration agreement for the development of GaN-on-Si LED technologies. Last May, Toshiba also made an equity investment in Bridgelux. This followed the achievement of what was claimed to be the industry's best-performing 8" GaN-on-Si LED, emitting 614mW from a 1.1mm-square chip (with an operating voltage of 3.1V and a drive current of 350mA). Subsequently, in July, Toshiba announced that it would enter mass production of white LEDs (on a new production line constructed in its 200mm wafer fabrication plant at Kaga Toshiba Electronics Co Ltd) last October. Both these milestones were achieved using Bridgelux's crystal growth and LED device technologies as well as Toshiba's silicon processes

and manufacturing technologies.

The firms say the new enhanced strategic relationship provides for new business opportunity through the expanded collaboration on next-generation LED chips and packages (or platforms) based on the jointly developed GaN-on-Si technology. In addition, a manufacturing deal secures Bridgelux a source of supply of GaN-on-Si LED chips for its lighting products.

"Our agreement with Toshiba marks a tremendous milestone in our long history of working closely together, allowing Bridgelux to capitalize on our strong core LED technology platform, providing us with significant new capital for growth, and reducing our capital requirements," comments Bridgelux's CEO Brad Bullington (who was promoted in February from VP, Strategy and Corporate Development & general manager, Technology Solutions). "This agreement also allows us to focus on what we do best, and what we think the market needs most at this point in time: commercializing, productizing and bringing to market LED-based solid-state lighting technologies alongside a proven global-scale semiconductor manufacturing partner," he adds.

"Gaining GaN-on-silicon technology and related assets will contribute to drastically strengthening our LED business, and bring us a high-performance and competitive product line-up," reckons Makoto Hideshima, executive VP of Semiconductor and Storage Products Company, corporate VP of Toshiba. "We fully expect our new Livermore team to play a leading role within Toshiba in the development and rapid market penetration of GaN-on-silicon LED chips," he adds. "Entering a new phase of our relationship with Bridgelux, we will be able to accelerate the scaled manufacturing of 8" GaN-on-silicon LED wafers, which will position both companies for strong growth in our respective LED businesses," Hideshima reckons. "The GaN-on-silicon technology that we acquire will also bring us a breakthrough for power devices development and production."

Assets included in the sale, and the related staff, will remain at Bridgelux's headquarters in Livermore after the transaction closes in order to assure continued technical and business collaboration between the companies.

www.bridgelux.com

www.toshiba.co.jp/index.htm

LED light engine, optics and luminaire technology licensed to CG

Electrical product, system and services provider CG of Mumbai, India has agreed a technology licensing deal with Bridgelux for its LED light engine, optics and luminaire expertise that will enable CG to deliver solid-state lighting (SSL) products to business, government and mass-market consumers.

CG has licensed proprietary technology for LED streetlights, luminaires, LED arrays, drivers, optics, and other components. Bridgelux will provide technology and support on design, and application engineering for commercial and indus-

trial lighting products such as streetlights, down-lights, high bays and medium bays, and well glass.

The agreement will drive synergistic benefits for both firms, it is thought. CG will become a completely vertically integrated firm, delivering lighting solutions from the semiconductor through to LED luminaires. The technology transfer should strengthen CG's product portfolio and enable it to penetrate lighting markets in India and elsewhere. CG will continue to ramp up and align its capacity to meet the growing demand for SSL products.

CG has a 30% share of India's street-lighting market. Bridgelux should enable CG's entry into the retail indoor lighting product sector, while CG's brand image and reach will help Bridgelux to gain access to the fast-growing Indian market.

"The technology agreement with Bridgelux further strengthens CG's position, while simultaneously bringing down overall costs and promoting energy savings," comments CG's CEO & managing director Laurent Demortier.

www.cgglobal.com

www.bridgelux.com

Bridgelux makes Vero LED arrays commercially available

LED chip and lighting array maker Bridgelux Inc of Livermore, CA, USA has announced the commercial availability of its Vero LED array solid-state light source, which was unveiled last December.

All form factors of Vero LED arrays are now commercially available and shipping to customers and distribution partners worldwide. Vero was showcased at LightFair International in Philadelphia (23–25 April).

"The immediate and wide-scale adoption of Vero is the tangible and powerful result of customer-driven product design," says Mick Wilcox, VP of marketing. "Vero's versatility minimizes not only the number of arrays needed, but it also reduces driver and optics inventory costs."

The new Vero LED arrays increase lumen output by 20% over existing Bridgelux LED arrays, and deliver typical luminous efficacy of 110lm/W, compared with 95lm/W for conventional arrays.

Bridgelux says that Vero enables lamp and luminaire makers to optimize for efficiency, cost, light density, or any combination of these attributes based on application-specific design requirements.



Bridgelux's Vero LED array.

Vero features what is claimed to be an industry-first onboard connector port that interfaces with the Molex Pico-EZmate connector to enable simple plug & play solder-free electrical interconnectivity and field upgradability.

The firm claims that its Vero packaged array technology offers advances in design flexibility, ease of use, and energy efficiency while also defining a platform for future smart functionality.

"We have been partnering with Bridgelux for years to deliver high-quality lighting to our customers for a broad range of retail and

commercial applications," comments Chuck Campagna, CEO & president of lighting manufacturer Amerlux LLC of Fairfield, NJ, USA. "The ease-of-use features and design flexibility in Vero helps us shorten design cycles, accelerate time to market and improve manufacturability."

The Vero platform provides broad interior and exterior application coverage via four form factors. Lumen output performance ranges from 400lm to 15,000lm, while correlated color temperature (CCT) options range from 2700K to 5000K, with 3SDCM (standard deviation of color matching) for the 2700–4000K CCT options. Color rendering index options include 70, 80, 90, and 97 CRI Décor products. A radial die pattern improves lumen density and beam control.

Thermally isolated solder pads reduce both manufacturing time and complexity, while top-side product marking and a 2D bar-code improve inventory management. A solder-less connector port enables plug & play connectivity and field upgradability. Bridgelux claims reliable operation at up to two times the rated drive current.

Licht + Design chooses Bridgelux as LED lighting array supplier

Luminaire developer and distributor Licht + Design of Hildesheim, Germany has chosen Bridgelux's Vero LED arrays for its retail food and product light applications.

A lighting designer serving major retail stores focusing on clothing and food products, Licht + Design was challenged by shop owners to reduce operating and energy costs, enhance interior designs and atmospheres, and provide optimal color and light levels while delivering functionality previously unattainable with traditional, vacuumed-based lighting. "Licht + Design has a significant impact in the European product and food retail sector," notes Max Hong, Bridgelux's executive VP, sales & marketing.

Bridgelux says that its Vero arrays provide Licht + Design's customers with 20% more lumens per watt than conventional LED arrays as well as a substantially higher color rendering index (CRI). The Vero also provides up to 2x increase in current rating. Licht + Design expects customers to see more than a 50% reduction in energy costs with the Vero array integration.

Due to its quick assembly design, the Vero array simplifies and streamlines luminaire product manufacturing while improving overall system reliability, claims Bridgelux.

Also, as LED light generated by the Vero array does not generate heat or ultraviolet radiation, retailers can expect a dramatic decrease in

food spoilage, reckons Bridgelux, further reducing operating and maintenance costs and extending the shelf life of perishable products.

Like other LED light sources, Vero LED arrays are also fully dimmable, easily connected to networks, and emit light with no ignition time.

"We have been partnering with Bridgelux for their LED technology for some time," says Licht + Design's CEO Frank Armbricht. "By moving to Vero arrays, we not only expect to see energy consumption drop even further, but we're well poised for the future of LED lighting as the arrays are fully optimized for smart connector integration."

www.licht-design.de
www.bridgelux.com

Epistar signs LED collaboration and IP licensing deal for Intermolecular's combinatorial technology platform

Intermolecular Inc of San Jose, CA, USA and LED chipmaker Epistar Corp of Hsinchu, Taiwan have signed a collaborative development program and royalty-bearing IP licensing agreement. The firms' engineers will work together to leverage Intermolecular's High Productivity Combinatorial (HPC) technology platform to accelerate development and manufacturing qualification of novel materials and processes relating to Epistar's LED products.

Founded in 2004, Intermolecular says it has pioneered a proprietary approach to accelerate R&D, innovation, and time-to-market for the semiconductor and clean energy industries. The approach consists of its HPC platform, coupled with its multi-disciplinary

team. Through paid collaborative development programs with its customers, Intermolecular develops proprietary technology and intellectual property for its customers focused on advanced materials, processes, integration and device architectures.

"After a rigorous review of Intermolecular's capabilities through an initial collaboration engagement, we have seen how their combinatorial approach to materials innovation and device integration can augment Epistar's leadership in LED technology," says Epistar's president M. J. Jou.

"Leveraging Intermolecular's team and technology platform will further increase our competitive advantage," he believes.

A multi-functional team of technologists from Epistar and Intermolecular will work together using the HPC platform to accelerate the pace of R&D ten times or more compared to what can be achieved in a conventional LED lab, says Intermolecular.

"Entering into a strategic engagement with a top-tier LED company like Epistar validates the applicability and disruptive potential of the HPC technology platform for LEDs, a market that continues to have tremendous room for growth and technology innovation," comments Sandeep Nijhawan, senior VP & general manager of Intermolecular's clean energy group.

www.intermolecular.com

www.epistar.com.tw

SemiLEDs' revenue falls 23% quarter-to-quarter LED chip over-capacity and price decline hit margins, but cost controls cut losses

For its fiscal second-quarter 2013 (to end-February), LED chip and component maker SemiLEDs Corp of Hsinchu, Taiwan has reported revenue of \$4.8m, down 23% on \$6.2m last quarter and 39% on \$7.9m a year ago.

Founded in 2005, SemiLEDs' makes proprietary blue, green and ultraviolet (UV) LED chips under the MvpLED (metal vertical photon LED) brand for sale mainly to chip-packaging customers in China, Taiwan and other parts of Asia such as Korea, 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).

Impacted by the drop in revenue, a decline in the average selling price (ASP) of LED chips, and excess capacity charges for the

firm's LED chips, gross margin has deteriorated further, from negative 9% a year ago and negative 53% last quarter to negative 69%.

"Demand has improved; however, the pricing environment for the general lighting market remains challenging," says chairman, president & CEO Trung Doan.

R&D expenses have been cut further, from \$2m a year ago and \$1.2m last quarter to

Impacted by the drop in revenue, a decline in the ASP of LED chips, and excess capacity charges for the firm's LED chips, gross margin has deteriorated.

The pricing environment for the general lighting market remains challenging

\$1m. Selling, general & administrative (SG&A) expenses have also fallen, from \$3.7m last quarter to \$2.6m. Total operating expenses have hence been cut from \$5.1m a year ago and \$4.9m last quarter to \$3.6m.

On a non-GAAP basis, net loss has been cut to \$5.4m, compared to \$8.6m last quarter and \$6.1m a year ago. Cash used in operating activities was \$4.2m, down from \$4.5m a year ago. Also, capital expenditure has fallen further, from \$3.3m a year ago and \$1.7m last quarter to just \$0.37m. Hence, total cash burn has been cut further, from \$7.8m a year ago and \$4.9m last quarter to \$4.6m.

"We are on the right track and this is a turning point for SemiLEDs," Doan believes. "From an execution standpoint, we need to focus on profitable markets and control cost," he concludes.

www.semileds.com

VPE reveals details of a new MOCVD System for high-volume GaN LED production

Valence Process Equipment (VPE) of Branchburg, New Jersey, has announced the commercial introduction of a high-performance MOCVD reactor for GaN LEDs.

According to founder and CEO, Frank Campanale, "The VPE GaN500 system is now available in a 59x2-inch configuration that can be upgraded to a 20x4-inch wafer configuration."

"Although a new name to many, VPE has been in R&D mode since 2007. Its core technology team has a long pedigree in the MOCVD industry" continued Campanale. "Prior to bringing the GaN500 to market, we successfully completed a number of custom epitaxial system design projects, including a continuous-flow III-V Solar MOCVD system and a dedicated AlN epitaxy system. In 2010, we decided to push forward with the design and build of a large-scale GaN system, and in 2011, we installed our first unit in a customer fab in Asia. Data from that, plus data from our in-house systems, over hundreds of process runs since 2011, clearly demonstrate the reliability and robustness of the VPE platform – so

much so, that we are fully confident to bring it to the market at this time." VPE's GaN500 design team took a radically different approach from other recent entrants to the MOCVD field. The system is built around a relatively small, multi-zone, proportional-flow injector housed in an elliptically-flared chamber producing excellent uniformity of the epitaxial layers with highly efficient use of the gases and precursor chemicals. According to Dr. Michael Begarney, founder and CTO "In side-by-side comparisons against a smaller-capacity competitive unit and, for the same process, the VPE GaN500 system can use up to 40% less Hydrides and Alkyls – with the added benefit that our injector is designed to run clean, so maintenance costs are low."

The emphasis on low cost of ownership extends to all aspects of the VPE design. "When faced with a choice between a complex and a simple solution – we chose the simple option" said Begarney. "For example, we worked closely with a manufacturer of in-situ monitoring tools to develop our own proprietary hardware and software for reflectance measurement – including the ability to monitor growth on PSS substrates. The result is a system that is affordable to acquire, efficient in operation and economical to maintain."

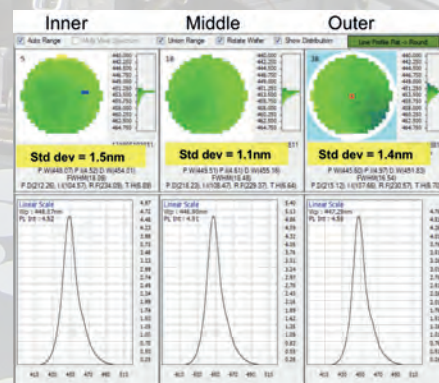
Low COO does not compromise epitaxial wafer quality. The VPE team believes that many aspects of its MOCVD system design directly translate into superior material quality. "GaN (002) and (102) XRD rocking curves are routinely in the low 200s of arc seconds" said VPE Vice President Dr. Tom Ryan "and independent third parties have been impressed by our level of control of both temperature and gas switching during

MQW growth. We believe that these attributes lead to higher IQE LEDs".

In mid-2012, VPE moved into a 24000ft² facility in Branchburg, New Jersey. The facility has a clean manufacturing area, with simultaneous production capacity of up to 12 MOCVD systems, as well as an engineering area and full characterization lab.

Campanale went on to talk about the VPE wafer capacity roadmap. "When we designed the GaN500 we deliberately used an over-sized chamber with room to accommodate a larger diameter platter. Our first system used a 52x2" wafer platter, which we have subsequently expanded to 59 wafers. We are currently testing an upgrade kit – that allows us to expand the capacity to 72x2" wafers or 20x4" wafers in the existing chamber, with the same efficient operating properties."

www.valenceprocess.com



VALENCE PROCESS EQUIPMENT

IN BRIEF

Cree introduces XLamp XQ LEDs

LED chip, lamp and lighting fixture maker Cree Inc of Durham, NC, USA has introduced the XLamp XQ LED product family. The XQ LEDs are Cree's smallest lighting-class LEDs at 1.6mm x 1.6mm, 57% smaller than Cree's XLamp XB package.

Built on Cree's SC3 Technology Platform, the ceramic-based XQ LEDs are designed to deliver the long-term calculated lifetimes of Cree's other high-power LEDs. The XQ LED's new light-emission pattern directs more light towards the edge rather than the center of the package, says the firm.

"The high reliability of the ceramic-based XQ-B LED allows us to offer a high-quality solution that does not compromise on lifetime," says Martin Hockemeyer, vice-chairman of the board of TELEFUNKEN Licht AG. "The unique optical advantage of the XQ-B gives us the opportunity to create the brilliant look that our customers are looking for."

"Unlike other mid-power packages, the XQ LEDs allow lighting manufacturers to meet their light-distribution requirements using fewer LEDs, without giving up the performance or reliability that they expect from Cree's lighting-class LEDs," says Paul Thieken, Cree's director of marketing, LED components.

The XQ family includes two new LEDs, the XQ-B and the XQ-D. In cool white (5000K), the XQ-B LED delivers up to 160 lumens-per-watt at 0.18W, and the XQ-D LED delivers up to 130 lumens-per-watt at 1W. Both LEDs are available in 2700K to 6500K color temperatures with minimum 80 CRI option.

Cree XLamp XQ LED samples are available now.

www.cree.com/xq

Luminus Devices and Vision X Lighting form strategic partnership; Big Chip LEDs for long-throw spot lighting aim to displace traditional high-intensity discharge technology

Luminus Devices Inc of Billerica, MA, USA, which makes PhlatLight (photonic lattice) LEDs for solid-state lighting applications, and Vision X Lighting of Seattle, WA, USA (a supplier of after-market automotive lighting fixtures) have formed a strategic partnership to extend the adoption of LED technology into lighting applications that

are currently dominated by high-intensity discharge (HID) lamp technology. The collaboration will create a new class of LED lighting products that can provide the power of HID-based systems, it is claimed.

With a Luminus LED at the heart of the light fixture, we can deliver useful light at distances that could only previously be achieved with HID lamps... a distance of over 1000 feet

"With a Luminus LED at the heart of the light fixture, we can deliver useful light at distances that could only previously be achieved with HID lamps," says Vision X Lighting's president Tony Georgitsis. "New products we will be releasing in the coming months."

Vision X Lighting recently launched its first product using a single Luminus LED. Light Cannon can produce a usable beam of light at a distance of more than 1000 feet.

Luminus' HB-LEDs produce thousands of lumens, says Jim Hunter, VP & general manager of Global Commercial Markets at Luminus. "As demonstrated through our partnership with Vision X Lighting, we enable our customers to create exciting lighting products capable of delivering high-brightness light at great distances with unprecedented center beam candle power."

www.luminus.com

www.visionxusa.com

Cree boosts LEDway Series LED street light performance by up to 15%

LED chip, lamp and lighting fixture maker Cree Inc of Durham, NC, USA has announced a performance upgrade to its LEDway Series LED Street Light. The luminaires, provided in several versions, replace high-pressure sodium (HPS) and metal-halide (MH) fixtures, says the firm. Providing improvements over the prior LEDway Series, select versions of the new street lights provide up to 20% additional energy savings and increased lumen output, while other versions provide up to 15% higher lumen output and extra energy savings.

"Cree is committed to helping

municipalities and facility owners lower their lighting energy costs and maintenance expenses," says Greg Merritt, vice president, lighting at Cree. "The increased performance of the new LEDway Series can improve payback up to 25% compared to the previous generation and strengthens the argument to replace antiquated lighting technologies."

With a ten-year warranty, Cree's LEDway Street Lights offer more than 20 optical distribution patterns, flexible drive currents and multiple lumen packages.

www.cree.com/lighting/ledwayseries

Cree launches higher-light-output CXA2540 and CXA3050 LEDs

LED chip, lamp and lighting fixture maker Cree Inc of Durham, NC, USA has extended its XLamp CXA family of integrated LED arrays with the introduction of higher-light-output CXA2540 and CXA3050 LEDs. Optimized to simplify designs and lower system cost, the new CXA LEDs deliver between 5000 and over 10,000 lumens, enabling new applications such as high-output track lights and downlights, outdoor area lighting and high-bay lighting, says the firm.

The CXA3050 is the brightest member of the CXA family and can enable LED replacements for up to 100-watt ceramic metal halide in spot lighting or up to 175-watt pulse-start metal halide in high-bay and outdoor area lighting. The CXA3050 LED Array also enables lighting manufacturers to expand their product portfolio with higher-lumen products.

The CX2540 LED delivers up to 20% higher efficacy (at 5000 lumens and 3000K) than competing LED arrays of similar size, says the firm. In addition, it shares the same mechanical package as the existing CXA2520 and CXA2530 LEDs, giving manufacturers access to the same connector and optics solutions currently available.

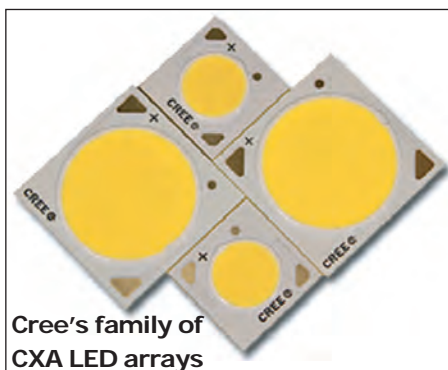
"We really like the ease-of-use and high performance of the CXA family, and we're looking for higher-lumen versions to address the high-bay lighting market," says Jong Hyun Woo, chief project manager of ILSUNG Ltd. "The CXA3050 LED Array gives us the performance that we need together with the high reliability that Cree is known for to create compelling designs for our customers."

The CXA2540 and CXA3050 LED Arrays use the same package technology as the CXA1507 LED, which now has 6000 hours of LM-80 data published and is able to support TM-21 calculated lifetimes of greater than 130,000 hours at binning current and greater than 85,000 hours at maximum current. This long-term calculated lifetime exceeds many other LED Arrays and plastic mid-power LEDs used today, it is claimed.

To help lighting manufacturers get started designing with the new CXA integrated LED arrays, Cree has also published three CXA-based LED reference designs: PAR30 replacement lamp, six-inch downlight, and retail track light. In addition, the new CXA LEDs are available in EasyWhite color temperatures.

CXA2540 and CXA3050 LED samples are available now.

www.cree.com/cxa



Cree's family of CXA LED arrays



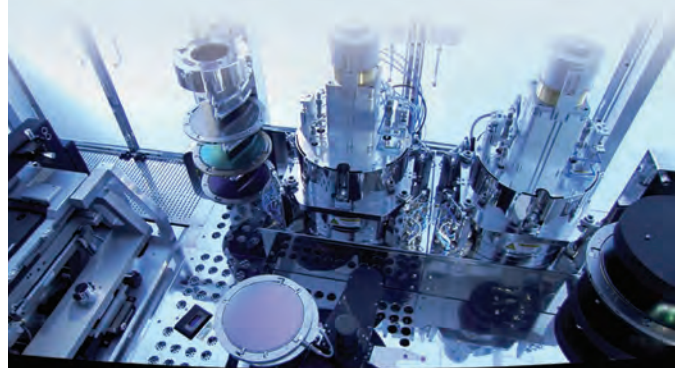
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www.EVGroup.com

Osram introduces brighter and longer-lasting Topled LEDs for mass-transit interior lighting

Osram Opto Semiconductors GmbH of Regensburg, Germany says that its new generation of Mini Topled and Topled LEDs produces a pleasant white light in varying tones that is suitable for interior illumination of buses, trains, airplanes and cars. The standard packages for these LEDs have been retained (3.2mm x 2.8mm for the Topled and 1.8mm x 2.2mm for the Mini Topled), but they now contain chips in a new brightness class with properties that include durability, resistance to electrostatic discharge (ESD), improved corrosion stability and certification to the automotive industry standard AEC Q101.

The new generation of Topled and Mini Topled LEDs has been tailored to the demands of public and private passenger transport for high-brightness and high-quality interior illumination. The light sources combine a pleasant white light with



a much longer lifetime of up to 50,000 hours for increased durability.

The LEDs are low-power components that consume only 0.1W. Also, despite their low power, the new Topled LW TVSG produces a luminous intensity of 2400 millicandelas (mcd) at a color temperature of 6000K from an operating current of 20mA. From the same operating current, the Mini Topled LW MVSG and LCW MTSG LEDs achieves a typical luminous intensity of 1700mcd at a color temperature of 4000K, and 1900mcd at 6500K.

Osram Opto says that the new generation of these two LED types benefits from further developments in chip and package technologies resulting in continual increases in light output. The firm adds that this is supplemented by its years of experience as a supplier in meeting the requirements of the automotive industry. These include the high electrostatic discharge (ESD) rating of 8kV and improved corrosion stability.

The new components are certified to the automotive supply industry standard AEC Q101 and meet the requirements that rail, road and air transport systems demand from components used for interior lighting. "LED light with different white tones helps create a feeling of well being without compromising brightness or durability," comments Mike Godwin, director, Visible LED at Osram Opto.

High-output, wide-beam-angle 850nm IR LED for gesture detection

Osram Opto reckons that its new infrared (IRED) Oslon black SFH 4716S is one of the most powerful IREDs on the market, with an optical output of 1030mW. With a beam angle of 150°, it provides illumination at a range of a few yards/meters and is hence suitable for gesture detection systems linked to computer games or for optical safety systems in the automotive sector. Also, with external optics and tight focusing, even distant objects can be illuminated with infrared light.

The compact (3.85mm x 3.85mm x 1.51mm) high-power IRED illuminates the relevant area so that a camera sensor can detect movement, which can then be used to control a computer or enter text. The wide beam angle ensures that the near-field area is uniformly illuminated and gestures are reliably detected. Text can therefore

be entered, even if the hand is a few centimeters away from the keyboard. The SFH 4716S is also certified in accordance with the automotive standard AEC-Q101, so it can be used in safety-related applications such as driver monitoring or seat occupancy detection systems in vehicles.

The high optical output of 1030mW is achieved at an operating current of 1A with an efficiency of about 35%. This increased performance is based on the stack technology used by Osram that provides each chip with two emission centers, doubling its output. Oslon black achieves a radiant intensity of up to 225mW/sr. Emitted light with a wavelength of 850nm is suitable for camera sensors but is barely visible to the human eye, so it is not considered an annoyance.

The high optical output of the Oslon black also makes it suitable

for combining with external reflectors. It may initially seem contradictory to create a narrow beam from a wide-angle light source, says Osram Opto, but this is a very efficient way to achieve high radiant intensity and long range. The firm claims that light from the SFH 4716S injects very well into an external reflector, which shapes the beam so that it can be tightly focused by an additional lens, making the LED suitable for surveillance and monitoring systems that operate with additional infrared illumination. "With the aid of external reflectors it is possible to produce very narrow beam angles and illuminate at distances of several hundred yards, or meters," comments Dr Amine Taleb-Bendiab, senior product marketing manager- IR Products, for Osram Opto.

www.osram-os.com

Multichip tunable white LEDs for Ostar Stage spotlight

Osram Opto Semiconductors says that its latest Ostar Stage LEDs offer a high luminance of 48 million candelas per square meter (48Mcd/m² at a drive current of 900mA) as well as tunable color tones from cold white to warm white. Combined with their low-profile design and glass cover with its anti-reflective coating, they provide the basis for compact spotlights with an very narrow beam, the firm says, suiting use in moving head spotlights on stage, for booth lighting at trade fairs and for architectural lighting.

Two warm-white and two cold-white chips, sited diagonally in the package, not only enable colors to be mixed at the component level but also allow all white tones between color temperatures of 2700K (warm white) and 10,000K (cold white) to be produced with appropriate control. The LED achieves a high color rendering index (CRI) of 94 for warm white and 74 for cold white.

Instead of the usual lens, the LEDs have a flat glass cover with an anti-reflective coating, making them suitable for injecting the light into lens systems. Its etendue (the emission angle/area ratio of the emitting light surface to the projected light surface) in conjunction with external optics is retained, enabling a very narrow beam ($\pm 9^\circ$) to be produced. This is smaller by a factor of 2 than for spotlights based on plastic-encapsulated LEDs, so the spotlight's luminance is doubled.

Due to the glass cover, the Ostar Stage LED also has a much lower profile than previous standard components. At 1.23mm its height is a quarter of the usual component height and its footprint is only 5.9mm x 4.8mm, so spotlights can be made very compact.

All versions of the Ostar Stage are based on the Ostar SMT platform and are suitable for standard solder processes. The chips are fabricated using Osram's latest thin-film technology, so almost all light produced internally is emitted at the top. The LED hence suits use with external

optics. In continuous operation (DC) the chips can handle current up to 900mA, giving maximum brightness of 390lm in cold white (10,000K) and 210lm in warm white (2700K). At a typical value of 1.8K/W the thermal resistance is very low and heat removal is hence no problem. In constant use the LEDs will last for more than 50,000

hours, giving moving heads and architectural fixtures a long life.

The LEDs can be used in spotlights of any size, from small stage spots to large moving heads.

Three versions of the Osram Ostar Stage LED are available, the Multi Color (RGBW), the pure white and now the tunable white.

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IN BRIEF

ProPhotonix adds Oclaro's high-power lasers to its range

ProPhotonix Ltd of Salem, NH, USA, a designer and manufacturer of LED illumination systems and laser diode modules as well as a distributor of laser diodes, is to distribute the high-power laser line of Oclaro Inc of San Jose, CA, USA in North America and Europe.

Oclaro's high-power lasers complement ProPhotonix's low-power laser diodes and laser modules in established markets such as medical, defense & security, and instrumentation. The new products will also enable ProPhotonix to address a wider set of applications including materials, processing and printing. ProPhotonix already distributes Oclaro's visible and near-infrared laser diodes.

Oclaro makes high-power lasers with multiple packaging options for industrial and consumer markets. ProPhotonix says they will offer its customers a comprehensive solution set for their applications and enable it to grow revenue in markets previously unavailable with its existing range.

"This new product line gives our customers the opportunity to work with one vendor on their critical applications, which has significant cost- and time-saving implications," reckons chairman & CEO Mark W. Blodgett.

"Strengthening our partnership with Oclaro not only extends that position, but also gives our customers the benefit of Oclaro's extensive experience in laser manufacturing and fiber-optic coupling," Blodgett continues.

"Given their recent expansion of technical sales teams in both the US and Europe, ProPhotonix is well positioned to increase sales of our product portfolio," says Gunnar Stolze, Oclaro's VP, global sales Industrial & Consumer.

www.prophotonix.com

QEOS unveils record-speed LEDs in its first commercial OEM products

Tilted Charge Dynamics light-emitting transistor cuts cost, power consumption, size

Quantum Electro Opto Systems (QEOS) of Cupertino, CA, USA, which focuses on the design and volume production of multi-Gb/s optical communications products, has launched its first commercially available OEM/ODM products.

Founded in 2008 by CEO Dr Gabriel Walter and professors Nick Holonyak Jr and Milton Feng (inventors of the Tilted Charge Light Emitting Transistor at the University of Illinois), QEOS has developed patented QEOS Tilted Charge Dynamics light-emitting technology, which forms the basis of the firm's new high-speed LEDs.

QEOS says that the technology enables it to develop products of lower total power consumption, smaller size, and lower cost compared to traditional multi-gigabit short-distance optical transmission products. The record-speed LED is 10 times faster than the traditional LEDs in the market, reckons CEO Dr Gabriel Walter. "And the products we're introducing are a fraction of the size, power, and cost of traditional laser-based products with the comparable functionality," he adds. "With the transistor structure, various new integrated optical and electronic functions can be realized that are not possible with the existing optical technology."

Bringing its Tilted Charge Dynamics technology to market for the first time, the firm has introduced its QEOS Optical Transceiver Kit, which consists of the new QEOS Transmitter Optical Full Assembly (TOFA) designed to operate with the new QEOS Receiver Optical Full Assembly (ROFA). The kit provides a low-power, low-cost product-ready 3.5Gbps solution for distances up to 100m.



(left) QEOS Transmitter Optical Full Assembly (TOFA). (right) Size of existing optical transmitter compared with QEOS TOFA.

Also unveiled is a higher-speed QEOS TOFA, an ultra-low power consumption, high-speed optical transmitter operating up to 6.5GHz (designed for 10Gbps applications) and available later this year.

All TOFAs and ROFAs are 'full-function' assemblies. QEOS says that, due to their lower cost and power consumption, the Tilted Charge Dynamics high-speed technology-enabled products can be used for active optical cables (AOCs), interconnecting computers, board-to-board interconnects and in power-sensitive portable applications.

QEOS says that its products aim to expand the use of optical technology for multimedia, audio/video and IT applications in the consumer, residential and commercial markets. "This technology can be used to support a range of transmission interfaces such as USB, HDMI, Ethernet, Thunderbolt, Infiniband, and also communications within portable devices," says chairman Raymond Chin. "Our lower-power-consumption and lower-cost products open up the market for new and expanded use of optical communications in data centers, and for industrial, commercial and residential optical connectivity."

The QEOS Optical Transceiver Kit will soon be available for sampling, and the higher-speed QEOS TOFA will be available later this year.

www.qeosystems.com



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Michigan demonstrates simpler, more efficient single-photon emitter for quantum cryptography

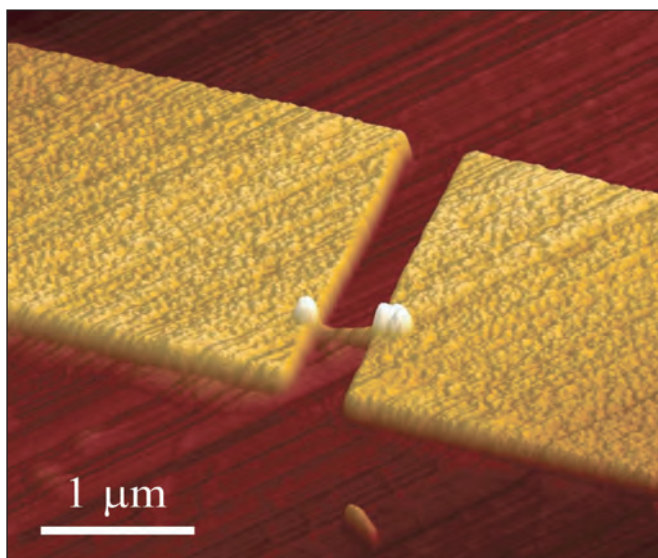
InGaN quantum dot in GaN nanowire on silicon promises practical electrically driven devices

In a development that could make the advanced form of secure communications known as quantum cryptography more practical, University of Michigan researchers — supported by the US National Science Foundation (NSF) — have demonstrated a simpler, more efficient single-photon emitter that can be made using traditional semiconductor processing techniques ('Electrically-driven polarized single-photon emission from an InGaN quantum dot in a GaN nanowire', published online in Nature Communications on 9 April; doi: 10.1038/ncomms2691).

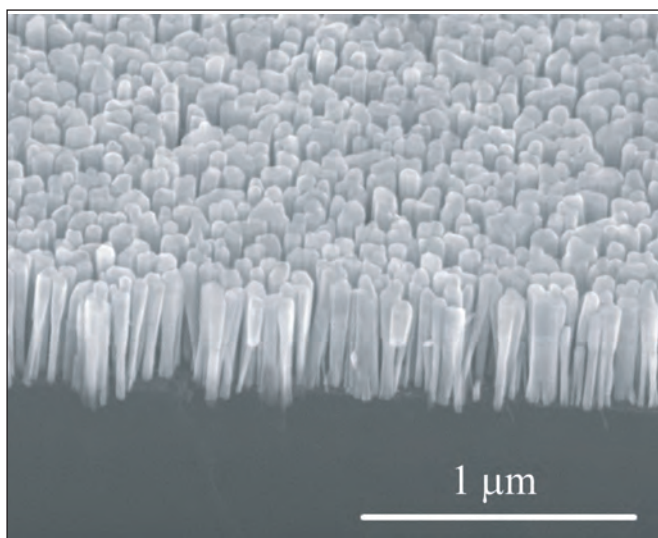
Single-photon emitters are essential for quantum cryptography, which keeps data secure by using the so-called observer effect: the act of an eavesdropper listening in jumbles the message, since in the quantum realm observing a system always changes it. For quantum cryptography to work, it's necessary to encode the message just one photon at a time. The sender and the recipient will hence know whether anyone has tampered with the message.

While the University of Michigan researchers didn't make the first single-photon emitter, they claim that their new device- which was fabricated at the University of Michigan Lurie Nanofabrication Facility - improves on the existing technology and is much easier to make.

"It is all based on silicon," says project leader Pallab Bhattacharya, the Charles M. Vest Distinguished University Professor of Electrical Engineering and Computer Science, and the James R. Mellor Professor of Engineering. Bhattacharya is co-author of the paper. The first author is Saniya Deshpande, a graduate student in electrical engineering and computer science.



Atomic-force microscope (AFM) image of nanowire single-photon emitter. (Courtesy of Pallab Bhattacharya.)



Nanowires growing on silicon. (Courtesy of Pallab Bhattacharya.)

The new single-photon emitter is a single nanowire made of gallium nitride with a very small region of indium gallium nitride (InGaN) that behaves as a quantum dot. The researchers grew the nanowires on a silicon substrate. Because the technique is silicon-based, the infrastructure to manufacture the emitters on a larger scale already exists. "It produces the pathway to

realizing a practical electrically injected single-photon emitter," Bhattacharya says.

Key enablers of the new technology are size and compactness. "By making the diameter of the nanowire very small and by altering the composition over a very small section of it, a quantum dot is realized," Bhattacharya says. "The quantum dot emits single-photons upon electrical excitation."

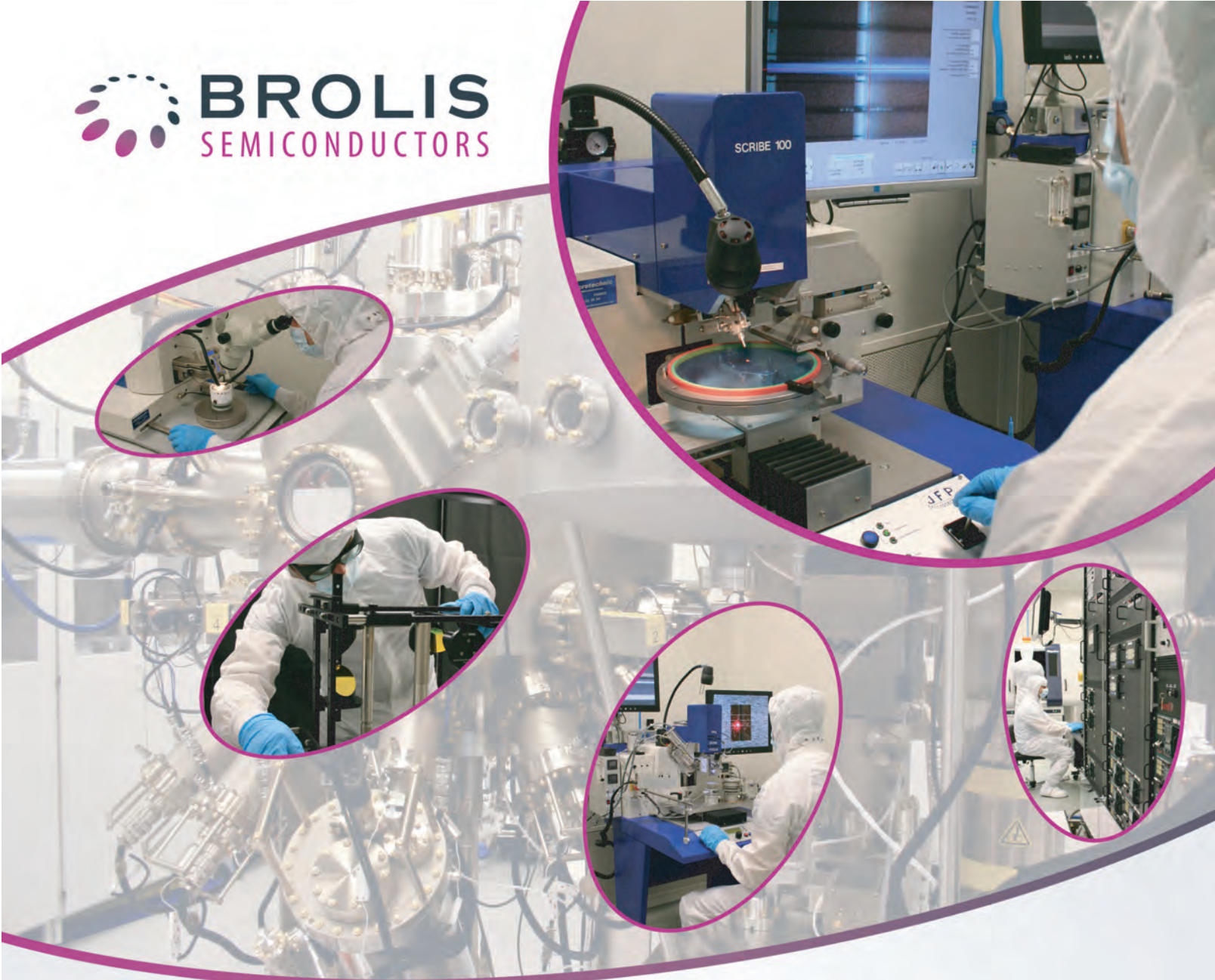
The University of Michigan emitter is electrically rather than optically pumped, helping to make it more practical. Each photon it emits has the same degree of linear polarization. Most other single-photon emitters release light particles with a random polarization. "Half might have one polarization and the other half might have the other," Bhattacharya says. "So in cryptic message, if you want

to code them, you would only be able to use 50% of the photons. With our device, you could use almost all of them."

The device operates at cold temperatures, but the researchers are working on one that operates closer to room temperature.

www.nature.com/ncomms/journal/v4/n4/full/ncomms2691.html

www.eecs.umich.edu



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NeoPhotonics completes acquisition of LAPIS' optical components business unit for \$35.2m

NeoPhotonics Corp of San Jose, CA, USA, a vertically integrated designer and manufacturer of both indium phosphide (InP) and silica-on-silicon photonic integrated circuit (PIC)-based modules and subsystems, has completed its acquisition (announced in January) of the optical components business unit (OCU) of LAPIS Semiconductor Co Ltd ahead of schedule.

OCU is a designer and manufacturer of lasers, laser drivers, photodiodes and amplifiers for high-speed networks, and was previously the component division of OKI Electric for high-speed lasers and III-V amplifiers before it was acquired by ROHM Semiconductor in 2008. The business now operates at its existing location near Tokyo as NeoPhotonics Semiconductor GK, a Japanese subsidiary of NeoPhotonics.

"We look forward to this expansion of our 100G product suite, our further strategic expansion into the Japan market, the addition of new global network equipment and module customers, and expanding our business opportunities with our current mutual customers," says NeoPhotonics' chairman & CEO Tim Jenks.

NeoPhotonics paid about \$10.2m in cash for OCU, after adjustments, and about \$3.7m in cash as the first of four equal payments for the

associated real estate. NeoPhotonics has also assumed employee retirement obligations of about \$6.5m and compensation obligations of \$0.6m. The total consideration for the real estate (including the payment made upon the closing) is \$14.6m, with the balance payable over the next three years. Including the future payments for real estate, the total purchase price is about \$35.2m (paid in Japanese Yen).

On 21 March, NeoPhotonics entered into a syndicated revolving credit and term loan agreement with Comerica Bank, as administrative agent and lead arranger. East West Bank has also become a lender under this facility. NeoPhotonics borrowed \$28m under the term loan facility and \$12m under

We look forward to this expansion of our 100G product suite, our further strategic expansion into the Japan market, the addition of new global network equipment and module customers, and expanding our business opportunities with our current mutual customers

the revolving credit facility to refinance existing company indebtedness of about \$20.9m and help to finance the OCU acquisition and related transaction expenses.

Prior to the closing, the LAPIS Semiconductor OCU business unit was not a standalone company, so audited financial information for it is not yet available. Based on preliminary unaudited pro forma financial information provided by the management of LAPIS, OCU had revenue of about \$45m for the first nine months of 2012 (to end-September). Based on company estimates, the addition of OCU is expected to be accretive to NeoPhotonics' adjusted EBITDA within the first year following the transaction. Transaction-related expenses of \$3–4m are expected to be incurred in first-quarter 2012.

The firm plans to provide an update on NeoPhotonics Semiconductor GK when it releases its financial results for Q1/ 2013, which is currently expected to be in the first half of May. It is also preparing the required historical and pro forma financial results reflecting the acquisition and plans to file the information with the US Securities and Exchange Commission (SEC) within the next 75 days (by 12 June).

www.neophotonics.com

NeoPhotonics reports stock option inducement grants to employees of LAPIS Semiconductor optical components business unit

NeoPhotonics says that, in connection with completing its acquisition of the semiconductor optical components business unit (OCU) of LAPIS Semiconductor Co Ltd (at the end of March), it has granted special inducement stock option grants under the NeoPhotonics 2011 Inducement Award Plan to retain certain OCU employees (20 in total) as employees of the NeoPhotonics group.

The firm granted options for an aggregate of 62,000 shares. Each option vests 25% on 1 April 2014 (approximately the first anniversary of the closing of the OCU acquisition) and the remainder in 36 substantially equal monthly installments thereafter, subject to such optionee being employed by the NeoPhotonics group on the vesting dates. The stock options have a 10-year term

and an exercise price equal to \$4.86 per share (the closing price of NeoPhotonics' common stock on the New York Stock Exchange on the date of grant). The options were approved by the Compensation Committee of NeoPhotonics' board of directors and were granted as a material inducement to employment with the NeoPhotonics group.

www.neophotonics.com

NeoPhotonics launches CFP2 pluggable 100G transceiver modules for both 10x10 and LR4 standards to enable double face-plate I/O density

NeoPhotonics Corp of San Jose, CA, USA, a vertically integrated designer and manufacturer of both indium phosphide (InP) and silica-on-silicon photonic integrated circuit (PIC)-based modules and subsystems, has launched two 100G CFP2 transceiver modules that include both the popular 10x10 MSA transceiver based on the '10x10' PIC architecture developed by NeoPhotonics and the '4x25' 100GBASE-LR4 transceiver.

The CFP2 form factor is a hot-pluggable module that is designed to offer lower power and smaller size compared to current-generation CFP transceivers and to enable doubling of the face-plate input/output port density. The CFP2 is also for use in data-center and

metro Ethernet applications.

The new 10x10 CFP2 transceiver is based on ten synchronous electrical lanes and is capable of operating at both 100GE and OTU4 data rates. It features NeoPhotonics' PIC-based 10-channel laser array powered by a 10-channel driver array. The 10x10 CFP2 is also backward compatible with the 10x10 CFP platform currently being commercially deployed. The firm also intends for the CFP2 electrical interface to support both 4x25 LR4 and 10x10 LR10 on the same line-card.

The CFP2 LR4 transceiver is based on four synchronous electrical lanes of 28Gbps signals and is designed to comply with the IEEE 100GBASE-LR4 and OTU4 specifi-

cations. The 4-channel PIC-based integrated transmitter is based on high-performance EML lasers designed to meet stringent OTU-4 optical performance requirements.

"The CFP2 platform is enabled by the company's ability to integrate lasers in arrays utilizing proprietary PIC technology, which we believe will continue to enable smaller transceiver form factors and lower power consumption for data-center and metro Ethernet applications," says chairman & CEO Tim Jenks.

NeoPhotonics demonstrated interoperability of its 100G CFP2 transceiver with Inphi's Tri-Rate PHY/SerDes Gearbox at the Optical Fiber Communication (OFC 2013) exhibition in Anaheim, CA, USA (19–21 March).

Small-form-factor narrow-linewidth micro-ITLA launched for coherent optical transport

NeoPhotonics has launched a small-form-factor, narrow-linewidth, micro-integrated tunable laser assembly (micro-ITLA) technology.

NeoPhotonics says that it is building upon its field-proven technology in creating the new generation of laser, which is designed to reduce footprint by more than a factor of three and reduce power consumption compared to current-generation ITLAs. The micro-ITLA is also intended to outperform current-generation narrow-linewidth lasers in both linewidth and output optical power. Designed to be compliant with the Optical Inter-networking Forum (OIF) implementation agreement, the new micro-ITLA uses NeoPhotonics' PIC technology, which allows the integration of many active and passive photonic functions within single-chip elements.

With demand for bandwidth continuing to grow rapidly, deploy-

ments of 100Gbps networks using advanced modulation techniques and coherent detection are increasingly preferred by carriers as these technologies provide improved signal quality and allow for longer spans in metro and long-haul backbone networks, lowering the overall cost of transporting high-bandwidth data from one place to another, says NeoPhotonics. The narrow-linewidth tunable laser is a key element in coherent optical communications systems, the firm adds. Much like tuning to a signal in a radio receiver, coherent detection uses a narrow-linewidth laser (local oscillator) tuned to the transmitter optical frequency. Laser linewidth must be in the range of a few hundred kilohertz to avoid penalties to signal-to-noise ratio and system performance.

"NeoPhotonics is one of the few companies that can design and

manufacture precision tunable lasers with linewidth suitably narrow for coherent network applications," claims chairman & CEO Tim Jenks. "We became the industry's largest supplier of narrow-linewidth tunable lasers in 2012," he adds. "In the micro-ITLA we utilize our PIC technology to minimize the device size and power consumption, while providing our customers with the device performance and production capabilities they need to capture the growth that is apparent in the 100G market space."

NeoPhotonics showcased its narrow-linewidth tunable laser products along with intradyne coherent receivers, 100G CFP and CFP2 transponders for client-side transmission and an extensive line of OLT transceivers for FTTH PON networks at the OFC 2013 exhibition in Anaheim (19–21 March).

www.neophotonics.com

Avago acquiring optical chip and component supplier CyOptics for \$400m

Single-mode InP laser and receiver capability to strengthen portfolio for emerging 40G and 100G enterprise and data-center markets

Avago Technologies Ltd of San Jose, CA, USA and Singapore (a designer and supplier of III-V-based analog components for communications, industrial and consumer applications) has agreed to acquire privately held company CyOptics Inc of Lehigh Valley, PA, USA, which makes indium phosphide (InP)-based and silica-on-silicon optical chips and components, for about \$400m.

Avago believes that the acquisition of CyOptics will strengthen its fiber-optics product portfolio for emerging 40G and 100G enterprise and data-center applications, with CyOptics' single-mode InP laser, receiver and photonics integration capability helping to extend its technology position.

Avago's optical transceiver products currently primarily leverage vertical-cavity surface-emitting laser (VCSEL)-based technology. Avago also expects the acquisition to facilitate its establishment of a complementary optical components business, not only to serve growing segments of the access, metro and long-haul markets but also for the enterprise and data-center segments.

Founded in 1999, CyOptics designs, fabricates and packages a broad portfolio of optical component products across enterprise, data-center, access, metro and long-haul market segments. Its optical components are integrated into optical transceivers, transponders and line-cards. Leveraging its heritage via its 2005 acquisition of TriQuint Semiconductor's optoelectronics division (which previously belonged to Bell Laboratories and spin-out Lucent Technologies), CyOptics has built a broad product portfolio and a customer base that includes the leading module and system OEMs, it is claimed.

Revenue has more than tripled over the past three years, including rising by 21% from \$174m in 2011 to about \$210m in 2012.

CyOptics' InP technology and optical manufacturing capability will accelerate Avago's ability to capture next-generation 40G and 100G enterprise and data-center sockets, believes Avago's president & CEO Hock Tan. "The company has traditionally focused these products on pockets of the telecom market. More recently, CyOptics has emphasized component and module solutions for fiber-to-the-home applications in the access space, as well as certain growth segments of the data enterprise market. In particular, the firm has developed a presence in the emerging 40 and 100Gb/s enterprise and data center market, working with leading OEM and modules customers as a premier chip and component supplier," says Tan. "The acquisition is an important next step in Avago's enterprise-focused strategy."

"Avago's strategy in the wired market is to focus on enterprise and data centers and target design-in opportunities where performance is the most important factor driving customer decisions. This focus has helped us to outgrow the market," he adds. "With enterprise and data-center markets in the early stages of

transitioning to higher bandwidth, 40G and 100G, and re-transmission distances expanding beyond 1km in data centers and between data centers, technologies which are used in metro and long-haul applications have value in serving parts of this segment," continues Tan. "Single-mode indium phosphide is well established. We have some capability here at Avago, but CyOptics is one of the very few companies in the optical industry that has scale with high-performance, vertically integrated technologies and manufacturing infrastructure for indium phosphide solutions," he notes. "With CyOptics, we also see interesting revenue growth opportunities in delivering a broad range of proprietary components to the market," he adds.

Avago has a strong position in the wired infrastructure market, comments CyOptics' president & CEO Ed Coringrato, who thanks CyOptics' founder Dr Erel Margalit, long-standing investors including Israel-based global venture capital firm JVP (Jerusalem Venture Partners, which owns nearly 55% of CyOptics) and recent partners TA Associates for their support and guidance over the past decade.

Avago intends to fund the transaction from its cash on-hand (which amounts to more than \$1.15bn, due partly to its IPO in 2009, which raised about \$650m). The transaction is subject to customary closing conditions, including the receipt of regulatory approvals in the USA, and is expected to close during Avago's fiscal third-quarter 2013 (ending 4 August). Since CyOptics has been profitable since 2010, Avago expect the transaction to be immediately accretive to its non-GAAP earnings per share.

www.CyOptics.com

www.avagotech.com

The acquisition of CyOptics will strengthen its fiber-optics product portfolio for emerging 40G and 100G enterprise and data-center applications, with CyOptics' single-mode InP laser, receiver and photonics integration

Kotura rolls out 100G silicon photonics chips with WDM in dense QSFP package

At the Optical Fiber Communication Conference & Exposition/ National Fiber Optic Engineers Conference (OFC/NFOEC 2013) in Anaheim (17–21 March), Kotura Inc of Monterey Park, CA, USA, which designs and makes silicon

photonics application-specific integrated circuits (ASICs) for the communications, computing, sensing and detection markets, demonstrated what it claims is the industry's first silicon photonics chips in an industry-standard, dense quad small-form-factor pluggable (QSFP) package.

Since Kotura's Optical Engine uses wavelength division multiplexing (WDM), the firm claims that it is the only silicon photonics provider to offer WDM and that it is now the only silicon photonics provider to demonstrate WDM in a 100Gb/s 4x25 QSFP package with 3.5W of power.

Kotura says that its Optical Engine provides a small form factor that reduces power consumption and provides a high level of integration. Consuming only 3.5W, the firm is addressing the need for 'green' solutions for 100G pipes desired by data centers and high performance computers (HPC).

The QSFP package has become the industry-standard footprint for 4x10G and 40G Ethernet in data centers as well as 40G and 56G Infiniband in HPC. Kotura predicts that the same package will become the industry's volume standard for 100G networks in both data centers and HPC applications.

"The QSFP package enables our customers to fit 40 transceivers across the front panel of a switch,



Kotura's 100G QSFP-packaged silicon photonics chips

providing 10 times more bandwidth than CFP solutions," says president & CEO Jean-Louis Malinge.

"Because we monolithically integrate WDM and use standard single-mode fiber duplex cabling, our solution eliminates the need for expensive parallel fibers," he adds. "No other silicon photonics provider can offer WDM in a 3.5W QSFP package."

Kotura has integrated all of the 100G optical and opto-electrical functions into two small chips. According to Malinge, Kotura's WDM can scale from four channels to many more, on the same chip. At 100G and higher, users need WDM to avoid the use of expensive ribbon fiber, parallel connectors and patch panels. For large data centers, reaches of 30m to 2km are common and expensive ribbon fiber dominates the interconnect fabric costs. For active optical cables (AOCs) and very short-reach links, Kotura also offers a parallel version of its 100G Optical Engine.

"The market for 40G transceivers in QSFP packages has grown much faster than expected," comments Vladimir Kozlov, founder & CEO of market research firm LightCounting. "Squeezing 100G in the same QSFP package and reducing power consumption is critical for applications of 100Gb/s optics in data centers", he adds.

www.kotura.com

IN BRIEF

Avago authorizes share repurchase program to replace 2012 program

Avago Technologies Ltd of San Jose, CA, USA and Singapore (a designer and supplier of III-V-based analog interface components for communications, industrial and consumer applications) says that its board of directors has approved a share repurchase program for 2013 authorizing the firm to repurchase up to 20 million of its ordinary shares. This replaces the 2012 share repurchase program for up to 15 million shares announced on in April 2012, which expired immediately prior to the firm's 2013 annual general meeting (AGM) of shareholders on 10 April 2013.

The 2013 share repurchase program was adopted pursuant to the share purchase mandate (approved by shareholders at the AGM) authorizing the repurchase of up to 10% of the firm's outstanding ordinary shares up to the date of the 2014 AGM.

The 2013 share repurchase program does not obligate Avago to repurchase any specific number of shares and may be suspended or terminated at any time without prior notice. Share repurchases, if any, will be made in the open market at such times and in such amounts as the firm deems appropriate. Avago intends to effect any such share repurchases in compliance with US Securities and Exchange Commission (SEC) Rule 10b-18 or pursuant to a trading plan adopted pursuant to Rule 10b5-1. The timing and actual number of shares repurchased will depend on a variety of factors including price, market conditions and applicable legal requirements.

www.avagotech.com

OneChip launches 100G interconnects for data centers

At OFC/NFOEC, OneChip Photonics of Ottawa, Canada launched a family of indium phosphide photonic integrated circuit (PIC)-based 100Gbps optical interconnect solutions, enabling transceiver makers to produce high-speed, low-power and small-size modules for data-center interconnect (DCI) applications.

The new family builds on the PIC-based receiver chips that OneChip announced, and made available for partner testing, in May 2012.

"OneChip can provide transceiver and system manufacturers with the integrated solutions that they need to meet their cost, power, size and speed requirements, without all of the problems inherent with silicon photonics," says CEO Jim Hjartarson.

"Integration of optics and electronics on one chip holds strong promise for providing low-power, cost-effective 100Gbps interface modules for data-center applications," says Vladimir Kozlov, founder & CEO of market research firm LightCounting. "These attributes will be important in this high-volume market. This market is only going to be high volume if low-power and low-cost products are available." 100 Gigabit Ethernet transceiver sales should rise at a compound annual growth rate (CAGR) of 36% from \$144m in 2012 to almost \$700m in 2017.

Integrated solutions needed for data center interconnects

System integrators want to drive costs down to the point where 100Gbps solutions are as cost-effective to implement as 10Gbps solutions, says OneChip. At the moment, 100GBASE-LR4 implementations are too expensive to be useful for data-center interconnects.

Also, transceiver providers want to fit 100Gbps solutions into QSFP modules, as QSFPs represent the smallest form factor for packaged transceivers, but they must dissipate only 3.5W of power or less.

The only way to meet DCI cost, power and size requirements is through tightly integrated chipsets and sub-assemblies, says OneChip.

OneChip integrates all of the optical functions required for an optical transceiver into a single InP-based chip. All active components — distributed feedback (DFB) laser, electro-absorption modulator (EAM) and waveguide photodetector (WPD) — and passive components — including wavelength-division multiplexing (WDM) combiner, splitter and spot-size converter (SSC) — are integrated in one epi growth step — without re-growth or post-growth modification of the epi material.

OneChip claims that these Multi-Guide Vertical Integration (MGVI)-based PICs enable cost, power and size advantages over solutions based on silicon photonics, discrete components and VCSELs.

PIC-based 100G solutions versus silicon photonics, discrete components and VCSELs

Silicon cannot lase or detect in the required spectral range (1300nm), so silicon photonics providers must add materials that can, for example, bond III-Vs (for lasing) or epitaxially overgrow germanium (for detection) on top of silicon.

Thus, silicon photonics chips cannot be manufactured simply by using standard CMOS materials and processes, OneChip says. This also makes adding photonics capability to advanced sub-micron silicon process nodes cost prohibitive, it adds.

These drawbacks prevent silicon photonics solutions from achieving the cost and size requirements — and the ability to manufacture in volume through standard electronics foundries — that are needed in data-center interconnect applications, the firm reckons.

In contrast, OneChip's single-growth MGVI platform eliminates the need for multiple epitaxial regrowth steps. OneChip can hence partner with standard, high-volume InP foundries to fabricate its PIC-based solutions, improving economies of scale. Simultaneously with the new product launch, OneChip also announced foundry relationships with IQE and Global Communica-

tion Semiconductors (GCS).

OneChip says its MGVI platform in InP is based on the same process that inherently produces the fastest HBTs used in RFICs. It can hence also integrate electronics, such as transimpedance amplifiers (TIAs) and modulator drivers, within a commercially available, volume-scalable process. The aim of silicon photonics to leverage high-volume electronic chip production, while combining photonics and electronics on the same substrate, is best realized in InP, the firm reckons.

These advantages are also true versus solutions based on discrete components and VCSELs, it adds; VCSEL-based solutions cannot accommodate WDM, are difficult to couple with single-mode fibers, and are costly for long-wavelength interconnect applications.

OneChip's PIC technology enables it to multiplex lasers together and produce chip and module solutions that support standard communications wavelengths (e.g. in the 1310nm window) cost effectively.

OneChip says its regrowth-free, PIC-based InP technology has proven successful in the cost-sensitive, high-volume PON market, as its transceivers and bi-directional optical sub-assemblies (BOSAs) are being deployed by the world's largest PON system providers.

Now, OneChip is extending the technology to the high-volume DCI market, which requires 100Gbps+ with higher interface density and longer reach than is reachable with existing systems in 0.85µm and multi-mode fibers. The DCI market also requires lower cost and power consumption than the solutions offered by the traditional telecom component vendors.

OneChip is working with partners to optimally package its 100G and 40G PICs for specific applications. It is also developing 100GE PSM4 TROSAs (transmitter-receiver optical sub-assemblies) for DCI applications.

www.onechipphotonics.com



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CDFP MSA forming to develop standard transceiver specs for 400G data transmission

At the Optical Fiber Communication/National Fiber Optic Engineers Conference (OFC/NFOEC 2013) in Anaheim, CA, USA (19–21 March), it was announced that five leading global companies — Avago Technologies, Brocade Communications Systems Inc, JDS Uniphase Corp, Molex Inc, and TE Connectivity — intend to enter into a multi-source agreement (MSA) to create the CDFP (400Gbps form-factor plug-gable) industry consortium to define a transceiver module/plug mechanical form factor and a host-board electrical edge connector and cage.

The new CDFP MSA is intended to specify and encourage the development and commercialization of a 400Gbps hot-pluggable module that integrates 16 transmit and

16 receive channels supporting passive and active copper cables, and active optical modules.

“This highly integrated transceiver module is expected to enable network equipment manufacturers to implement 400Gbps solutions with high port density and increased system data throughput,” says Scott Kipp, senior technologist, Brocade. “The MSA group intends to make specification details available to promote industry-wide adoption of compatible high density products.”

The CDFP MSA participants aim to provide products that are mechanically and electrically interchangeable. The project scope will specify the electrical interfaces, optical interfaces and mechanical interfaces, which may include optical

connector and mating fiber-optic cable plug, electrical connector, guide rail, front-panel and host PCB layout requirements. Also, the MSA specification is expected to include thermal, electromagnetic and electrostatic discharge design recommendations.

“The collaboration is committed to enhancing customer choice and assuring interoperability and interchangeability by establishing multiple compatible sources of front-panel, hot-pluggable, 16-channel 400Gbps modules that will essentially allow the entire copper cable and fiber-optics transceiver market to grow more rapidly,” says Scott Sommers, group product manager, Molex.

www.cdfp-msa.com

CFP2 specifications completed for 40G/100G transceivers

Avago Technologies, Finisar Corp, Fujitsu Optical Components Ltd, Oclaro Inc and Sumitomo Electric Industries Ltd have announced the completion of CFP2 specifications defining the electrical and physical requirements for 40Gbps and 100Gbps CFP2 optical transceiver products and systems. The CFP2 specifications document is now

available at the CFP multi-source agreement (MSA) website.

The CFP MSA member companies and interest groups, including the Ethernet Alliance and the Optical Internetworking Forum (OIF), showcased a broad range of CFP2 products and systems at the Optical Fiber Communication/National Fiber Optic Engineers Conference

(OFC/NFOEC 2013) exhibition in Anaheim, CA, USA (19–21 March), with attendees experiencing the ecosystem including CFP2 modules, systems and test equipment.

Other firms displaying CFP2 technology included Altera, Ericsson, InPhi, JDSU, Juniper Networks and NeoPhotonics.

www.cfp-msa.org

M/A-COM Tech launches lowest-power electro-absorption modulator driver, enabling CFP/CFP2 applications

At the Optical Fiber Communication/National Fiber Optic Engineers Conference (OFC/NFOEC 2013) in Anaheim, CA (19–21 March), analog semiconductor maker M/A-COM Technology Solutions Inc of Lowell, MA, USA launched what it claims is the industry's lowest-power electro-absorption modulator laser (EML) driver.

Available in a 4mm x 4mm surface-mount package, the MAOM-002203 is a high-performance electro-absorption modulator

driver IC, with a maximum data rate of 28Gbps for 100G applications. The device has power consumption of just 0.75W, low RMS jitter and a typical rise and fall time of 12.5ps, making it suitable as a 100G driver.

“This driver enables customers to effectively meet next-generation CFP/CFP2 power, size and cost requirements,” says M/A-COM Technology Solutions' business development manager Ray Moroney.

The MAOM-002203 is driven with a differential input signal that can range from 250mV_{pp} to 500mV_{pp}, providing an output that can be controlled from 1.0V_{pp} to 2.5V_{pp}. The driver also has separate integrated high-frequency coils, which allows for biasing the driver and the EML, providing an efficient device for CFP and CFP2 applications.

Samples of the MAOM-002203 are available from stock.

www.macomtech.com

Amonix raises photovoltaic module efficiency record in test at NREL

Efficiency record increased from 33.5% to 34.9% under standard CPV operating conditions

Amonix Inc of Seal Beach, CA, USA, which makes utility-scale concentrator photovoltaic (CPV) solar power systems using III-V multi-junction solar cells, says that, during outdoor testing from late February to April, a module showcasing its latest-generation CPV technology demonstrated a peak operating solar energy conversion efficiency of 36.2%, measured on 14 March with a direct normal irradiance (DNI) of 876W/m², an ambient temperature of 16°C and instantaneous wind speed of 1m/s. This exceeds the previous 34.2% peak efficiency set by Amonix in May 2012.

Over the entire testing period, the module earned a National Renewable Energy Laboratory (NREL) outdoor efficiency rating of 34.9%, under international standard operating conditions for CPV of 900W/m², 20°C ambient temperature and 2m/s wind speed, breaking the previous 33.5% rated efficiency world record that was also set by Amonix in May 2012. The module uses 40%-efficient solar cells made by Boeing Spectrolab.

Amonix was previously first to convert over a third of the sun's energy, also in May 2012, and the first to break 30% module efficiency in 2011.

"Amonix's proprietary technology platform allows us to continue driving rapid performance improvements in our CPV system," says founder & chief technology officer Vahan Garboushian. "The advances we have demonstrated over the last 2 years have all been with the same generation 40% cells, demonstrating an unprecedented cell-to-module conversion efficiency of greater than 90%," he adds. "With improvements that are underway in cell efficiency and additional advances in our module technology, we will continue to drive efficiency higher over the coming years," he reckons.

www.amonix.com

Soitec and Khaled Juffali Co create solar energy joint venture for Saudi Arabian market

Soitec of Bernin, France and Jeddah-based Saudi Arabian investment firm Khaled Juffali Company (KJC) have signed a memorandum of understanding (MOU) to cooperate in driving solar industry growth in Saudi Arabia and the Middle East.

The two firms will create a joint venture to market and sell concentrator photovoltaic (CPV) systems in the Kingdom of Saudi Arabia, maximizing the local content. Soitec will provide the technical and commercial solar expertise, while KJC will facilitate access to key local and regional stakeholders and share its long track record in managing international joint ventures.

Soitec's CPV technology, which uses triple-junction cells mounted on a glass plate, achieves at least twice the performance of conventional photovoltaic technologies, making it the most cost-efficient solution for high-volume power generation in regions with high direct normal irradiation (DNI), claims the firm.

The KJC-Soitec MOU is in line with the ongoing thrust of Saudi Arabia to explore and tap into renewable energy sources, as shown by the white paper recently published by the King Abdullah City for Atomic and Renewable Energy (K.A.CARE) which outlines the competitive procurement process for solar, wind, geothermal and waste to energy projects in Saudi Arabia.

Soitec has a pipeline of projects totaling hundreds of megawatts in the USA and South Africa and operates in 14 countries around the world, including a demonstration system at the Medina College of Technology (MCT) in Saudi Arabia, notes KJC's founder & chairman Sheik Khaled Juffali. "Soitec has already demonstrated its ability to industrialize disruptive innovations with high-quality standards," he adds. "CPV is indeed perfectly suited for countries which benefit, like Saudi Arabia, from intensive solar radiation."

"Soitec has shown its willingness to contribute to the Kingdom's skills training in the cooperation with the Saudi Arabian Technical and Vocational Training Corporation (TVTC)," comments Sheik Khaled Juffali.

"Their ability to understand our local needs as well as their very strong commitment was also pivotal in our decision to sign this agreement."

KJC has an extensive track record of creating multinational partnerships that gain a strong position in the Kingdom, notes Gaetan Borgers, executive VP of Soitec's Solar Division. "KJC's profile perfectly matches our need for a high-level Saudi partner with an in-depth understanding of how to build a long-term sustainable business in this very important country for us," he adds. "Solar energy will play a key role in meeting Saudi Arabia's increasing electricity demand and thanks to KJC, we hope to establish CPV as a key solution to this challenge."

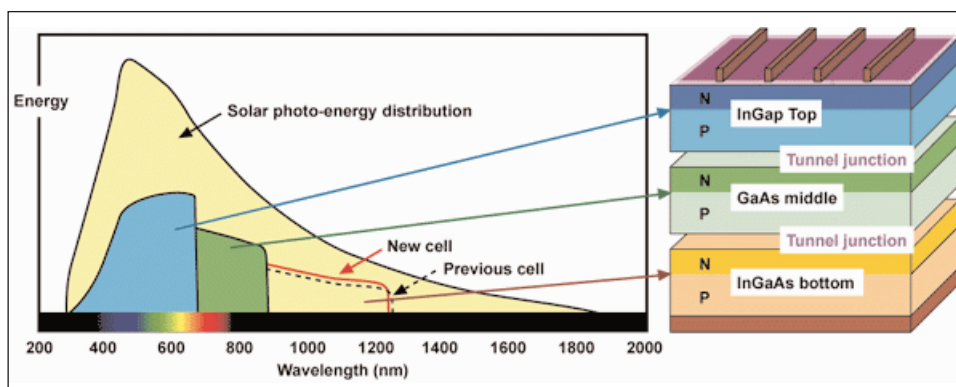
www.soitec.com

Sharp raises triple-junction non-concentrator solar cell efficiency record to 37.9%

Using a triple-junction solar cell, Japan's Sharp Corp has surpassed its record for energy conversion efficiency in research-level non-concentrator solar cells from 37.7% (set last September, though beaten by Spectrolab's 37.8% earlier in April) to 37.9%.

Sharp says that it achieved this latest breakthrough as a result of an R&D initiative promoted by Japan's New Energy and Industrial Technology Development Organization (NEDO) on the theme of 'R&D on Innovative Solar Cells' (in which Sharp has previously achieved triple-junction cell efficiency of 35.8% in 2009 and 36.9% in 2011, as well as 43.5% for a concentrator triple-junction cell, at 360-fold concentration, in June 2012). Measurement of the value of 37.9% was confirmed by Japan's National Institute of Advanced Industrial Science and Technology (AIST).

The basic structure of the latest triple-junction solar cell uses pro-



Wavelength distribution of solar photo-energy and wavelength sensitivity of triple-junction cell for the InGaP, GaAs and InGaAs parts of the structure.

proprietary Sharp technology that enables efficient stacking of the three photo-absorption layers, with an InGaP top layer, GaAs middle layer and InGaAs bottom layer, separated by tunnel junctions. By optimizing the relative proportions of indium, gallium and arsenide, Sharp succeeded in increasing the efficiency with which the cell absorbs sunlight at its various wavelengths, enabling it to achieve

the latest 37.9% efficiency record.

Sharp says that its aim for the future is to apply this latest development to concentrator photovoltaic (CPV) power systems that use lenses to collect and convert sunlight into electricity. The firm also foresees many other practical applications for the cells, such as on space satellites and vehicles.

<http://sharp-world.com>

Solar Junction and IQE to develop high-efficiency satellite solar energy cells

Solar Junction of San Jose, CA, USA, which makes III-V multi-junction solar cells for concentrated photovoltaics (CPV), is in contract negotiation along with epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK for the development of next-generation satellite solar cells for the European Space Agency (ESA).

"Solar Junction and IQE have been working closely for the past year as strategic manufacturing partners of the world's most efficient multi-junction solar cells," says Jim Weldon, CEO of Solar Junction. "Our dilute nitride technology and high-efficiency roadmap is a proven and sustainable pathway for present and future space and terrestrial applications," he adds. "Winning this contract

proves that we're on-track."

Founded in 2007 with investors including New Enterprise Associates, Draper Fisher Jurvetson and Advanced Technology Ventures, Solar Junction says that its proprietary adjustable-spectrum lattice-matched (A-SLAM) architecture provides material bandgap tunability, which enables it to more optimally partition the solar spectrum for maximum solar energy absorption efficiency by CPV modules. Last October, Solar Junction raised its own world record for the energy conversion efficiency of a commercial-ready production solar cell, from 43.5% at a concentration of 418 suns (achieved in April 2011) to 44% at 942 suns.

A-SLAM also maintains the crystal lattice matching, which has been the

foundation of semiconductor and multi-junction solar cell reliability for decades, says Solar Junction.

In February 2012, IQE signed a strategic investment agreement and exclusive epiwafer supply agreement, enabling Solar Junction to scale up manufacturing significantly. Now, as a commercial-ready manufacturer of what are claimed to be the industry's highest-efficiency solar cells and receivers for CPV systems, Solar Junction reckons that it is the only firm in the solar industry to offer a complete design, test, develop, deploy, and service platform, which includes testing, production and a complete software suite.

www.iqep.com

www.sj-solar.com

Spectrolab sets 37.8% efficiency record for ground-based non-concentrator solar cell

Over 45% possible under low concentration, expects Boeing subsidiary

Boeing Company says that its subsidiary Spectrolab Inc of Sylmar, CA, USA recently set a record of 37.8% for energy conversion efficiency in a ground-based solar cell without solar concentration (i.e. without the common practice of using lenses or mirrors to focus solar rays onto the cell).

This exceeds the record of 37.7% for research-level non-concentrator solar cells, set by Japan's Sharp

Corp last December using a triple-junction III-V solar cell.

The new efficiency record has been verified by the US Department of Energy's National Renewable Energy Laboratory (NREL) in Golden, CO.

The cell used a new class of high-efficiency multi-junction solar cell leveraging Boeing technology that makes semiconductor materials more reliable, it is claimed. "We expect this solar cell technology

will have significant benefits for space, ground-based, and sensor applications," says Spectrolab's president Troy Dawson.

Spectrolab believes that its solar cell technology can attain higher levels of efficiency, "possibly more than 45%, even under low concentrations," according to Nasser Karam, vice president for advanced technology.

www.spectrolab.com

Spectrolab expands from 100mm to 150mm wafers

Factory upgrade yields faster, more cost-efficient production

Spectrolab has introduced 150mm-diameter germanium wafers into production (50mm larger than its prior 100mm wafers). The 50% increase in wafer diameter allows more than 2.5 times more gallium arsenide (GaAs) solar cells — or cells that are three times larger — to be grown on each wafer, reducing customers' costs on solar cells by 10-25%, it is estimated.

For over 55 years, Spectrolab has produced solar cells and panels for the space industry (powering satellites and interplanetary craft). Spectrolab became part of Boeing in 2000. For the past 10 years it has also produced ground-based concentrated photovoltaic (CPV) solar cells. In August 2009,

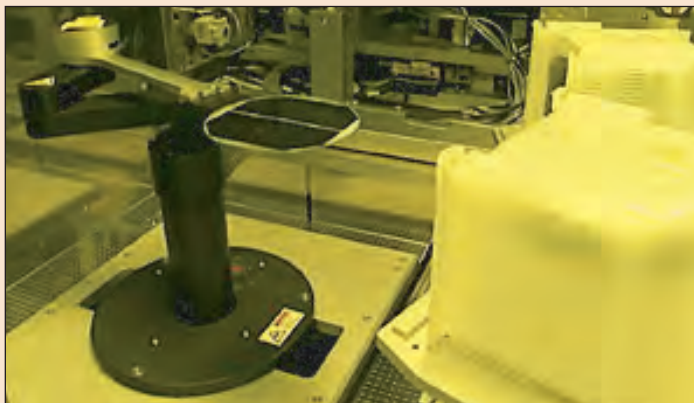


Wafer manufacturing supervisor Ali Glaser examines 150mm wafers.

Spectrolab set what was then a record for CPV solar cell energy conversion efficiency of 41.6%.

Now, to accommodate for the larger wafers, Spectrolab has modernized its factory to create a new 150mm solar cell wafer line. The upgrade, which involves repurposing floor space previously used to produce silicon-based solar cells, also includes a new class 1000 cleanroom facility (requiring the use of full bunny suits) as well as material handling equipment.

A short video describing the wafer-size expansion and factory upgrade can be viewed at www.boeing.com/Features/2013/04/bds_spectrolab_04_16_13.html



A 150mm wafer-handling robot in the new cleanroom.



Expansion re-purposed floor space used for silicon.

UK funds £1m R&D project into III-V quantum-dot solar cells based on silicon substrates

The UK's Engineering and Physical Sciences Research Council (EPSRC) has awarded funding totaling £1m to two universities — University College London (UCL) and Bristol — to support the development of compound semiconductor solar cells based on quantum-dot structures.

Professors Huiyun Liu and Alwyn Seeds of the Department of Electronic and Electrical Engineering at UCL have been awarded £600,519 (EPSRC reference EP/K029118/1) to develop low-cost, high-efficiency III-V quantum-dot solar cells based on silicon substrates.

Their work will be in collaboration with the University of Bristol, which was awarded £356,624 (EPSRC reference EP/K029665/1) to do the modeling and characterization.

The project 'Energy and the Physical Sciences: Semiconductor III-V Quantum-Dot Solar Cells on Silicon Substrates' covers a research period of 42 months, running from April 2013 to end-September 2016.

To help combat climate change, the UK has a target to reduce carbon emissions by 80% by 2050. This is an enormous task requiring changes to energy generation and supply. To limit the impact on scarce natural resources and the environment, these reductions need to be delivered by providing affordable green energy.

"This research project will address this problem by developing high-efficiency and low-cost solar cells by growing III-V compound semiconductor self-organized QD structures on cheap and plentiful silicon substrates," comment Liu and Seeds.

"We aim to exploit the advantages of both QD technology and germanium-on-silicon substrates to develop both multi-junction solar cell and intermediate-band solar cell designs. UCL will carry out the epitaxial material growth of III-V on germanium-on-silicon substrates by the molecular beam epitaxy (MBE) facility at the department of Electronic and Electrical Engineering,

and the device fabrication in the London Centre for Nanotechnology."

The Bristol University component will be led by principal investigator professor J Rorison of the Department of Electrical and Electronic Engineering. Project partners are the Defense Science & Tech Lab (DSTL), IQE Silicon Compounds Ltd, and Sharp Laboratories of Europe Ltd.

The project leaders agree that the widespread implementation of photovoltaics and solar cells will be a notable means of achieving sustainable energy production, together stating: "These green energy developments will require vast areas of semiconductor materials to be structured into PV cells in order to capture the power of sunlight."

There are two general approaches to be taken: either to use very large-area, low-cost and low-efficiency semiconductor materials (such as organic materials) or to use small-area highly efficient but expensive semiconductor materials and concentrate the light into the small-area concentrator photovoltaic (CPV) cells.

The cost of the housing is a significant cost of the PV cell and therefore making the material cheaper for large-area PV does not improve cost below a certain value. The efficiency of the CPV cells is being improved continuously by improved design, growth and fabrication.

Experimentally, III-V compound semiconductor CPV cells have recently achieved efficiencies of more than 40%, making them the highest-efficiency PVs available in any technology. Further increase of efficiency for CPVs is the key for utilizing solar energy worldwide, say the researchers.

There are two main approaches to developing inorganic III-V CPV cells: multi-junction solar cells (MJSCs) and intermediate-band solar cells (IBSCs). In MJSCs a number of semiconductor material junctions are connected in series, each designed to efficiently absorb a

section of the solar spectrum appropriate to its bandgap with the largest-bandgap material placed at the front and the smallest-bandgap material placed at the back.

A single-junction SC has a maximum predicted efficiency of 30%, while a double-junction SC consisting of two optimized bandgaps increases the predicted efficiency to 41%. Much effort has gone into designing a number of MJSCs with an increased number of junctions. Intense effort is going into investigating materials to absorb near the peak of the spectrum around 1.0eV.

The research partners say they plan to employ 1.0eV-bandgap quantum dots as a solution for this. In short, a QD is one semiconductor embedded into another, arising from self-organized growth. QDs enable material combinations to be grown together that would not normally occur in a planar environment as strain is incorporated into the interface. This allows novel materials to be combined in a QD system, opening up new material combinations and allowing these materials to be grown on silicon using only a thin germanium sandwich layer.

In IBSCs, an intermediate energy band is introduced into the energy gap of the single semiconductor material junction, introducing three possible optical transitions. The photo-generated carriers in the intermediate level must only link to the host material through optical transitions for the IBSC to function correctly.

The IBSC with one intermediate band (IB) level is predicted to have ultra-high conversion efficiency (up to 63%). Increasing the number of levels to 4 is predicted to increase efficiencies up to 80%. However, these high efficiencies are not seen experimentally. The researchers say they will hence investigate using QD systems to make IBSCs.

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CdTe PV maker First Solar acquiring silicon PV firm TetraSun to expand addressable market

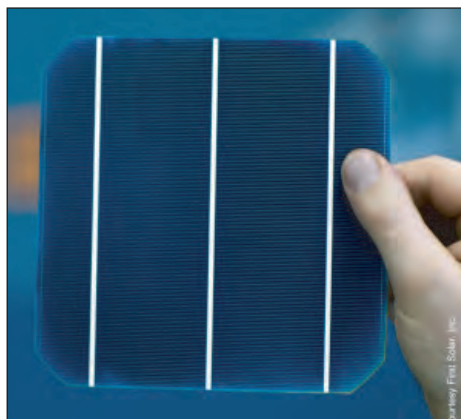
High-efficiency, low-cost monocrystalline cell technology targets Japanese small-rooftop market

First Solar Inc of Tempe, AZ, USA – which manufactures thin-film photovoltaic (PV) modules based on cadmium telluride (CdTe) as well as providing engineering, procurement & construction (EPC) services – is acquiring TetraSun of San Jose, CA. The solar PV technology startup was founded in 2009 and has developed a proprietary monocrystalline silicon solar cell architecture capable of conversion efficiencies exceeding 21% with commercial-scale manufacturing costs comparable to conventional multicrystalline silicon solar cells (due partly to having copper electrodes instead of silver).

First Solar signed a definitive agreement to acquire TetraSun from JX Nippon Oil & Energy Corp and other investors including TetraSun management. The transaction is expected to close in second-quarter 2013.

First Solar and JX Nippon Oil & Energy have also entered into discussions on an agreement to distribute the technology in Japan. First Solar focuses mainly on utility-scale power plants and does not market its solar panels for rooftop systems but, according to First Solar's CEO Jim Hughes at an analyst meeting, "Japan is the highest-value, space-constrained market, so that's why we're starting there". TetraSun's cells have greater energy conversion efficiency than First Solar's CdTe PV cells. Also, Japan is expected to become the second-largest PV market this year (behind China) after the introduction in July of an incentive program offering above-market rates for energy from renewable sources.

Compared to other high-efficiency crystalline silicon cells, TetraSun's cell design is said to be simpler and optimized for manufacturing, requiring fewer process steps with



TetraSun's cell architecture is capable of conversion efficiencies exceeding 21% with commercial-scale manufacturing costs comparable to conventional multicrystalline silicon solar cells.

wider tolerances. The design enables high-volume production with higher yields using readily available equipment, it is claimed. Cost-effectiveness is further enhanced by using large-format (156mm) n-type wafers and eliminating the need for expensive silver and transparent conductive oxide (TCO).

First Solar says that the technology also benefits from a low temperature coefficient of power, which produces superior energy yields in hot climates compared to typical silicon PV modules. First Solar tentatively plans to begin commercial-scale manufacturing of the new technology in second-half 2014.

"This breakthrough technology will unlock the half of the PV market

This breakthrough technology will unlock the half of the PV market which favors high-efficiency solutions, which has been unserved by First Solar to date

which favors high-efficiency solutions, which has been unserved by First Solar to date," says CEO Jim Hughes. "This new capability to meet the needs of customers with distributed generation applications, coupled with our leading CadTel [CdTe] offering which remains the benchmark for utility-scale systems, gives us a unique end-to-end suite of solutions to serve the full spectrum of commercial applications," he adds.

Joining First Solar brings global reach, financial strength and a proven track record scaling disruptive technologies, says TetraSun's CEO Denis De Ceuster. "With First Solar we have the freedom to continue our blank-canvas approach, unconstrained by pre-existing designs or production equipment, and backed by the strongest balance sheet in the industry," he adds.

"JX Nippon Oil & Energy was among the first to recognize the potential of this technology, and we are very pleased to continue working with this leading energy company to bring this product to market," says Hughes. "Japan is an important market with unique energy challenges, and we believe this new technology is well suited to help them meet their energy needs."

All 14 of TetraSun's associates will join First Solar and continue to be based in San Jose. First Solar says that the technical team brings expertise in silicon PV R&D and a track record of innovation at companies like SunPower and Fraunhofer ISE, where they achieved world records for silicon cell efficiency.

According to Hughes, First Solar expects to open a factory that will produce 25-50MW of TetraSun panels next year for the Japanese market, and as much as 100MW annually in total initially.

<http://tetrasun.com>

First Solar expects sales to grow 15% to \$3.8–4.0bn in 2013 Sales to grow from \$3.5–4.0bn in 2014 to \$4.2–4.8bn in 2015

At its 2013 Analyst Day event in New York, First Solar Inc of Tempe, AZ, USA — which makes thin-film photovoltaic (PV) modules based on cadmium telluride (CdTe) as well as providing engineering, procurement & construction (EPC) services — said that, for full-year 2013, it expects total module shipments of 1.6–1.8GW and net sales of \$3.8–4.0bn, including about \$3.6bn from systems sales. This would be up about 15% on 2012's sales of \$3.4bn.

Consolidated gross margin is expected to be 20–22%. Excluding

up to \$10m in restructuring expense (as previously announced), diluted earnings per share (EPS) should be \$4–4.50 (down on 2012's \$4.90), and consolidated operating income should be \$430–460m. The firm expects to generate \$0.8–1.0bn of operating cash flow (up from \$762m in 2012) and plans for \$350–400m in capital expenditures in 2013. Working capital is expected to fall by \$50–200m from 2012.

First Solar notes that revenue recognition for the Desert Sunlight project is currently expected to begin

in second-half 2013 and conclude by late 2014. This assumption is reflected in the 2013 guidance and 2014 outlook.

In addition, for 2014 the firm targets module shipments of 1.8–2.2GW, net sales of \$3.5–4.0bn, diluted EPS of \$2.50–4.00, and operating cash flow of \$500–800m. For 2015 First Solar targets module shipments of 2.3–2.7GW, net sales of \$4.2–4.8bn, diluted EPS of \$4.00–6.00, and operating cash flow of \$600–1000m.

www.firstsolar.com

First Solar acquires 60MW_{AC} North Star project from NorthLight

First Solar has acquired the 60MW_{AC} North Star solar project developed by NorthLight Power LLC, becoming First Solar's first utility-scale photovoltaic power project in Fresno County, CA. NorthLight is a joint venture of Renewable Energy Corporation ASA (REC) and Seattle-based low-carbon energy project developer Summit Power Group LLC.

The North Star project is located near the city of Mendota and has a 20-year power purchase agreement with Pacific Gas & Electric Company.

The photovoltaic (PV) solar plant is expected to start construction in 2014 and be completed in 2015, providing up to 410 construction jobs. "North Star will provide much-needed construction employment in a hard-hit economy, while helping the state satisfy its renewable energy requirements," says James F. Cook, First Solar's director of project development.

When fully operational, it will produce enough energy to power over 21,000 average California homes while displacing about 33,000

metric tons of water consumption and 39,000 metric tons of CO₂ per year (equivalent to taking about 7500 cars off the road each year).

"We have received and been thankful for tremendous support from the local community, and look forward to continuing success with other solar projects that are in our current development portfolio within NorthLight Power," says Dana Zentz, VP of Commercial Development for Summit & managing director of NorthLight Power.

<http://northlightpower.com>

First Solar acquires 150MW_{AC} Solar Gen 2 project

First Solar Inc of Tempe, AZ, USA has acquired the 150MW_{AC} Solar Gen 2 power project from an affiliate of The Goldman Sachs Group Inc, Energy Power Partners and a third equity partner for the project. Construction of the facility near El Centro in Imperial County, CA, is expected to start this year and be completed in 2014.

The solar plant will generate enough electricity to power more than 60,000 average California homes, displacing more than 115,000 metric tons of CO₂ per year (equivalent to taking 22,000 cars off the road) and

saving 93,000 metric tons of water per year.

The project's electrical output will be purchased by San Diego Gas & Electric Company (SDG&E) under a 25-year power purchase agreement. Solar Gen 2 is expected to provide on average more than 800 construction jobs in Imperial County (an area currently suffering from high unemployment).

"We are grateful to SDG&E, the Imperial Irrigation District [with which the plant will interconnect], the County of Imperial and the California Public Utilities Commission for their leadership and support in

contributing to the successful outcome of this development effort," says Steve Zaminski, Solar Gen 2's CEO and owner of Energy Power Partners.

The acquisition includes 40MW_{AC} of solar modules that the project previously purchased from another supplier, which will be integrated into the installation.

First Solar will supply the balance of modules for the power plant, along with its project development, engineering, procurement & construction (EPC), and grid-integration services.

www.solargen2.com

First Solar raises CdTe total area module efficiency record from 14.4% to 16.1%; Series 3 Black module launched

Production module efficiency roadmap accelerated and extended to 16.4–17.1% for 2017

First Solar Inc of Tempe, AZ, USA has raised its world record for cadmium telluride (CdTe) photovoltaic (PV) total area module efficiency from 14.4% (set in January 2012) to 16.1%, as confirmed in tests by the US Department of Energy's National Renewable Energy Laboratory (NREL).

Separately, First Solar has also set a record for CdTe open-circuit voltage (VOC), a critical parameter for PV performance, reaching 903.2mV in NREL-certified testing. The firm notes that this new record marks the first substantial increase in CdTe VOC in over a decade of international R&D.

The new records come just six weeks after First Solar announced a new record for CdTe solar cell efficiency of 18.7%.

Transferring its success in the R&D lab to its commercial modules, First Solar also launched a new evolution of its Series 3 thin-film PV module platform, the Series 3 Black, incorporating the firm's latest advances in conversion efficiency as well as additional features to enhance its performance in utility-scale power plants. The all-black module's change in appearance results from the use of an all-black edge seal technology combined with encapsulation material that further enhances field durability and demonstrates improvements in accelerated life-testing results.

First Solar says that the Series 3 Black's performance in a wide range of operating environments is further validated by its new IEC 60068-2-68 'sand and dust test' certification, which measures durability in harsh desert environments characterized by blowing abrasive sand. The certification complements existing IEC salt mist and ammonia certifications to provide a comprehensive range of independent



First Solar's R&D team in Perrysburg, OH, which set the new record.

testing reflecting durability and performance in the harshest operating conditions. The Series 3 Black module maintains all the existing IEC certifications and UL listings for the Series 3 family that enable the 1000V system designs that typify the firm's utility-scale power plants. First Solar began to implement the Series 3 Black enhancements in production modules earlier this year.

"The technology [for the latest efficiency record] was created for production-scale implementation, as evidenced by our accelerated efficiency roadmaps," says chief technology officer Raffi Garabedian. Based on the firm's record-setting technology and Series 3 Black platform, First Solar has accelerated its module conversion efficiency

roadmap, raising its lead production-line module efficiency target for 2015 to 15–16.2%. It has also extended its module conversion efficiency roadmap to 2017, with targets for lead production-line module efficiency of 16.2–16.9% in 2016 and 16.4–17.1% in 2017.

"Measurements in the lab are an important benchmark, but our R&D mission is to deliver technology that is designed to shine in real-world conditions as part of our integrated power plant systems," says Garabedian. "The Series 3 Black is a testament to our integrated approach to product development, combining technological advances from the lab with years of real-world data and experience operating utility-scale power plants in harsh environments," he adds.

Since it began commercial production in 2002, First Solar has produced more than 90 million of its thin-film solar modules with a capacity of over 7GW (enough to provide clean electricity for more than 3.7 million homes and displace about 5 million metric tons of CO₂ annually, based on world averages).

www.firstsolar.com/Innovation/Advanced-Thin-Film-Modules



First Solar's Series 3 Black panel.

Sol Voltaics unveils SolInk nanomaterial to boost PV module performance by 25%

Aerotaxy process cuts cost and complexity of producing nanowires for photovoltaics, LED bulbs etc

Sol Voltaics AB of Ideon Science Park, Lund, Sweden has unveiled SolInk, a nanomaterial that promises to boost the efficiency of crystalline silicon or thin-film solar modules by up to 25%, leading to solar power plants and rooftop solar arrays that can generate far more electricity than the best systems currently available commercially, it is claimed.

The firm reckons that the increase in efficiency will allow SolInk-enhanced panels to deliver power at prices that can compete directly against electricity from fossil-fuel plants while improving the economics for manufacturers. Global demand for solar energy is expected to grow from 29.8GW of new solar installations in 2012 to 50.8GW in 2016, according to Greentech Media.

"About two-thirds of the cost of commercial solar systems revolves around land, labor costs and other factors that solar developers cannot directly control," says Sol Voltaics' CEO David Epstein. "By raising the efficiency of solar modules, we give solar manufacturers the opportunity

to sell more valuable, higher-margin products and solar developers the opportunity to generate more power — at a lower price — with essentially the same physical assets," he adds.

Sol Voltaics' strategy revolves around two fundamental technologies: gallium arsenide nanowires measuring 1–2µm in length and 100–200nm in diameter (the active ingredient in SolInk) and Aerotaxy (a process for producing nanowires created by company founder and Lund University professor Lars Samuelson).

GaAs has been used in solar for years (e.g. in orbiting satellites) because of its reliability and high energy conversion efficiencies, but GaAs solar cells typically cost far more to produce than crystalline silicon or thin-film cells, confining the material to niche market segments, says the firm.

SolInk reduces the cost by minimizing materials: less than a gram of nanowires is added to the surface of crystalline silicon panels.

With SolInk, module makers can make commercially feasible, high-efficiency GaAs solar modules or multi-junction solar modules combining GaAs nanowires on top of crystalline silicon, reckons the firm.

SolInk also enables light concentration without the use of optics or mechanical components, Sol Voltaics adds. Nanowires need to cover only a small portion of the surface area of a crystalline silicon or thin-film solar cell to achieve substantially all of the benefits of adding GaAs. In the academic journal *Science* earlier this year, Lund University and Sol Voltaics researchers demonstrated that indium phosphide (InP) nanowires covering just 12% of the substrate surface produced a solar cell with an efficiency of 13.8%. The results were certified by Germany's Fraunhofer Institute. The phenomenon, called wave concentrated photovoltaics (WCPV), combined with the other advantages of GaAs nanowires leads to the high performance of SolInk, it is claimed. ►

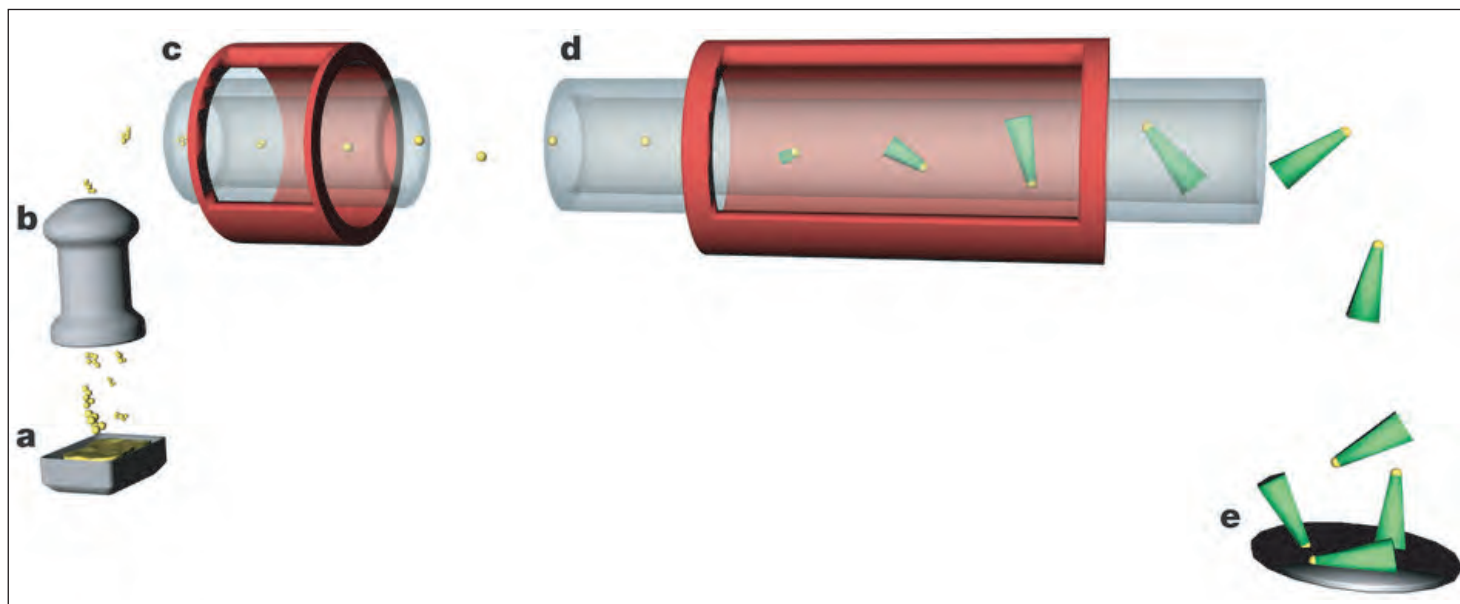
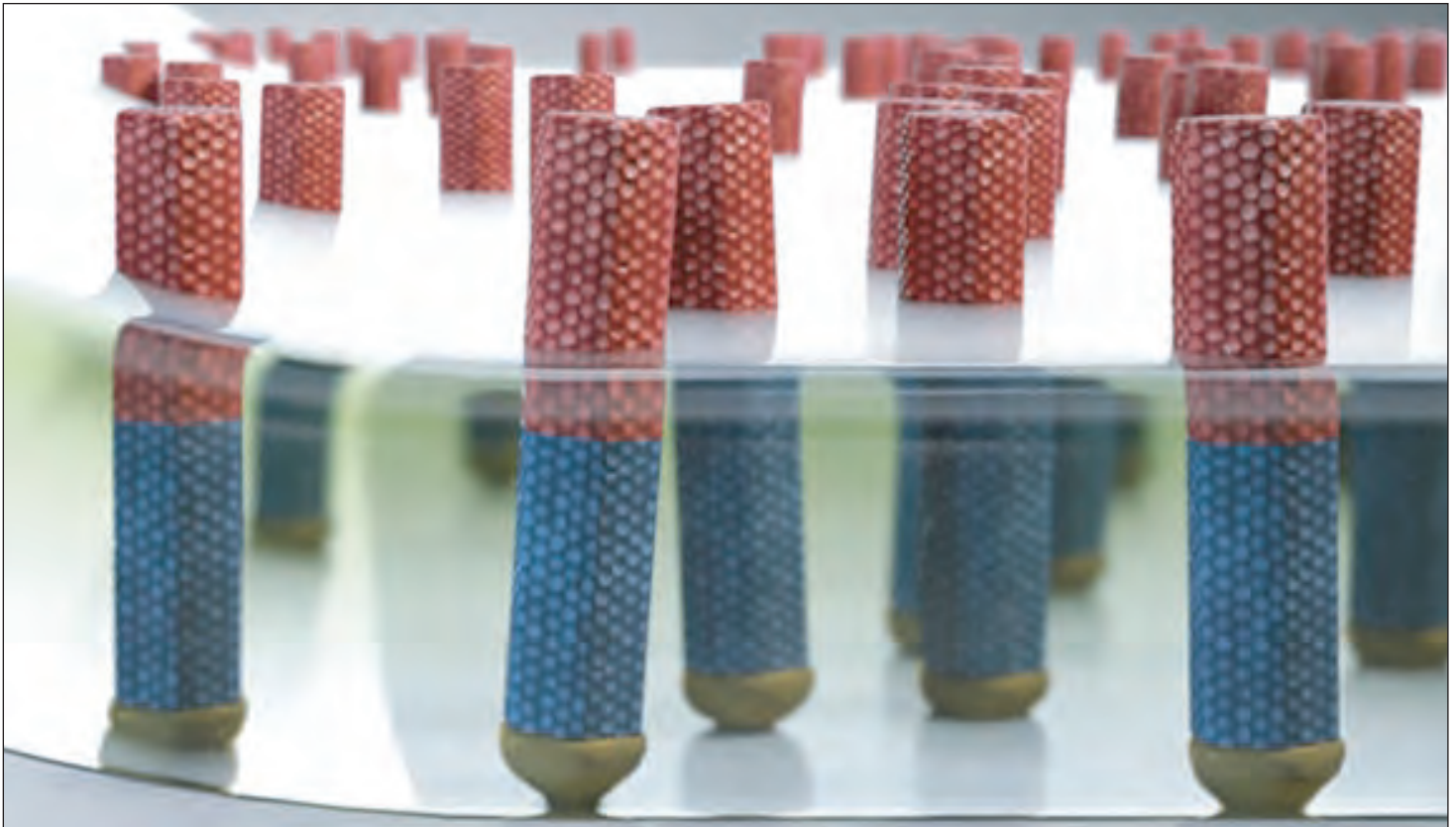


Figure 1: Aerotaxy growth of nanowires: a, Au agglomerate formation; b, Au agglomerate size sorting using a DMA; c, Au agglomerate compaction into spherical particles in a furnace; d, nanowire growth; e, nanowire deposition.



Sollnk nanowires grown by Aerotaxy process.

► Aerotaxy manufacturing method

Nanowires and nanotubes are typically produced via a process of epitaxial crystal growth on a substrate. But because of the inherent physical limits of the epitaxial process, nanoparticles often need to be grown in place or harvested and sorted in batch processes that can be both time-consuming and expensive.

Instead, Aerotaxy creates nanomaterials by suspending and mixing active materials in carrier gas streams. The active materials bond to form larger, uniform structures while in flight: nanowires are literally grown in air. Aerotaxy can hence generate tens of billions of nanowires per second on a continuous basis. The finished nanowires can be integrated into a solar panel or other products, or can be stored indefinitely. A paper published in *Nature* late last year details how professor Samuelson and his team used Aerotaxy to manufacture GaAs nanowires ('Continuous gas-phase synthesis of nanowires with tunable properties' by Magnus Heurlin et al, *Nature*, 492, 90–94 (6 December 2012); doi: 10.1038/nature11652).

"The results have been far better than we ever expected," says Samuelson. "We understand how different materials react or bond to one another," he adds. "With Aerotaxy, we essentially create an atmosphere where we can better harness those physical and chemical properties."

Business model: selling Sollnk, rather than modules

Rather than produce modules or sell capital equipment, Sol Voltaics will produce and sell Sollnk to solar cell and module makers. Hence a single, relatively small manufacturing facility will be able to provide megawatts worth of materials, it is reckoned. Module makers likewise will be able to integrate new materials into their products without replacing existing production lines, the firm adds.

Sol Voltaics expects to produce functional solar cells with GaAs nanowires for demonstration by the end of 2013. Commercial production of Sollnk-enhanced modules should begin in 2015 and move into volume production in 2016. Total invested capital to get into high-

volume commercial production will come to less than \$50m, the firm estimates.

Founded in 2008, Sol Voltaics has previously raised \$11m from private investors including Stockholm-based venture capital firm Industrifonden, Foundation Asset Management AB of Sweden, Teknoinvest AS, Provider, Nano Future Invest and Scatec Energy of Norway. The firm has also received public funding from the European Union, Vinnova, Nordic Innovation Center, and others. Sol Voltaics aims to raise \$10–20m this year.

The firm reckons that other potential applications for Aerotaxy include producing nanomaterials for power electronics, LEDs, batteries and energy storage.

"The promise of nanotechnology has been held back by complexity, low yields and cost," says Scatec's chairman Alf Bjørseth. "Aerotaxy paves the way for integrating new materials into products in a streamlined manner." ■

www.solvoltaics.com

www.nature.com/nature/journal/v492/n7427/full/nature11652.html

Textured ZnO improves III-V on germanium solar cell performance

Reduced reflection boosts conversion efficiency from 24% to 29.8%.

National Formosa University in Taiwan has developed a liquid-phase deposition (LPD) process of textured zinc oxide on III-V semiconductor to provide improved absorption of multi-junction solar cells [Po-Hsun Lei et al, J. Phys. D: Appl. Phys., vol46, p125105, 2013].

The textured layer reduces reflection of the incident light over a broad band of wavelengths (300–1000nm). Traditional anti-reflective coatings tend to be wavelength selective. The researchers were seeking a low-cost process to produce randomly textured surfaces as a means to improve solar cell light absorption performance.

The gallium indium phosphide/indium gallium arsenide/germanium (GaInP/InGaAs/Ge) solar cell material formation process consisted of MOCVD on germanium for the active material and a liquid-phase deposition in a Teflon vessel in a controlled-temperature water bath for the textured zinc oxide layer (Figures 1 and 2).

The epitaxial material was cut up into 5mm x 5mm square chips. The ohmic p-contact was made to the back of the Ge substrate with a gold/zinc/silver/gold alloy. The ohmic n-electrode structure consisted of germanium-gold/nickel/gold on the n-InGaAs top layer. A ridge n-contact was made by partially exposing regions of n-type aluminium indium phosphide (n-AlInP) window layer underneath by etching into the n-InGaAs.

A silicon nitride (Si₃N₄) anti-reflective coating was applied to the n-AlInP using plasma-enhanced chemical vapor deposition (PECVD). The n-InGaAs is used for the electrical contact, but absorbs wavelengths that should be converted by the GaInP layer.

The ZnO was deposited on the silicon nitride. The researchers carried out a number of experiments to

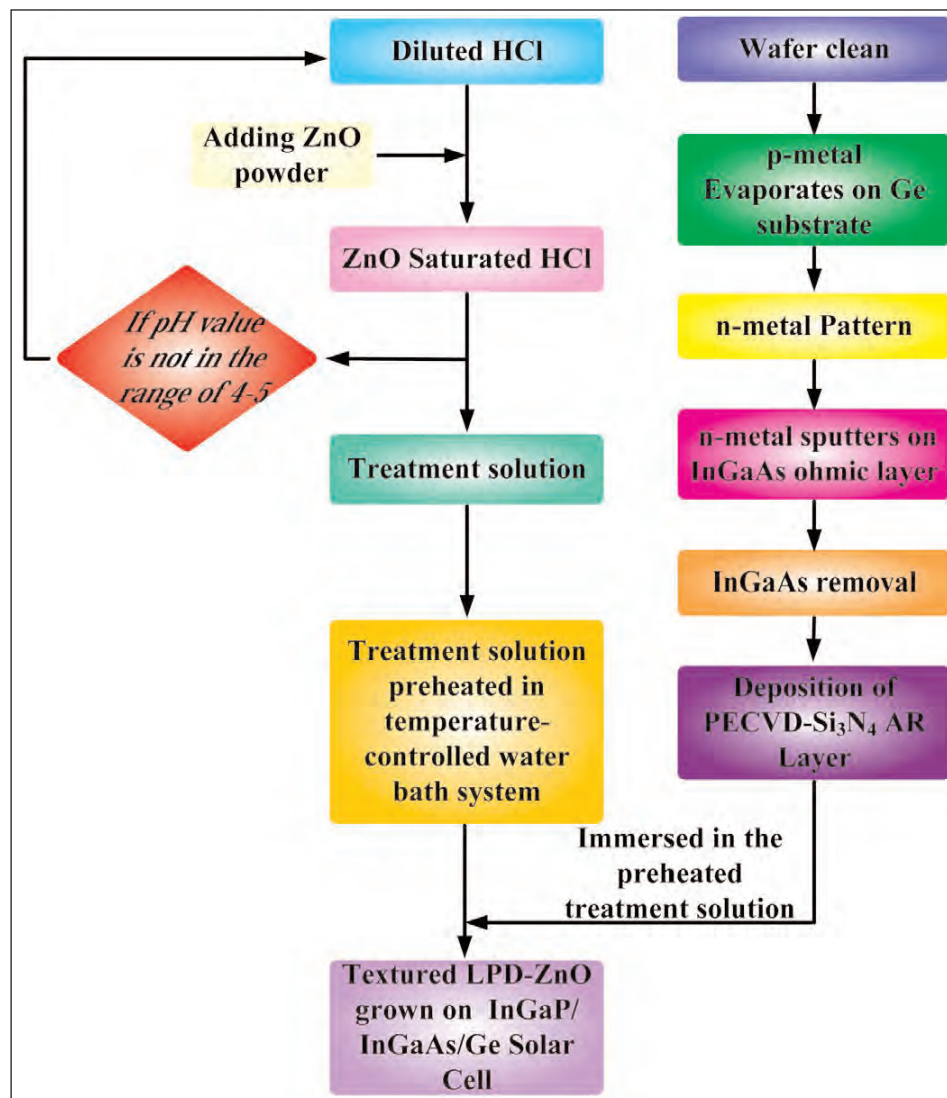


Figure 1. Flow chart for the LPD-ZnO process (left side) and fabrication of GaInP/(In)GaAs/Ge solar cells (right side).

optimize the process parameters (pH, temperature) for control of layer thickness and root-mean-square (RMS) roughness. The textured ZnO layer consisted of nests of hexagonal flakes (Figure 3).

The aim of the ZnO layer was to reduce the reflection of light away from the solar cell. The optimum growth conditions for this were found to be 25°C with 6 mole/liter (M) hydrochloric acid solution. Also, the researchers performed simulations suggesting that the maximum

n-contact/window	n-InGaAs/n-AlInP
Sub cell	GaInP
Tunnel junction	p-AlGaAs/n-GaInP
Sub cell	InGaAs
Tunnel junction	n-GaAs/p-GaAs
Substrate	p-Ge

Figure 2. MOCVD heterostructure.

enhancement for solar cells designed for a broad wavelength range would come from 95nm RMS roughness.

A bare solar cell without ZnO had a short-circuit current density of 12.5mA/cm² and energy conversion of 24%. This is similar to the performance achieved by others, according to the researchers. With ZnO deposited from 6M solution at 25°C, these were increased to 14.22mA/cm² and 29.8%, respectively.

Over a series of runs (Table 1), ZnO deposited from 6M solution at 25°C showed small variations in the character of the ZnO layer and in the performance of the solar cells. The RMS roughness of the ZnO layer varied in the range 90–100nm, while the pH value of the growth solution was kept in the range 4–5.

The researchers comment: "The uniformity of the RMS roughness is extremely significant because this is the primary factor determining the absorbed light intensity or scattering between air and the textured LPD-ZnO."

The variation in performance values were 3.31% for short-circuit current, 0.87% for open-circuit voltage, 3.75% for conversion efficiency, and 2.51% for fill factor.

The solar cells were also tested at operating temperatures up to 100°C. The variation in open-circuit voltage was 5.8mV/°C for cells without textured ZnO and 5.9mV/°C with. The respective rates for short-circuit current density were 7.9 and 8.0μA/°C-cm². The performance of solar cells tends to show that degraded energy conversion at high temperature and an increase in thermal resistance from added layers can be a concern for thermal management. The negligible

Table 1. Performance of GaInP/(In)GaAs/Ge solar cells with textured LPD-ZnO window layer grown at 25°C in 6M HCl solution.

Run	SC current (mA/cm ²)	OC voltage (V)	Conversion efficiency (%)	Fill factor
1	14.25	2.43	29.71	0.85
2	14.35	2.43	29.65	0.84
3	15.09	2.41	29.64	0.81
4	14.92	2.34	28.43	0.81
5	14.57	2.42	29.78	0.84
6	15.00	2.42	29.79	0.82
7	14.85	2.41	29.81	0.83
8	14.81	2.41	28.92	0.811
9	14.73	2.39	29.50	0.83
10	14.73	2.39	29.63	0.84
11	14.81	2.39	29.81	0.84
12	14.72	2.38	29.80	0.85

changes in performance at raised temperature suggest that the ZnO layer does not significantly trap heat.

The researchers comment: "The introduction of the textured LPD-ZnO window layer for GaInP/(In)GaAs/Ge solar cells shows similar temperature characteristics as compared with those without the textured LPD-ZnO window layer. This may be attributed to the porosity of LPD-ZnO, which offers a path for reducing the thermal energy." ■

<http://iopscience.iop.org/0022-3727/46/12/125105>

Author: Mike Cooke

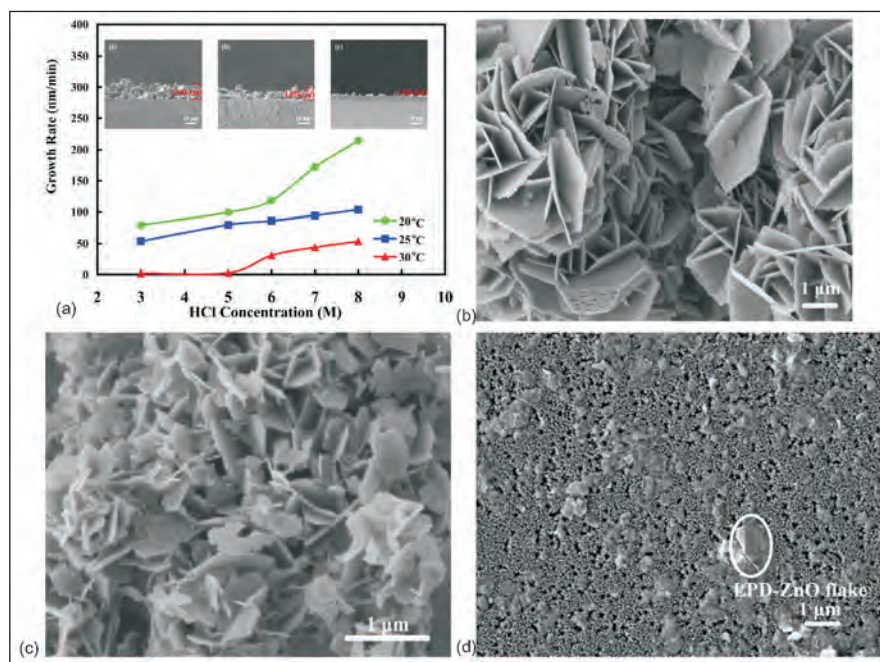


Figure 3. (a) Deposition rate of LPD-ZnO grown on Si₃N₄ as function of HCl concentration at various deposition temperatures, and FESEM images for LPD-ZnO grown at (b) 20°C, (c) 25°C and (d) 30°C. Insets of (a) show the cross-section FESEM images for LPD-ZnO grown at (a) 20°C, (b) 25°C and (c) 30°C at 6M HCl.

Direct growth of indium-rich InGaN on silicon

High-indium-content material has been produced with an ohmic contact between the nitride layer and the silicon substrate.

Researchers in Spain have grown high-indium-content indium gallium nitride (InGaN) directly on silicon (Si) substrates [Praveen Kumar et al, Appl. Phys. Express, vol6, p035501, 2013]. The work was carried out at Universidad Politécnica de Madrid's Institute for Systems based on Optoelectronics and Microtechnology (ISOM).

InGaN is an important optoelectronic material capable of producing longer-wavelength light-emitting diodes and laser diodes than other nitride semiconductor materials. The energy bandgap can be varied in the range from infrared through visible light to near-ultraviolet. The material is also of interest in energy conversion/solar cells.

However, InGaN is challenging to grow, particularly at higher indium fractions. Among the difficulties is a tendency for phase separation where regions of InGaN with different indium concentrations form. Further problems arise from InN decomposition and In desorption that reduces indium content.

Generally, InGaN is grown at lower temperature than pure GaN to avoid some of these problems. Previously, direct growth of InGaN on silicon has been considered impossible, and instead aluminium nitride/gallium nitride buffer layers are usually grown first. The junction of InGaN/GaN/AlN/Si isolates the InGaN layer from the substrate. One would like an ohmic junction between InGaN and silicon devices in tandem solar cells. In fact, the $\text{In}_{0.46}\text{Ga}_{0.54}\text{N}/\text{Si}$ junction has been theoretically predicted to be ohmic due a unique band alignment effect.

The InGaN was grown directly on p-type Si (111) substrates using plasma-assisted molecular beam epitaxy (PAMBE) on a MECA 2000 system. The growth was preceded by native oxide removal at 800°C and annealing at 850°C for 20 minutes. The silicon surface was then exposed to active nitrogen for 5 minutes at 850°C, leaving a layer of silicon nitride. Such a nitride preparation was developed previously for GaN PAMBE on Si (111) by Japan-based researchers in 1998.

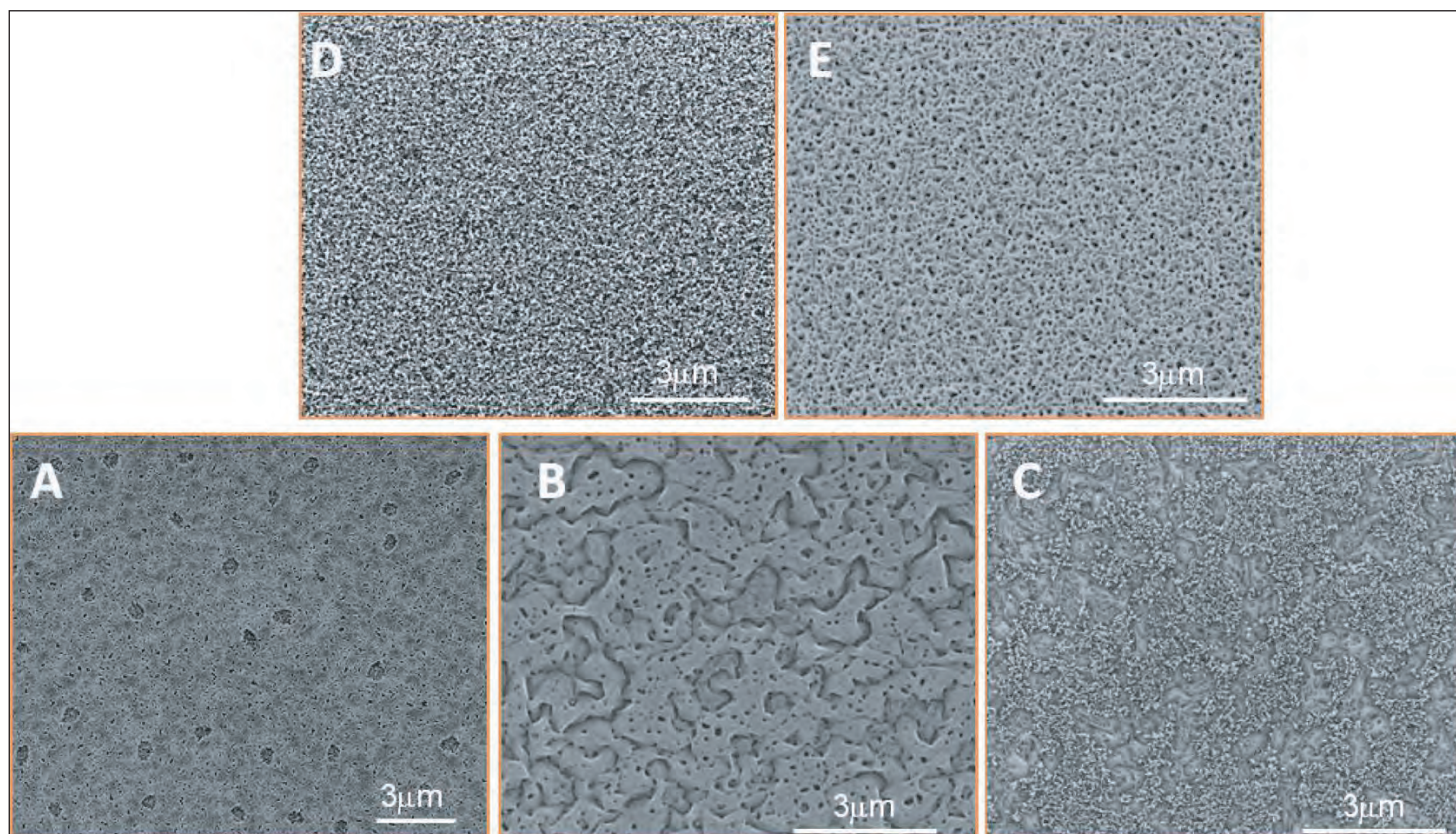


Figure 1. Diagram of the growth conditions of the InGaN layers A–E. Inset: scheme of the sample structure.

The InGaN growth was carried out using an indium flux of 4.2nm/min and a gallium flux of 4.6nm/min. The nitrogen flux was varied from slightly above 'stoichiometry' at 9.2nm/min (i.e. $> (4.2 + 4.6)\text{nm/min}$) until columnar growth conditions were achieved. The InGaN growth rate was 0.45 $\mu\text{m}/\text{hour}$. The target layer thickness was 450nm. Various growth temperatures were tried (Figure 1).

Sample B gave the best structure for device applications (Figure 2). The other samples suffered from nanoscale flake, network, hole, or dot-like structures. By contrast, sample B has laterally extended, micrometer-sized planar areas together with trenches and holes. In particular, macroscopic planar regions of sample B have a very smooth root-mean-square roughness of only 1.7nm in atomic force microscopy (AFM) measurements.

The researchers comment on the macroscopic planar regions that they are connected to each other and are large enough to serve as barrier layers for active structures such as quantum wells and quantum dots.

The absence of In or Ga droplets on the surface is taken as an indication that all the In is incorporated into the layer. The target In composition was 40–50%. The researchers believe that there is no InN decomposition and the growth temperature is considered too low for In desorption.

X-ray analysis of the GaN(0002) reflection peak indicates InGaN layers fluctuating between 45% and pure GaN for all samples except B. The low-growth-temperature sample A has no x-ray reflection peak, suggesting amorphous InGaN. In sample B, instead of a broad peak, there are two narrower peaks for regions of GaN (17.26°) and InGaN (16.59°). The half-width of the GaN peak is 0.14°. The InGaN peak width suggests In compositions between 38 and 45%.

The researchers comment: "The existence of these well-separated reflections is evidence for distinct, well-separated, and macroscopically extended regions of GaN plus low-In-composition InGaN and of InGaN with high and relatively uniform In composition. It is likely that the high-In-composition regions are the macroscopically extended planar layers, while the GaN plus low-In-composition regions are associated with the trenches and holes, exposing slow-growth planes to inhibit the incorporation of In."

Photoluminescence (PL) of sample B at 12K had peaks at 358nm, 383nm and 794nm, associated with GaN, low-In-composition InGaN, and high-In-composition InGaN, respectively. According to the researchers, the long-wavelength peak would be associated with the

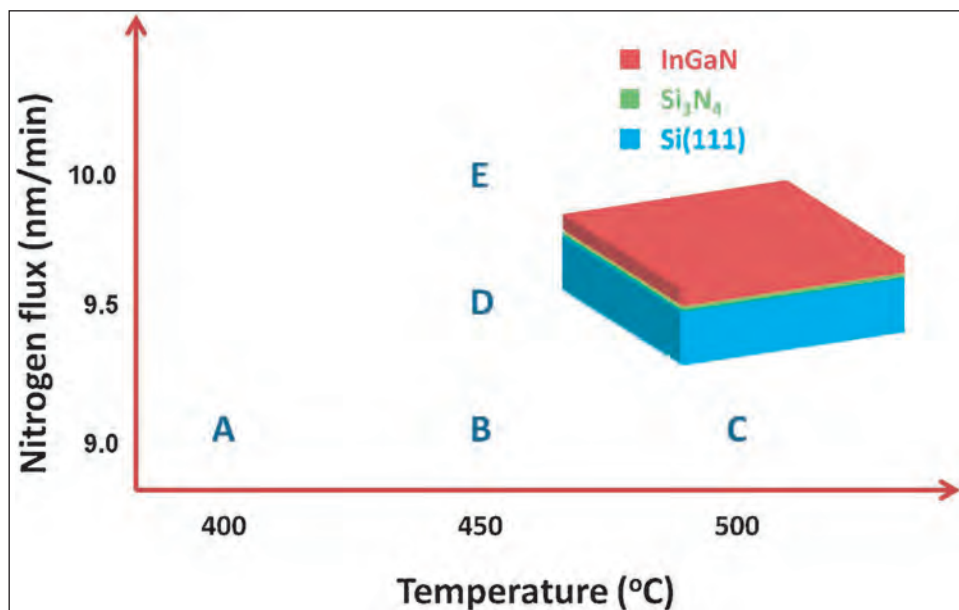


Figure 2. Top-view SEM images of InGaN layers A–E grown directly on Si.

energy gap of $\text{In}_{0.41}\text{Ga}_{0.59}\text{N}$. The long-wavelength peak is rather small due to the presence of defects.

"However, the mere observation of PL opens space for further improvement of the optical quality," the researchers write.

Current–voltage measurements of the junction between the n-type InGaN and p-type Si substrate were made by applying top and bottom aluminium contacts to the structure. The junction was perfectly ohmic between -3V (-60mA) and $+3\text{V}$ ($+60\text{mA}$). The n-type conduction of the InGaN layer is the result of native defects such as nitrogen vacancies in the crystal structure. The low-In-content InGaN/pure GaN trench and holes regions do not reach the silicon layer nor the top contact, so the conduction is due to the junction between high-In-content InGaN and Si substrate.

The silicon substrate is very high quality and the resistivity of the InGaN/Si structure is found to be almost the same as a bare silicon control sample.

The researchers comment that the comparison with the bare silicon measurement suggests that "no energy barrier is introduced by the SiN and, most importantly, proves that an ohmic contact is formed between the p-Si substrate and n-InGaN layer, confirming the theoretical prediction and consolidating the foundation for advanced device applications."

The team concludes: "After having achieved this crucial step of the growth of macroscopically extended planar layers of InGaN with high In composition directly on Si, fine tuning of the growth parameters in the regime of low growth temperature and low active N flux is now straightforward to further improve the material quality." ■

<http://apex.jsap.jp/link?APEX/6/035501>

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Author: Mike Cooke

Laser-processed sapphire allows increased thickness of HVPE gallium nitride

Layers up to 200μm have been grown by hydride vapor phase epitaxy with threading dislocation density down to $1 \times 10^7/\text{cm}^2$.

Researchers in Japan and Switzerland have used a laser treatment of sapphire substrates to increase the thickness of gallium nitride (GaN) layers grown by hydride vapor phase epitaxy (HVPE) to around 200μm [Hideo Aida et al, Appl. Phys. Express, vol6, p035502, 2013]. The researchers were based at Namiki Precision Jewel Co Ltd, École Polytechnique Fédérale de Lausanne (EPFL), Namiki Precision of Europe SA, and Ritsumeikan University.

HVPE is an attractive GaN growth technology since it is much more rapid than metal-organic chemical vapor deposition (MOCVD) or molecular beam epitaxy (MBE).

Growth speeds for HVPE can reach hundreds of microns per hour. However, the approach is presently limited by differences in lattice constants and thermal expansion between sapphire and GaN. In particular, the sapphire substrate tends to crack on cooling with thicker GaN layers. On the other hand, thicker layers are desired for reducing the effects of threading dislocations (TDs) and for developing free-standing GaN substrates.

The researchers used 1045nm femtosecond laser light to control stress in the c-plane sapphire substrates (Figure 1). The laser light was focused within the sapphire material to create amorphous

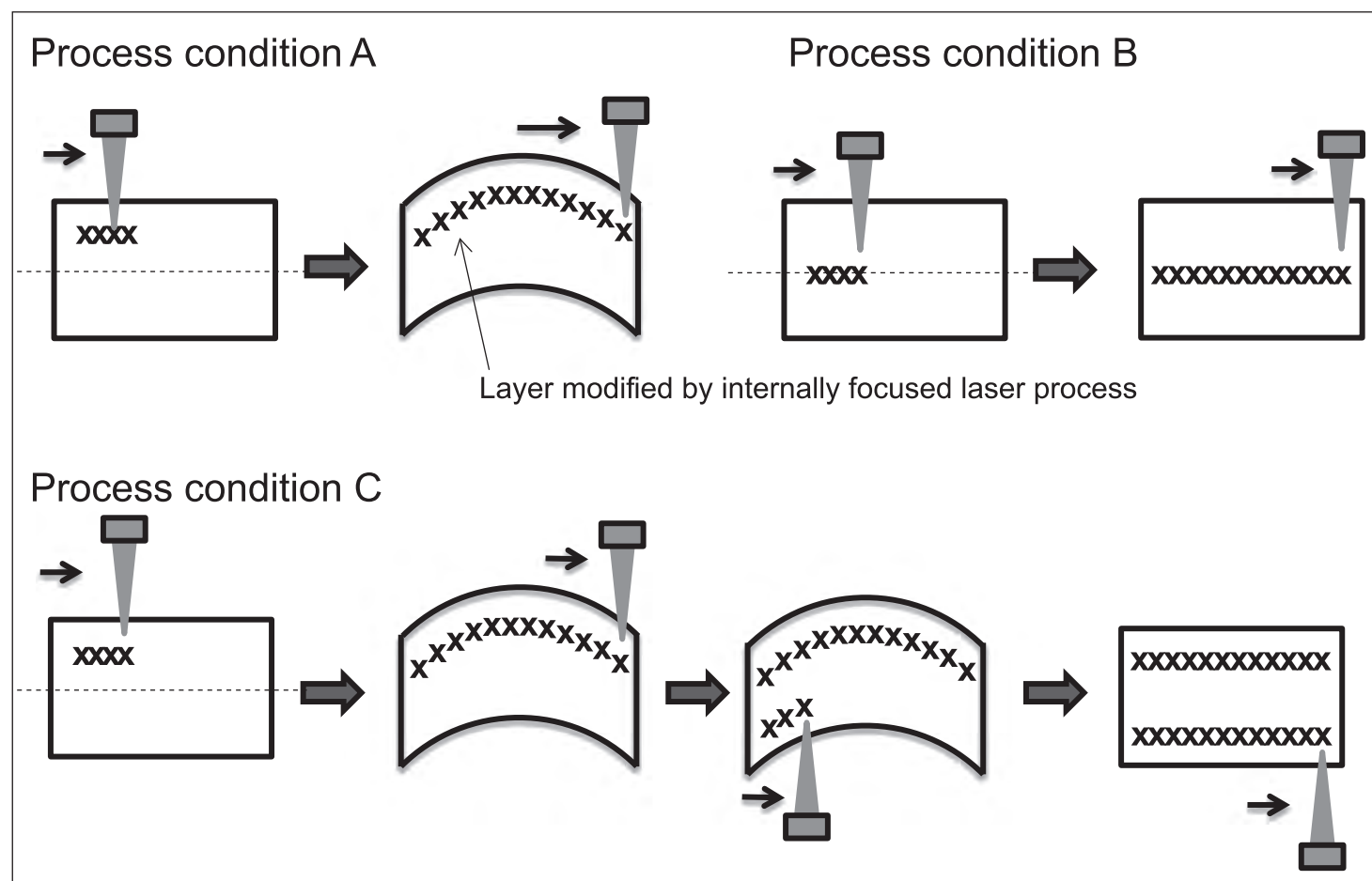


Figure 1. Schematic of laser processing within the substrate and the related substrate bow changes.

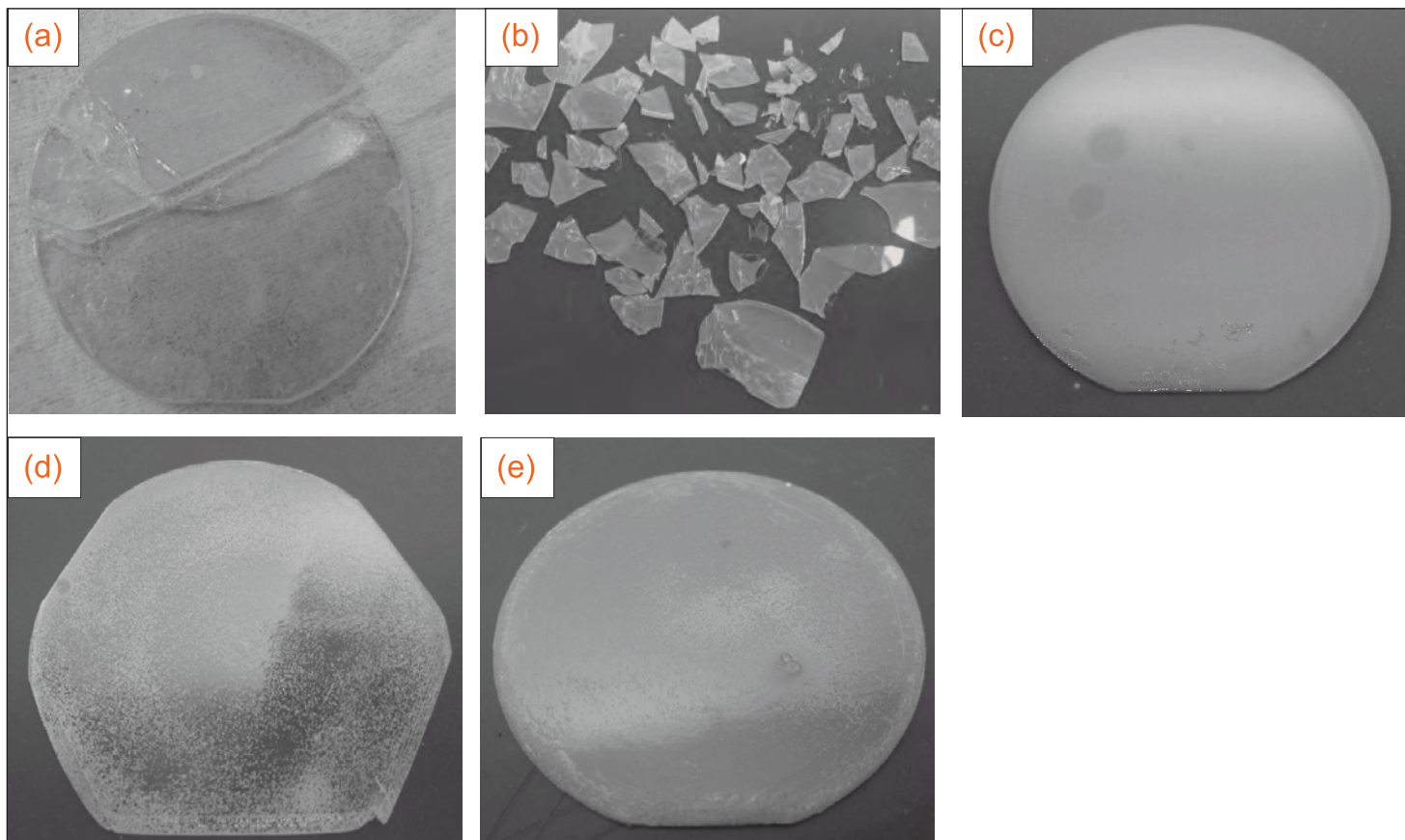


Figure 2. Photographs of the GaN layers on sapphire substrates: (a) 50µm GaN on plain sapphire (S-substrate), (b) 80µm GaN on S-substrate, (c) 80µm GaN on A-substrate, (d) 200µm GaN on the B-substrate (slight cracks seen at edge giving near-hexagonal shape), and (e) 200µm GaN on C-substrate (no cracking).

layers without damaging the crystalline surface used for epitaxy. The effect of the amorphous regions is to create strain due to volume expansion. Various laser treatments were performed: A, with the laser focused in the upper half of the substrate thickness, giving a 70µm bowing effect; B, with the laser focused in the middle of the thickness, giving near-zero bowing; and C, with two amorphous regions from focusing the laser in the upper and lower halves, again giving near-zero bowing.

The HVPE growth began with nitridation and ex-situ surface preparation. The substrate was then returned to the HVPE reactor for thick GaN growth. The researchers liken their procedure to the two-step process (low-temperature nucleation/high-temperature growth) for GaN metal-organic chemical vapor deposition.

On an unprocessed substrate, the critical thickness was 15–20µm before the GaN template cracked. For layers greater than 80µm, the substrate shattered (Figure 2). Laser-treated substrates allowed much thicker layers to be grown (Table 1).

The sapphire is able to withstand greater amounts of bowing before cracking... The laser process may improve the flexibility of the sapphire substrate under bending stress

Beyond the critical thickness, the cracks seem to be generated during the cooling process due to differences in coefficient of thermal expansion between sapphire and GaN. Another effect of the laser treatment seems to be that the sapphire is able to withstand greater amounts of bowing before cracking. The researchers speculate that the laser process may improve the flexibility of the sapphire substrate under bending stress.

The quality of the GaN material was analyzed using cathodoluminescence (CL) and atomic force microscopy (AFM). The threading dislocation density of thin layers grown on plain sapphire was estimated to be $2 \times 10^8/\text{cm}^2$. This was reduced to $1 \times 10^7/\text{cm}^2$ for a 200µm GaN layer grown on a laser-processed substrate. It is thought that the reduction in TDs is due to the mutual annihilation of dislocations. ■

<http://apex.jsap.jp/link?APEX/6/035502>

Author: Mike Cooke

Substrate	Critical thickness	Extracted critical bow
S	15–20µm	116–138µm
A	80–90µm	423–466µm
B	190–210µm	623–669µm
C	220–250µm	547–613µm

Table 1. Critical GaN thickness and extracted critical bow for crack generation of sapphire substrates.

Bringing photoelectrochemistry and catalysis to bear on GaN planarization

RMS roughness reduced to 0.3nm, promising low-defect GaN growth.

Researchers in Japan have been developing planarization techniques for gallium nitride (GaN) surfaces [Shun Sadakuni et al, Jpn. J. Appl. Phys., vol52, p036504, 2013]. The researchers from Osaka University, Ritsumeikan University and Ebara Corp are interested in enabling the growth of single-crystal GaN with low dislocation densities using methods such as hydride vapor phase epitaxy (HVPE), ammonothermal and sodium-flux techniques. These processes need atomically flat GaN surfaces to promote high-quality, low-defect growth.

The team has been developing photoelectrochemical etch techniques for some time that involve ultraviolet (UV) illumination. In the latest work, the researchers have explored the additional use of electrical biasing, along with a catalyst plate that creates local acidity to cause removal to occur only at protruding regions of the wafer surface. Although the root-mean-square

(RMS) roughness of the plate is $0.5\mu\text{m}$, the resulting roughness of the GaN wafer is much less due to rotation averaging out the removal rate.

The purpose of the UV illumination is to generate carriers (electron-hole pairs) that encourage oxidation and etching of the GaN surface. However, the effect of the UV tends to be quickly saturated due to the recombination of carriers at defects. This results in a rough surface. By applying the bias, the carriers are separated and hence are less likely to recombine (Figure 1).

The researchers processed a commercial 2-inch free-standing n-type GaN(0001) wafer with a carrier concentration of $1\text{--}3\times 10^{18}/\text{cm}^3$. The surface was first polished mechanically using a diamond slurry with particle sizes of $\sim 1\mu\text{m}$.

The researchers then investigated etching and planarization processes under UV illumination and electrical biasing. The planarization system uses a

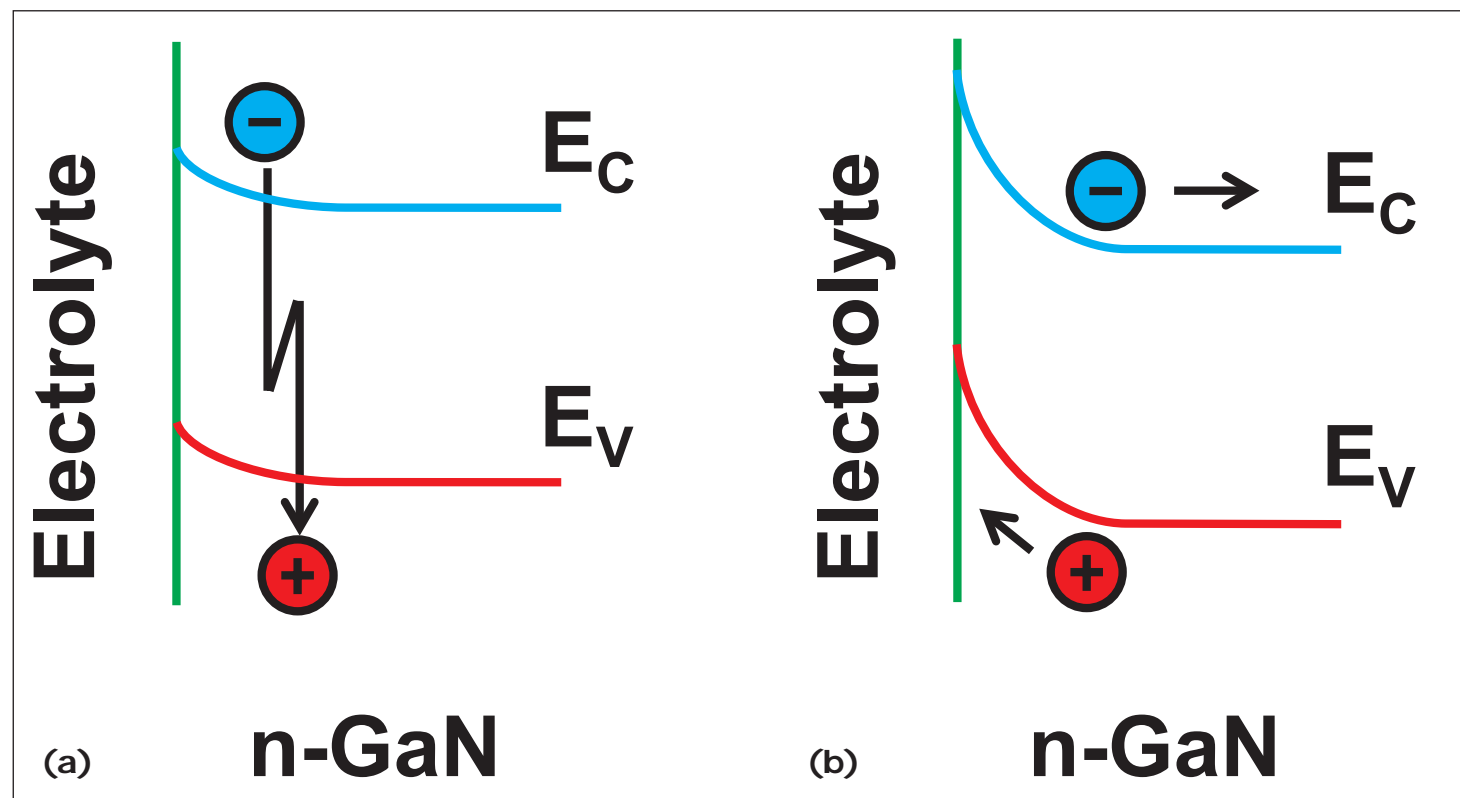


Figure 1. Surface energy band diagram for n-GaN: (a) without an external bias, photo-induced carriers are depleted; (b) the carriers separate when a positive bias is applied, resulting in effective oxidation.

grooved silica glass catalyst plate (Figure 2). The wafer and catalyst plate were independently rotated. The pressure between the wafer and catalyst plate was 400hPa. The process was performed in a neutral buffer solution containing 25 millimole/liter (mM) monopotassium phosphate (KH_2PO_4) and 25mM disodium hydrogen phosphate (Na_2HPO_4) (pH 6.9). The aim of the buffer is to prevent isotropic dissolution of the oxide. Silanol groups ($\text{Si}-\text{OH}$) at the surface of the silica glass donate protons to create local acidity. The $4\text{mW}/\text{cm}^2$ UV radiation was transmitted through the transparent plate and wafer.

The bias was applied to platinum wires in the 1mm-deep plate grooves as cathode and the wafer surface was the anode. The gap between grooves was 3mm.

In the planarization process, the application of a 1V bias produced a removal rate of 60nm/hour. A similar removal rate was seen after 30 hours without the bias, but there is then a long period of increase in removal beginning at 0nm/hour.

With the bias applied, the RMS roughness was reduced to 2.2nm from 3.3nm (Figure 3a). Scratches from the mechanical polishing step are removed, but stripe patterns from the crystal growth process appear.

The stripe patterns were blamed on the solution near the GaN surface becoming excessively acidic due to anodic reactions with positive bias. "The acidic solution removes the oxide even from areas that did not contact the catalyst plate," the researchers write.

A second planarization step without bias for 30 minutes reduced the RMS roughness to 0.3nm (Figure 3b).

As a preliminary to the planarization work, the team

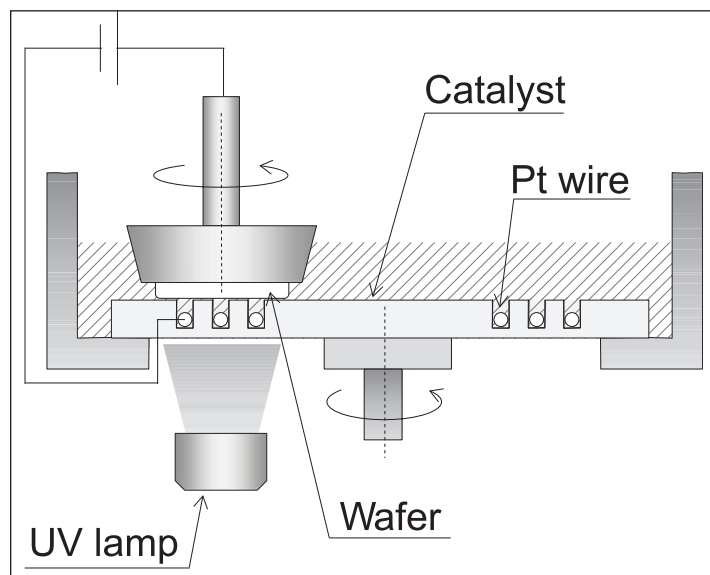


Figure 2. Schematic diagram of planarization apparatus. Pt wires, which act as cathode, are set in grooves of catalyst plate. The GaN surface is illuminated by UV light through transparent catalyst.

also studied an etch process that used a $10\text{mW}/\text{cm}^2$ mercury-xenon lamp and 0.01M-concentration potassium hydroxide solution. An electrical bias was applied through a platinum foil cathode in the solution with the wafer surface acting as anode. The etch process removed scratches from the mechanical polishing, but created stripe patterns from the crystal growth process. ■

<http://jjap.jsap.jp/link?JJAP/52/036504>

Author: Mike Cooke

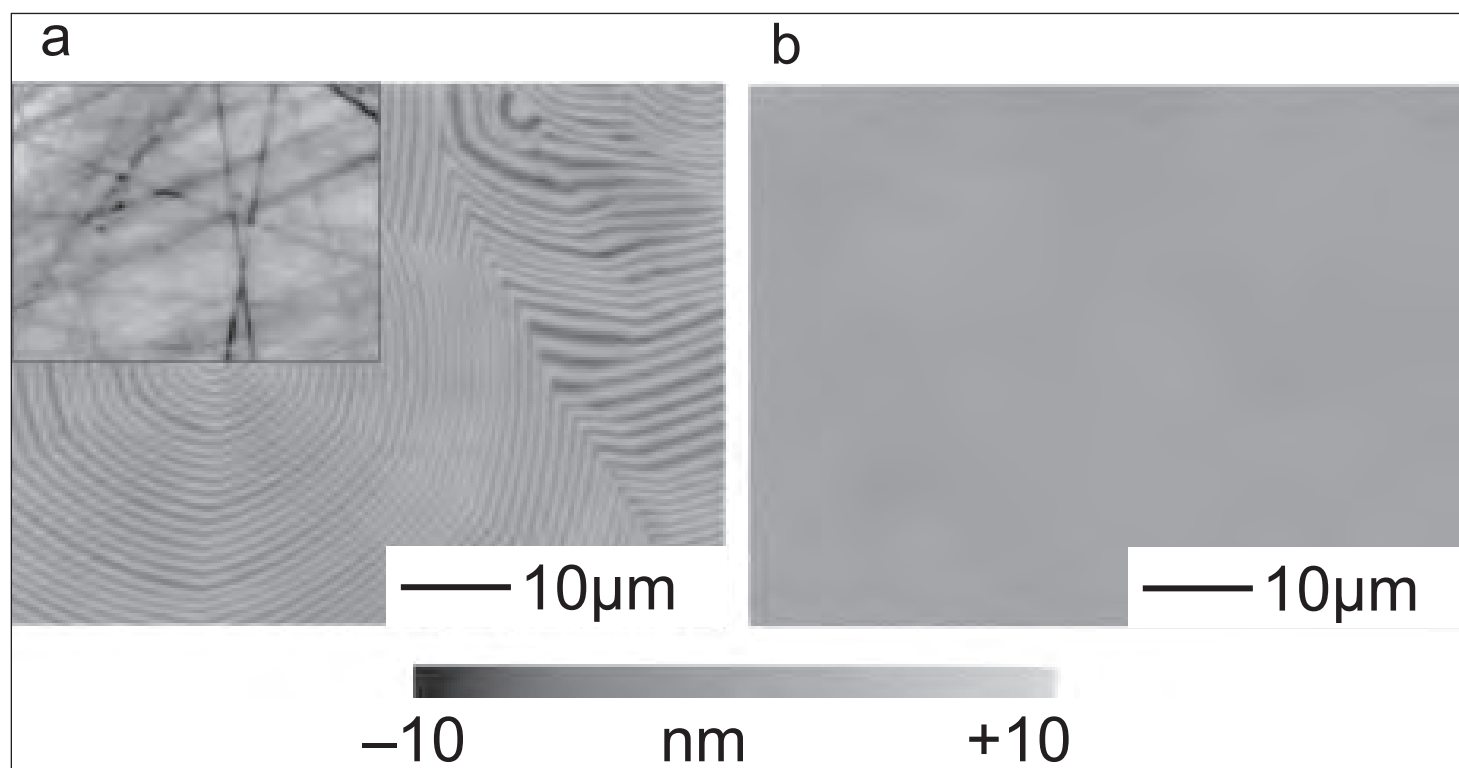


Figure 3. Optical interferometric images ($71\mu\text{m} \times 53\mu\text{m}$) of (a) processed surface with applied voltage of 1V and (b) surface processed without applying a voltage. The inset shows an unprocessed surface.

UV LED market to grow at 43% CAGR from \$45m in 2012 to nearly \$270m by 2017

New applications could add \$30m to UV lamp replacement market, says Yole Développement.

Due to UV curing, UV LEDs should become a \$270m business by 2017, and could hit \$300m if new applications boom, according to a report 'UV LEDs: Technology & Application Trends' from market research firm Yole Développement that presents new UV LED applications and associated market metrics for 2012–2020 as well as an analysis of UV LED technology and the UV LED lighting industry.

Due to their compactness, low cost of ownership and environmentally friendly composition, UV LEDs continue to replace incumbent technologies like mercury. Hence, the UV LED market is expected to rise at a compound annual growth rate (CAGR) of 43% from \$45m in 2012 to nearly \$270m by 2017, while the traditional UV lamps market grows at just 10%.

In 2012, UVA/UVB applications represented 89% of the overall UV LED market. Amongst these applications, UV curing is the most dynamic and most important market, due to significant advantages offered over traditional technologies (e.g. lower cost of ownership, system miniaturization etc). This trend is reinforced by the whole supply chain, which is pushing for the technology's adoption: from UV LED module and system manufacturers to ink formulators and the associations created to promote the technology. Also, with Heraeus Noblelight's acquisition in January of Fusion UV, all major UV curing system manufacturers are now involved in the UV LED technology transition.

Regarding UVC, applications are still in their infancy and sales are mainly for R&D purposes and analytic instruments such as spectrophotometers. However, given some newly published results — e.g. an increase in external quantum efficiency (EQE) over 10%, etc — and commercialization in 2012 of the first UVC LED-based disinfection system, the market should kick into gear within the next two years, says Yole.

In addition to traditional applications (UV lamps replacement), and due to their unique properties (compactness, higher lifetime, robustness, etc), UV LEDs are also creating new applications that are not accessible to traditional UV lamps, i.e. applications that

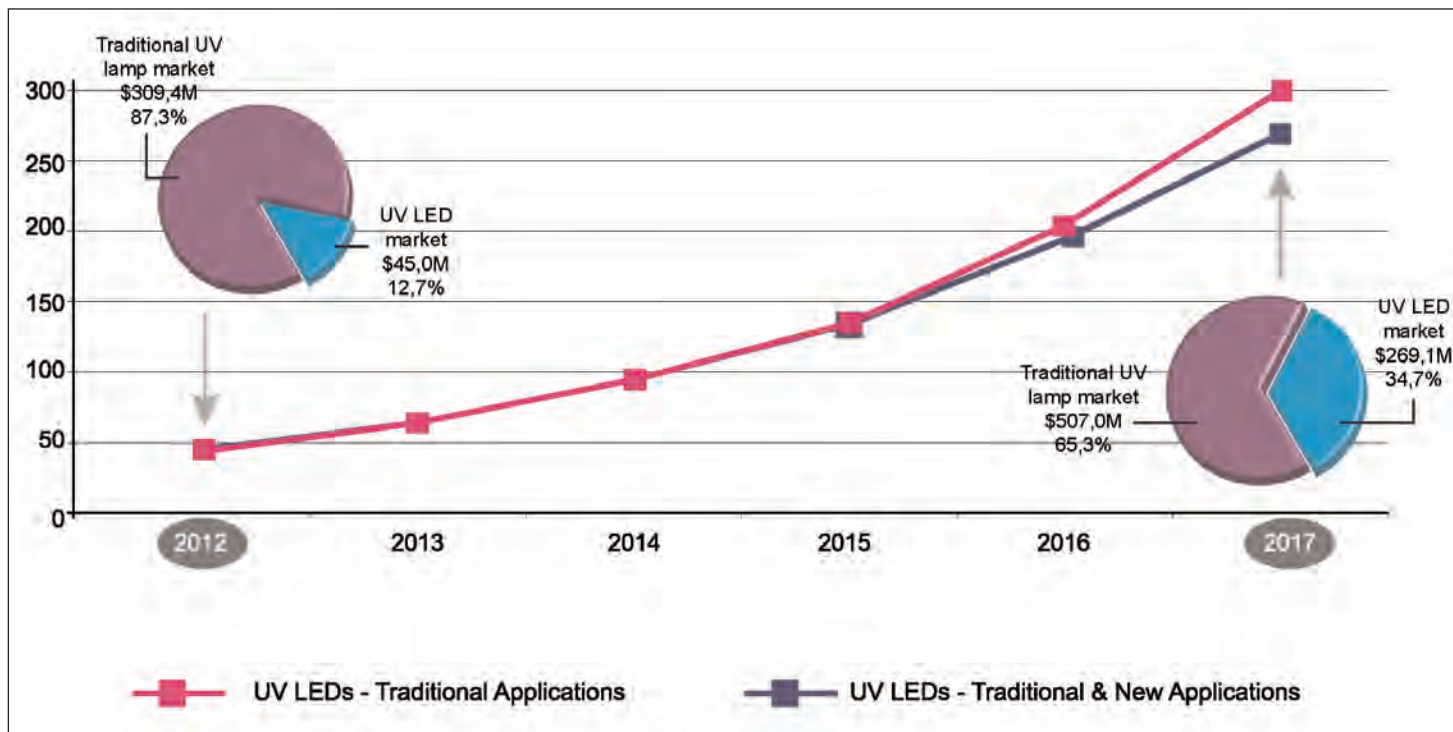
are miniaturized and portable. "In 2012, several new UV LED-based products were launched, including cell-phone disinfection systems, nail gel curing systems and miniaturized counterfeit money detectors — and this is likely to continue," says Pars Mukish, Technology & Market Analyst, LED, at Yole. "We estimate that if new UV LED applications continue emerging, the associated business could represent nearly \$30m by 2017, which would increase the overall UV LED market size to nearly \$300m," he adds.

Once UVC LED performance is sufficient, the supply chain battle will intensify

The booming UVA/UVB market (mostly UV curing) has attracted several new players from different backgrounds over the past few years: traditional UV lamp suppliers, traditional UV system suppliers, pure UV LED system suppliers, and others. Each player employs a different strategy for capturing the maximum value created by this disruptive technology: horizontal integration (from UV lamp to UV LED), vertical integration (from UV LED device to UV LED system and vice-versa) or both (from UV lamp to UV LED system). Yole notes that traditional UV lamp manufacturers are under the most pressure since they have to compensate for the waning lamp replacement market by diversifying their activities to higher levels of the supply chain.

In the end, each UV LED device/system maker faces the same technical issues when it comes to integrating UV LEDs into a system (thermal management, optics, etc), but experience is gained with each passing year. Once UVC LEDs achieve sufficient performance, no manufacturer will allow the opportunity to pass it by, reckons Yole. When that moment comes, the whole supply chain will become a mess due to an increasingly competitive environment, and consolidation will be necessary, it adds.

Yole's analysis covers the entire UV LED industry, detailing: the main players & associated strategies/business models, 2012 industrial value & supply chains, revenues and market shares of key players, etc.



UV LED market size (chip & package) for traditional and new applications to 2017. (Source: 'UV LEDs: Technology & Application Trends' report, March 2013, Yole Développement.)

Bulk AIN vs AIN-on-sapphire templates: no current winner

AIN-on-sapphire templates are definitely the substrate of choice for UVA applications, notes Yole, as they provide the right mix between cost and performance. However, for UVC applications (and some UVB applications) the competition with bulk AIN substrate is strong, since such material could allow for improvements at the device level in terms of lifetime, efficiency — internal quantum efficiency (IQE) and external quantum efficiency (EQE) — and power output.

Just now, the debate is still on. And, even if bulk AIN's superior performance has been demonstrated by companies such as Crystal-IS and HexaTech, the associated cost (2.5–4x more compared to AIN-on-sapphire

template) remains an obstacle to developing UVC LEDs at a reasonable price.

Indeed, such a situation has already occurred with GaN substrate for visible LEDs. Bulk GaN was the ideal technical candidate, but its cost was too high and sapphire was widely adopted instead. Will UV LEDs meet the same fate?

In addition to substrate issues for UVC LED development, epitaxy represents another challenge for increasing device performance, notes Yole. Such barriers will have to be overcome before we see commercialized UV LED-based disinfection/purification systems, it concludes. ■

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UCSB and École Polytechnique identify Auger recombination as cause of nitride LED efficiency droop

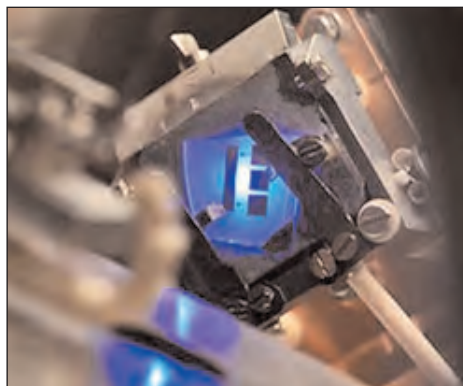
Auger electrons from InGaN/GaN LED correlate with droop current

Researchers at University of California, Santa Barbara, in collaboration with the École Polytechnique in Paris, France, say they have identified Auger recombination as the mechanism that causes nitride LEDs to be less efficient at high drive currents ('Direct Measurement of Auger Electrons Emitted from a Semiconductor Light-Emitting Diode under Electrical Injection: Identification of the Dominant Mechanism for Efficiency Droop', be published in *Physical Review Letters*; a similar version of the accepted manuscript can be found at <http://arxiv.org/abs/1304.5469>).

Until now, scientists had only theorized the cause behind the phenomenon of LED 'droop' (a drop in light output at higher applied drive current). The high cost per lumen of LEDs has so far held the technology back as a viable replacement for incandescent bulbs for all-purpose commercial and residential lighting. But an explanation of the cause of LED efficiency droop could change this, according to researchers professor James Speck and Claude Weisbuch of the UCSB Center for Energy Efficient Materials, an Energy Frontier Research Center sponsored by the US Department of Energy (DOE) Office of Science.

Knowledge gained from the study is expected to result in new ways of designing LEDs with much higher light emission efficiencies. LEDs have great potential for providing long-lived high-quality efficient sources of lighting for residential and commercial applications. The DOE recently estimated that the widespread replacement of incandescent and fluorescent lights by LEDs in the USA could save electricity equal to the total output of fifty 1GW power plants.

"Rising to this potential has been contingent upon solving the puzzle of LED efficiency droop," says Speck, professor of Materials and



LED emitting light under forward bias in an ultra-high-vacuum chamber allowing simultaneous electron emission energy.

the Seoul Optodevice chair in Solid State Lighting at UCSB. "These findings will enable us to design LEDs that minimize the non-radiative recombination and produce higher light output," he adds.

"This was a very complex experiment—one that illustrates the benefits of teamwork through both an

international collaboration and a DOE Energy Frontier Research Center," comments Weisbuch, distinguished professor of Materials at UCSB. Weisbuch, who is also a faculty member at the École Polytechnique in Paris, enlisted the support of colleagues Lucio Martinelli and Jacques Peretti. UCSB graduate student Justin Iveland was a key member of the team working both at UCSB and École Polytechnique.

In 2011, UCSB professor Chris van de Walle and colleagues theorized that the complex non-radiative process of Auger recombination was behind nitride LED droop, whereby injected electrons lose energy to heat by collisions with other electrons rather than emitting light (Emmanouil Kioupakis et al, 'Indirect Auger recombination as a cause of efficiency droop in nitride light-emitting diodes', *Appl. Phys. Lett.*, vol98, p161107, 2011).

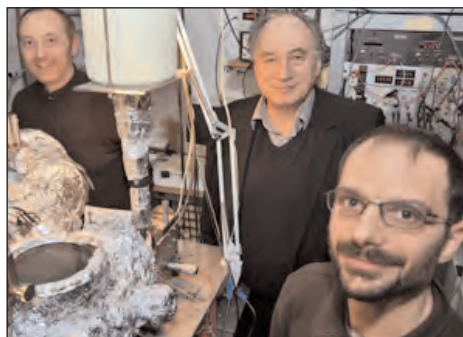
Speck, Weisbuch and their research team claim that they have now achieved a definitive measurement of Auger recombination in LEDs. The experiment used an LED with a specially prepared surface that allowed the researchers to directly measure the energy spectrum of electrons emitted from the LED. The results unambiguously showed a signature of energetic electrons produced by the Auger process.

The research was funded by the UCSB Center for Energy Efficient Materials. Additional support for the work at École Polytechnique was provided by the French government. The Center for Energy Efficient Materials at UC Santa Barbara is a research program within the Institute for Energy Efficiency, a cross-campus institute dedicated to science and engineering research for a more efficient sustainable energy future. ■

<http://ceem.ucsb.edu>
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Justin Iveland (left) and professor James Speck, UCSB. (Credit: UCSB.)



From left: Jacques Peretti, Claude Weisbuch and Lucio Martinelli. (Credit: École Polytechnique, Ph. Lavalie.)



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CMOS-based front-end targets single, global 4G LTE design for mobile devices

In February, Qualcomm Technologies Inc (a subsidiary of fabless chip manufacturer Qualcomm Inc of San Diego, CA, USA) introduced the RF360 front-end solution, a system-level solution addressing cellular radio-frequency band fragmentation and enabling for the first time, it is claimed, a single, global 4G LTE design for mobile devices.

With 40 cellular radio bands worldwide, band fragmentation is the biggest obstacle to designing global LTE devices, says Qualcomm. The RF front-end solution comprises a family of chips designed to mitigate this problem while improving RF performance and helping OEMs more easily develop multi-band, multi-mode mobile devices supporting all seven cellular modes, including LTE-FDD, LTE-TDD, WCDMA, EV-DO, CDMA 1x, TD-SCDMA and GSM/EDGE.

The front-end includes what is claimed to be the first envelope power tracker for 3G/4G LTE mobile devices, a dynamic antenna matching tuner, an integrated power amplifier-antenna switch, and a 3D-RF packaging solution incorporating key front-end components.

The RF360 is designed to work seamlessly, reduce power consumption and improve radio performance while reducing the RF front-end footprint inside a smartphone by up to 50% compared to current-generation devices, says Qualcomm. It also aims to reduce design complexity and development costs, allowing OEMs to develop multi-band, multi-mode LTE products faster and more efficiently. By combining the new RF front-end chipsets with Qualcomm Snapdragon all-in-one mobile processors and Gobi LTE modems, Qualcomm Technologies says that it can supply OEMs with a comprehensive, optimized, system-level LTE solution that is truly global.

As mobile broadband technologies evolve, OEMs need to support 2G, 3G, 4G LTE and LTE Advanced technologies in the same device in order to provide the best data and voice service to consumers regardless of where they are, says Qualcomm.

"The wide range of radio frequencies used to implement 2G, 3G and 4G LTE networks globally presents an ongoing challenge for mobile device designers," says Alex Katouzian, Qualcomm Technologies' senior VP of product management. "Where 2G and 3G technologies each have been implemented on four to five different RF bands globally, the inclusion of LTE brings the total

number of cellular bands to approximately 40," he adds. "Our new RF devices are tightly integrated and will allow us the flexibility and scalability to supply OEMs of all types, from those requiring only a region-specific LTE solution, to those needing LTE global roaming support."

The RF360 front-end solution represents an advance in overall radio performance and design, claims Qualcomm, and includes the following components:

- Integrated power amplifier/antenna switch (QFE23xx) — claimed to be the first chip featuring an integrated CMOS power amplifier (PA) and antenna switch with multi-band support across 2G, 3G and 4G LTE cellular modes. This provides what is reckoned to be unprecedented functionality in a single component, with smaller PCB area, simplified routing and one of the smallest PA/antenna switch footprints in the industry, it is claimed.
- Dynamic antenna matching tuner (QFE15xx) — The first modem-assisted and configurable antenna-matching technology extends antenna range to operate over 2G/3G/4G LTE frequency bands, from 700MHz to 2700MHz. In conjunction with modem control and sensor input, this dynamically improves the antenna's performance and connection reliability in the presence of physical signal impediments, like the user's hand.
- Envelope power tracker (QFE11xx) — The first modem-assisted envelope tracking technology designed for 3G/4G LTE mobile devices, this chip is designed to reduce overall thermal footprint and RF power consumption by up to 30%, depending on the mode of operation. By reducing power and heat dissipation, it enables OEMs to design thinner smartphones with longer battery life.
- RF POP (QFE27xx) — The first 3D RF packaging solution, integrates the QFE23xx multi-mode, multi-band power amplifier/antenna switch with all the associated SAW filters and duplexers in a single package. Designed to be easily interchangeable, the QFE27xx allows OEMs to change the substrate configuration to support global and/or region-specific frequency-band combinations. The QFE27xx RF POP enables a highly integrated multi-band, multi-mode, single-package RF front-end solution that is truly global, claims Qualcomm.

OEM products featuring the complete RF360 solution are due to be launched in second-half 2013.

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Qualcomm's CMOS PA throws market into flux

GaAs suppliers will have to continue to innovate to maintain edge

Qualcomm's new RF360, a family of RF front-end cell-phone products including multi-band CMOS power amplifiers (PAs), marks the firm's entry into the \$5bn cellular RF front-end component market, notes the Strategy Analytics report 'PA Market in Flux: CMOS PAs and Envelope Tracking Emerge as Major Themes at MWC 2013', issued following GSMA Mobile World Congress 2013 in Barcelona, Spain in February. The report evaluates Qualcomm's RF360 in the context of new developments in power management and high-efficiency multi-band power amplifiers by established PA suppliers, other chipset suppliers and power management IC specialists.

"Qualcomm is the first to launch a CMOS PA alternative to GaAs-based multi-band, multi-mode PAs for mid- to high-tier 3G/4G smartphones, a phone seg-

ment formerly the exclusive domain of GaAs PAs," notes Christopher Taylor, director of the Strategy Analytics RF & Wireless Components market research service. "Envelope tracking (ET) power management enables this, and we expect adoption of CMOS PAs from Qualcomm and others to accelerate in mobile phones as a result," he adds.

"GaAs is not dead yet, but GaAs PA suppliers will have to continue to innovate to maintain an edge over CMOS, and they may also need to consider offering their own CMOS PAs for the most cost-sensitive phones, as Skyworks and RFMD now do," comments Eric Higham, director of the Strategy Analytics GaAs and Compound Semiconductor market research service.

www.strategyanalytics.com

GaAs device revenue grew 2% to record \$5.3bn in 2012

Above-average 8–10% growth in 2013; CMOS PAs threaten long term

In a blog in March, Eric Higham of market research firm Strategy Analytics noted that gallium arsenide device revenue closed 2012 at a new record of just over \$5.3bn, albeit up by just under 2% on 2011. The small gain was driven by a strong fourth-quarter performance from the industry after a sub-par third quarter almost erased the gains for the entire year.

With the exception of 2009, when the global economy took a sharp dip and the GaAs market fought back to breakeven, the growth rate in 2012 was the lowest since the GaAs device market began a steady rise in 2004.

Handsets and smartphones, in particular, remain the driving force behind GaAs device revenue growth, says Higham. Due to their increasing GaAs device content, the growth of smartphones helped propel the handset segment to more than 50% of the entire GaAs device market. Unsurprisingly, the companies associated with handset devices remain the revenue leaders. Skyworks Solutions again saw its revenue grow faster than the market, and it remains the largest GaAs device maker, stretching its lead over TriQuint. Regarding pure-play foundry, Taiwan's WIN Semiconductors continues its impressive growth trajectory and has become the dominant firm in this segment.

Strategy Analytics expects a good uptick in cellular terminal shipments in 2013, along with smartphones continuing to capture market share. This will drive GaAs device revenue growth in 2013 to 8–10%, Higham says, adding that there are signs this growth is taking root.

However, even with above-average growth looking likely in 2013, all is not rosy for the GaAs device market long-term, reckons Higham.

The first threat to growth comes from within. The number of LTE bands, coupled with a desire for the 'world-phone' has led to the multi-mode, multi-band power amplifier (MMMB PA). This has some serious repercussions, because this market is so price sensitive that it will not tolerate bigger and more costly parts, says Higham. So, MMMB PAs must be smaller and cheaper than the PAs they replace otherwise it won't make sense to use them. We have already seen substantial design and design-in activity, so these devices are beginning to see commercial traction, notes Higham.

The other serious threat was unveiled at the 2013 Mobile World Congress (MWC) in Barcelona, Spain at the end of February. Qualcomm fired the first shot across the bow with the pre-conference announcement of its RF360 family of devices, described as a complete, all-encompassing CMOS RF front-end subsystem, consisting of an antenna tuning IC, an envelope tracking (ET) IC for Qualcomm's PA, and a MMMB CMOS PA fabricated using a silicon-on-insulator (SOI) substrate. This announcement sent GaAs PA makers' share prices plummeting. Then at MWC, a host of firms announced their ET development efforts aimed at CMOS-based PAs in LTE handset applications.

These events and particularly CMOS developments will influence growth for GaAs devices in the next several years, says Higham, who hosts the panel session 'The Death of GaAs (?)' on 6 June at the IEEE MTT-S International Microwave Symposium (IMS2013) in Seattle, and is presenting an overview of the 2012 GaAs market at CS MANTECH in New Orleans (13–16 May).

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ALE boosts surface-channel GaAs transistor drive

The maximum drain current in GaAs NMOSFETs has been raised to a record 336mA/mm.

Researchers at Purdue and Harvard universities have developed gallium arsenide (GaAs) enhancement-mode (E-mode) surface/n-channel metal-oxide-semiconductor field-effect transistors (NMOSFETs) with a maximum drain current of 336mA/mm, which is claimed to be a record high for such devices [L. Dong et al, IEEE Electron Device Letters 34 (4) p487; published online 7 March 2013, DOI: 10.1109/LED.2013.2244058].

The performance was enabled by atomic layer epitaxy (ALE) of the gate dielectric and annealing to reduce interface trap densities. Such traps kill performance by collecting charge that shields the gate, reducing its electrostatic effectiveness.

The NMOSFETs (Figure 1) were produced from semi-insulating GaAs 2-inch wafers. The crystal orientation used was (111)A, which avoids As-As bonds on the GaAs surface. Such bonds can lead to pinning of the Fermi level, killing device performance.

Dielectric deposition followed a number of surface preparation steps designed to degrease the wafers, remove native oxide layers and passivate the surface. The ALE dielectric stack consisted of 7.5nm lanthanum yttrium oxide ($\text{La}_{1.8}\text{Y}_{0.2}\text{O}_3$) and 6.5nm aluminium oxide (Al_2O_3). The Al_2O_3 was used to protect the lower dielectric layer from reacting with water molecules from the air and from the following process steps. The equivalent oxide thickness of the structure was around 4.5nm.

Metal-organic precursors were used: lanthanum tris(N,N'-diisopropylformamidinate), yttrium tris(N,N'-diisopropyl-acetamidinate), and trimethyl-aluminium. The oxygen source was water. Atomic layer epitaxy consisted of pulsing the precursors. The chamber was purged with nitrogen after each water vapor pulse. Water molecules and/or hydroxyl groups trapped in the deposited material degrades crystallinity and dielectric permittivity.

Further fabrication consisted of implanting the source-drain regions with silicon to create n^+ -type semiconductor regions. The implant was followed by rapid thermal annealing (RTA) at 860°C for 15 seconds in nitrogen for dopant activation. The metallization of the source-drain regions consisted of gold/germanium/nickel/gold stacks defined by lift-off photolithography. Ohmic contact was created through more RTA at

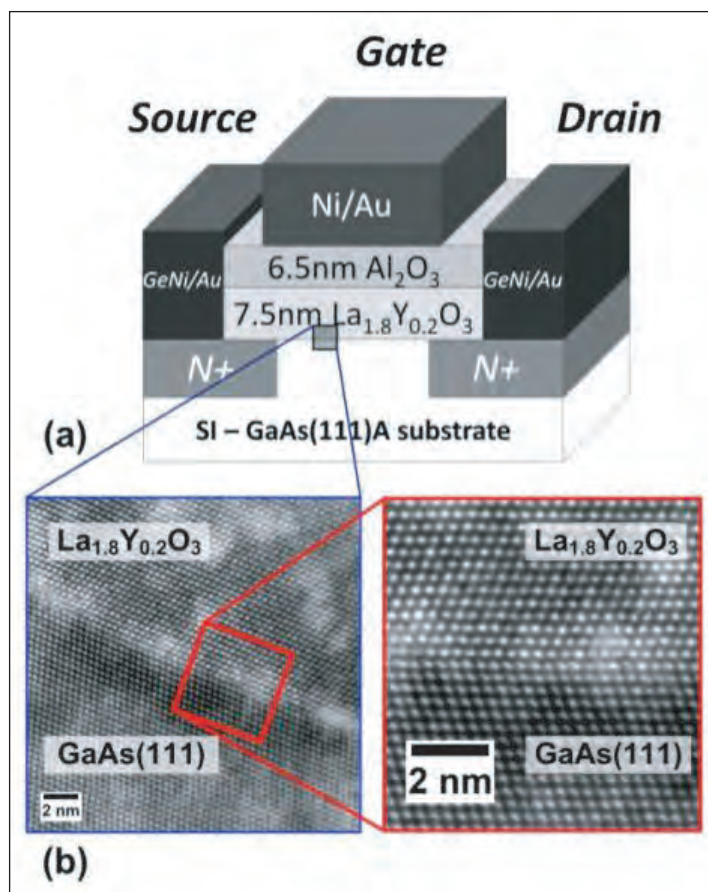


Figure 1. (a) Cross section of a GaAs(111)A surface channel E-mode NMOSFET. (b) High-resolution TEM image and enlarged view of single-crystalline GaAs-single-crystalline $\text{La}_{1.8}\text{Y}_{0.2}\text{O}_3$ interface after 860°C RTA annealing. Epitaxial $\text{La}_{1.8}\text{Y}_{0.2}\text{O}_3$ forms flat and sharp interface on GaAs(111)A substrate.

400°C for 30 seconds in nitrogen. Further lift-off photolithography created a nickel/gold gate electrode.

The resulting devices were 100µm wide with various gate lengths (0.5–40µm). MOS capacitors (formed in a similar way on n- and p-type substrates, but without source-drain regions) were also produced for capacitance-voltage analysis of dielectric/semiconductor interface traps.

An NMOSFET with 0.5µm-long gate had a maximum drain current of 336mA/mm (Figure 2), described as a “significant improvement of the on-state current compared with the previously reported GaAs (111)A NMOSFETs with amorphous Al_2O_3 as the gate dielectric”. The peak current was achieved at 5V gate and 2V drain biases.

The researchers believe that the high quality of their

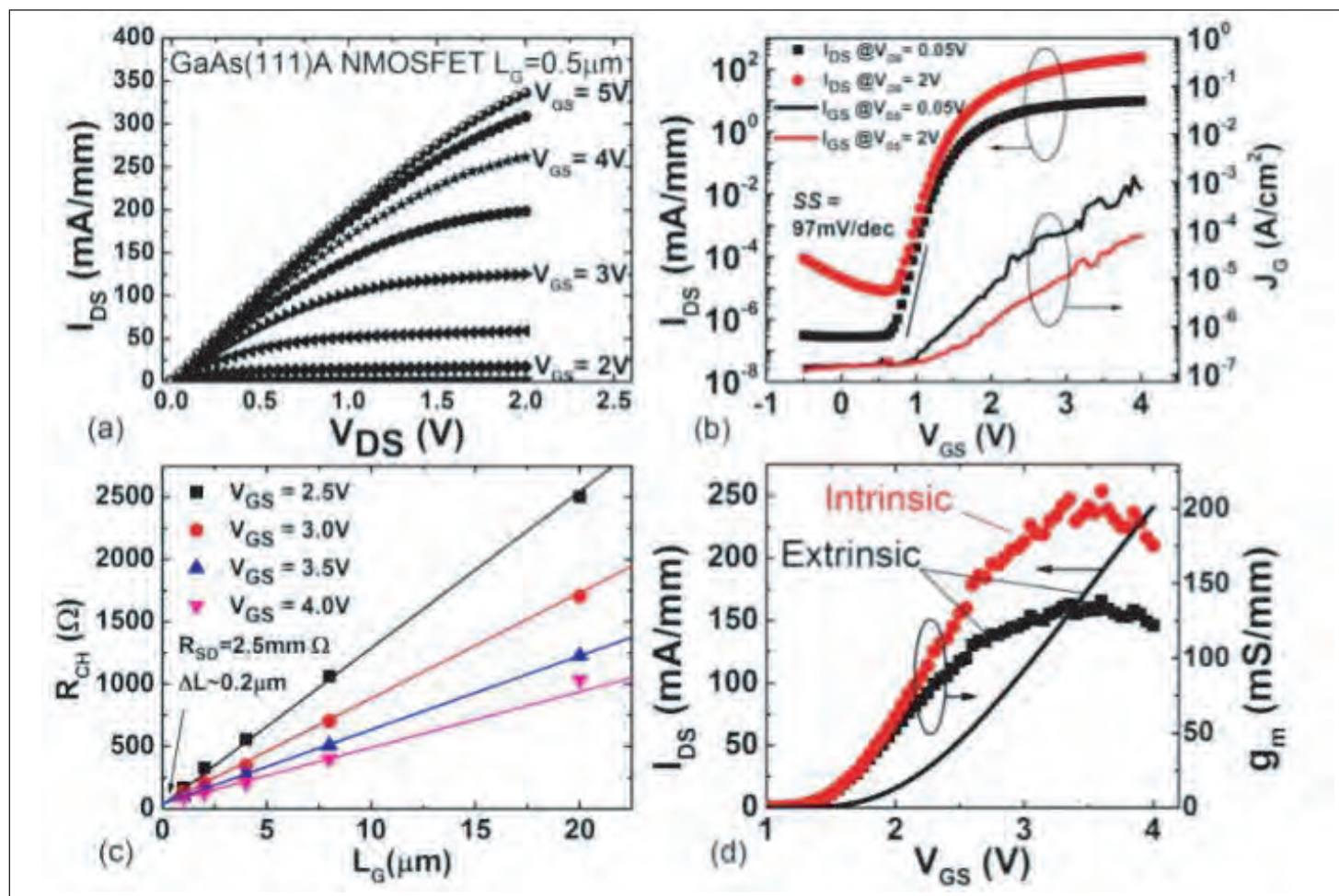


Figure 2. (a) Current–voltage (I – V) characteristic of 0.5 μm-gate-length GaAs NMOSFET with ALE La_{1.8}Y_{0.2}O₃ oxide. (b) Transfer characteristics and gate leakage current density of same GaAs NMOSFET as (a). (c) Measured channel resistance vs different mask gate-length as function of gate bias. Source–drain resistance (R_{SD}) of 2.5 Ω-mm and $\sim 0.2 \mu m$ for difference of the designed and effective gate-length (ΔL) are determined from fitting lines. (d) Extrinsic and intrinsic transconductance (g_m) and extrinsic drain current versus gate bias of the same GaAs NMOSFET in (a).

novel La_{1.8}Y_{0.2}O₃ epitaxial interface passivates dangling bonds on the GaAs surface, reducing the number of interface traps.

The channel mobility peaked at 310 cm²/V-s at an inversion charge density of 2×10^{12} /cm². The researchers believe that the drive current and mobility could be further enhanced by using buried channel structures or high-mobility channel material such as InGaAs.

The on/off current ratio was more than 10^7 with a drain bias of 2V (on = 2.3V gate, off = 0.5V gate). "This high I_{ON}/I_{OFF} ratio is a promising feature for GaAs as compared to InGaAs, since the latter usually suffers from high S/D leakage current as a result of its relatively narrower bandgap," the researchers comment.

The subthreshold swing was 97 mV/dec across the range of gate lengths produced, again suggesting low interface trap densities in the mid-gap region.

The gate leakage increased from $\sim 10^{-7}$ A/cm² to $\sim 10^{-3}$ A/cm² as the gate bias increased from 0V to 4V. Despite this, the leakage remains at least five orders of magnitude smaller than the drain current up to 4V.

The maximum intrinsic transconductance for the 0.5 μm-long gate NMOSFET was ~ 210 mS/mm. The extrinsic value (i.e. not correcting for source-drain resistance) was ~ 138 mS/mm. The researchers believe that the device transconductance could be further improved by reducing the dielectric thicknesses.

Capacitance measurements confirmed the importance of annealing for reducing interface trap densities from around 3×10^{12} /cm²-eV to 5.5 – 7×10^{11} /cm²-eV. The significant reduction is seen as key to realizing high performance in the surface-channel GaAs transistors.

The work at Purdue University was supported by the Air Force Office for Scientific Research (AFOSR). The work at Harvard University was performed at the Center for Nanoscale Systems (CNS), a member of the US National Nanotechnology Infrastructure Network (NNIN). ■

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Author: Mike Cooke

New orientation for GaN-on-silicon transistors

Researchers in France show how the use of (110) silicon can form a better base for combining GaN and Si electronics.

The first millimeter-wave power demonstration of aluminium gallium nitride/gallium nitride (AlGaN/GaN) high-electron-mobility transistors (GaN) grown on a (110) silicon substrate has been claimed by a French team of researchers [A. Soltani et al, IEEE Electron Device Letters, published online 7 March 2013]. The team consists of workers from Institut d'Electronique, de Microélectronique et de Nanotechnologie (IEMN) and Centre de Recherche sur l'Hétéro-Epitaxie et ses Applications (CRHEA).

GaN-based transistors are promising for future high-frequency/high-power devices such as RF power amplifiers for wireless network base-stations. Also, the material is being developed for power switching that needs to operate at high voltages and temperatures. Traditional growth substrates for GaN such as sapphire and silicon carbide are expensive and there has been a combined industry-research push to develop high-performance devices on lower-cost silicon substrates. In addition, silicon is available in much larger-diameter formats (up to 300mm) that offer potential economies of scale.

Most reports of silicon substrate nitride semiconductor transistors up to now have used the (111) orientation because it offers a hexagonal surface crystal structure onto which it would appear to be most natural for

the hexagonal nitride semiconductor wurtzite structure to grow. Mainstream silicon semiconductor production prefers the (001) orientation, but GaN growth is more difficult because the surface has square symmetry. One particular problem with (001) growth is cracking of GaN material thicker than 1µm.

Recently, researchers have suggested using (110) silicon since it has a quasi-lattice that is matched with AlN. Aluminium nitride is often used for nucleation layers before the growth of thick GaN buffers on silicon. Another potential advantage is that (110) silicon has much better electron transport properties than (111) silicon, raising the prospect of silicon/GaN electronics co-integration.

The epitaxial material for the IEMN/CRHEA transistor was grown using molecular beam epitaxy (MBE) on 2-inch high-resistivity (HR, more than 5kΩ-cm) silicon

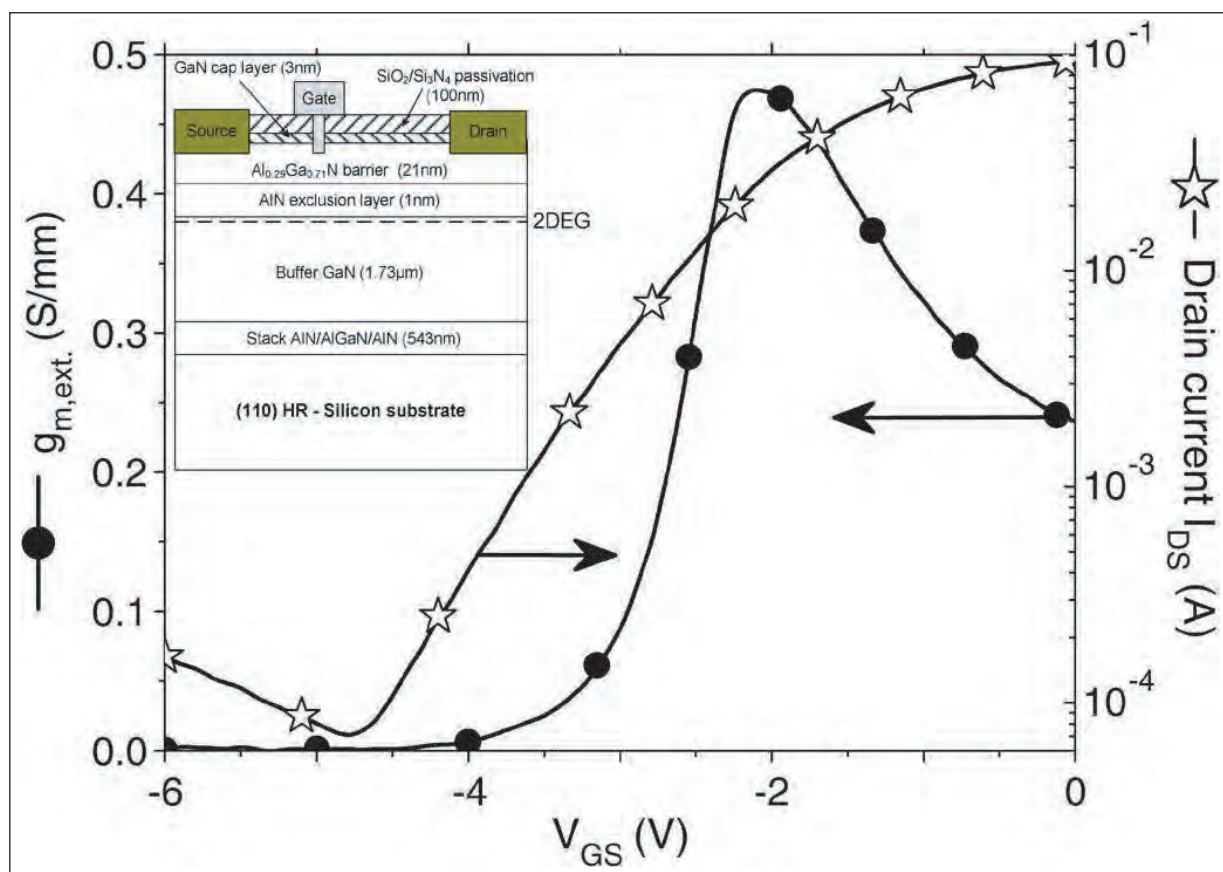


Figure 1. Transfer (drain current I_{DS}) and extrinsic transconductance ($g_{m,ext}$) characteristics versus gate potential V_{GS} at 10V drain bias for IEMN/CRHEA HEMT. Inset: cross section of fabricated AlGaN/GaN HEMT.

with (110) surface orientation. The initiation layer was 43nm aluminium nitride (AlN). This was followed up with a stress-mitigating stack of 250nm aluminium gallium nitride ($\text{Al}_{0.15}\text{Ga}_{0.85}\text{N}$) and 250nm AlN. This was followed by buffer, exclusion/spacer, and barrier layers (Figure 1). The aim of the exclusion layer was to reduce alloy scattering and to improve confinement of the two-dimensional electron gas (2DEG) channel.

Simulation suggested that the stress-mitigation stack could also provide a back-barrier equivalent to that provided by a $1\mu\text{m}$ -thick $\text{Al}_{0.15}\text{Ga}_{0.85}\text{N}$ layer 10nm from the active area.

Scanning electron microscopy and atomic force microscopy inspection of the epitaxial material did not find any surface cracking. The threading dislocation density was estimated at $3.7 \times 10^9/\text{cm}^2$, similar to the level found with GaN on (111) silicon.

The transistors that were produced had 60nm-long T-gates with 10nm recess depth. The gate width was $2\mu\text{m} \times 30\mu\text{m}$. The source-drain distance was $2\mu\text{m}$ and the source-gate distance $0.15\mu\text{m}$. The ohmic source-drain contacts were recessed to 18nm to reduce contact resistance.

The ohmic contact recess was achieved using argon ion milling. The contact electrodes consisted of titanium/aluminium/nickel/gold annealed at 870°C for 30 seconds in nitrogen.

Electrical isolation was achieved using helium ion implantation. Surface passivation consisted of nitrous oxide (N_2O) pretreatment, followed by silicon nitride/silicon dioxide bilayer plasma-enhanced chemical vapor deposition.

Formation of the T-gate consisted of patterning, reactive-ion etch, recessing in the barrier using argon ion milling and 4nm depth digital etch, and metallization with nickel/platinum/titanium/molybdenum/gold. Thick titanium/gold metal interconnect lines were added using lift-off techniques.

The completed device was finally annealed at 400°C for 20 minutes in nitrogen with the aim of electrically stabilizing the rectifying contact of the Schottky gate. The measured reverse leakage current of the gate was $-30\mu\text{A}/\text{mm}$ at -10V .

Hall measurements of the epitaxial material gave carrier mobility of $2045\text{cm}^2/\text{V}\cdot\text{s}$ with density $1.21 \times 10^{13}/\text{cm}^2$, and sheet resistance $245\Omega/\text{square}$. Capacitance-voltage measurements under reverse bias found that the 2DEG was located 24nm below the surface.

The maximum DC drain current of $1.55\text{A}/\text{mm}$ was achieved at 10V drain and 0V gate potentials. The peak extrinsic transconductance of $476\text{mS}/\text{mm}$ was obtained at -2.2V gate potential. Pinch-off occurred with the gate

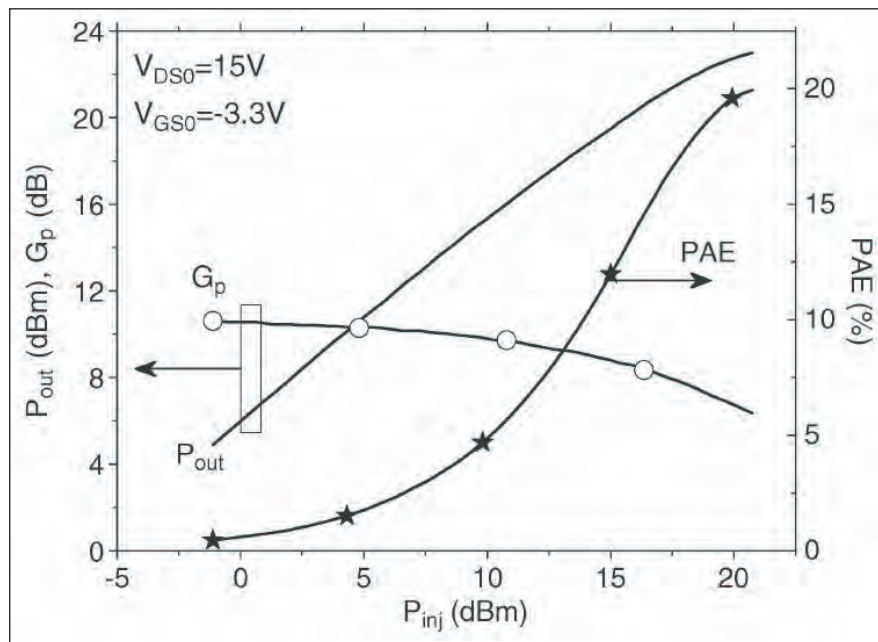


Figure 2. CW power performance of IEMN/CRHEA HEMT at 40GHz.

at -3.9V . Three-terminal off state breakdown ($1\text{mA}/\text{mm}$ drain current) occurred at 24V drain-gate bias.

The researchers estimate the peak intrinsic transconductance at $566\text{mS}/\text{mm}$. "This high transconductance value can be explained by the low source access resistance (evaluated to 5.6Ω for $L_{GS} = 150\text{nm}$)," the researchers comment.

The cut-off (f_T) and maximum oscillation (f_{max}) frequencies at -2.2V gate and 4V drain were 81GHz and 106GHz, respectively.

Pulsed measurements (400ns, 0.4% duty cycle) were carried out to determine trapping and thermal effects. Under gate pulsing from -6V to 0V and drain pulsing from 0V, the maximum drain current was $1.67\text{A}/\text{mm}$, a drop of 6.2% indicating some gate lag effects. Drain lag effects were investigated by pulsing from the quiescent point of 15V drain and -6V gate. In this case, the current dropped 20.9%.

The researchers considered the lag effects small enough for reproducible and high microwave power performance. A continuous-wave active load-pull measurement at 40GHz was performed in conjunction with a large-signal network analyzer working up to 50GHz. There was no external cooling applied. The device achieved a saturated output power of 2.3dBm ($3.3\text{W}/\text{mm}$) with associated power gain of 10.6dB and power-added efficiency (PAE) of 20.1%.

Similar 40GHz measurements on devices produced on (111) silicon have been reported that gave $2\text{W}/\text{mm}$ output power with an AlGaIn barrier and $2.5\text{W}/\text{mm}$ with an AlN barrier. A device produced on (001) silicon has achieved $2.9\text{W}/\text{mm}$ at the lower frequency of 10GHz. ■

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Author: Mike Cooke

GaN FinFET without heterostructure

A junctionless, heterostructure-free device with a gate length of $1\mu\text{m}$ has achieved near-ideal subthreshold swing for a GaN MISFET.

Researchers based in South Korea and France have developed gallium nitride (GaN) fin field-effect transistors (FinFETs) with the lowest claimed subthreshold swing for nitride semiconductor metal-insulator-semiconductor FETs (MISFETs) [Ki-Sik Im et al, IEEE Electron Device Letters, published online 30 January 2013].

The FinFET devices, produced by Kyungpook National University (South Korea), Grenoble Polytechnic Institute (France) and Samsung LED Company, are also the first to use heterostructure-free GaN. Usually, nitride semiconductor transistors use heterostructuring to create a two-dimensional electron gas (2DEG) near the junction between two or more different nitrides. The 2DEG serves as the channel conducting medium in these devices.

Some research groups, starting in 2009, have produced FinFETs using heterostructured nitride semiconductors, but the devices have suffered from parasitic conduction of the 2DEG. This creates problems for reliable operation due to poor GaN/gate oxide insulator interface quality.

The researchers see their device as a promising

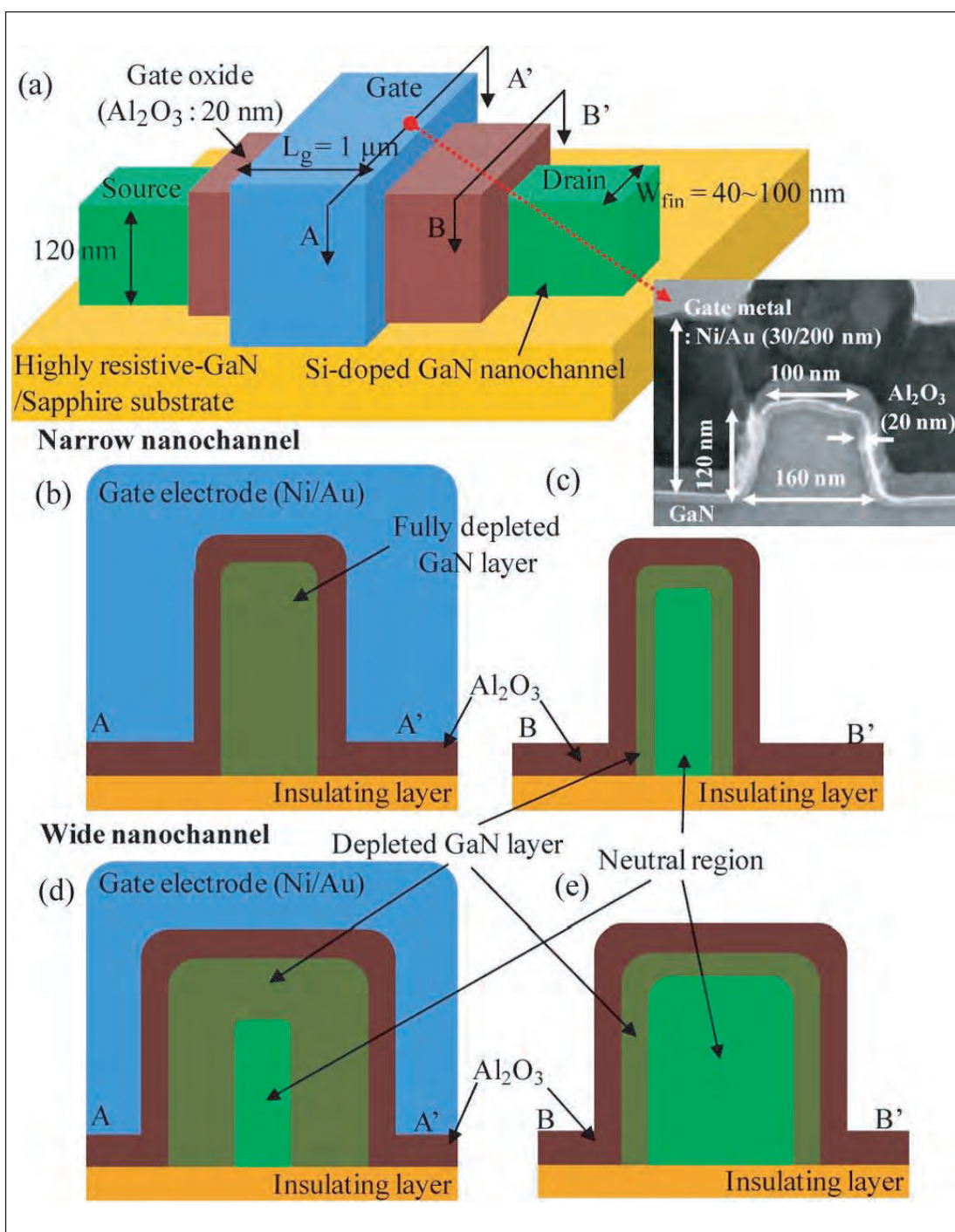


Figure 1. (a) Schematic illustration of GaN nanochannel FinFET including device dimensions. (b) and (c) Narrow fin: The (dark green) depletion region extends across whole body (full depletion) in OFF state and gradually reduces with increasing gate bias. (d) and (e) Wide fin: Body cannot be fully depleted. Inset: cross-sectional TEM image.

candidate for high-performance and high-speed integrated circuits, and also for high-power applications, since GaN semiconductor is able to withstand stronger electric fields than silicon and most other semiconductor materials.

The epitaxy for the GaN FinFET (Figure 1) consisted of a simple 120nm n-type (silicon-doped) GaN metal-organic chemical vapor deposition (MOCVD) layer on a GaN/sapphire template. The Hall carrier density and mobility were $1 \times 10^{18}/\text{cm}^3$ and $234 \text{ cm}^2/\text{V}\cdot\text{s}$, respectively. The fin channel was patterned with electron-beam lithography and plasma reactive-ion etching. The plasma damage was repaired using tetramethyl ammonium hydroxide solution to create smooth surfaces. The height and width of the fin were 120nm and in the range 40–120nm, respectively.

The maximum drain current of a 5-finger FinFET with nanochannels of 60nm width and $1 \mu\text{m}$ length was more than 1mA (Figure 2). The peak transconductance of 0.25mS occurred at 6V gate and 7V drain. Normalizing according to the effective gate width ($5 \times (120\text{nm} + 60\text{nm} + 120\text{nm}) = 1.5 \mu\text{m}$) gives a maximum drain current density of 670mA/mm and a peak transconductance of 168mS/mm.

The researchers comment that these results are higher than those of state-of-the-art planar-type AlGaIn/GaN-based normally-off (enhancement-mode) MISFETs and MISHFETs.

The off-state current for devices with channel widths less than 100nm were as low as 10^{-11}mA due to the total depletion of the fin below threshold. The on/off current ratio was 10^8 .

A device using 60nm-wide fins had a subthreshold swing (SS) of 68mV/dec, the lowest value ever reported for GaN MISFETs, according to the researchers, and close to the theoretical limit of 60mV/dec for planar devices. Lower values of SS can be reached with tunnel-junction devices.

The researchers suggest that the junctionless/heterostructure-free architecture reduces the effect of interface traps, but they also point out that the effect on subthreshold swing of such structures is the subject of controversy in the research community.

With a $1 \mu\text{m}$ gate-length and $2 \mu\text{m}$ gate-drain underlap,

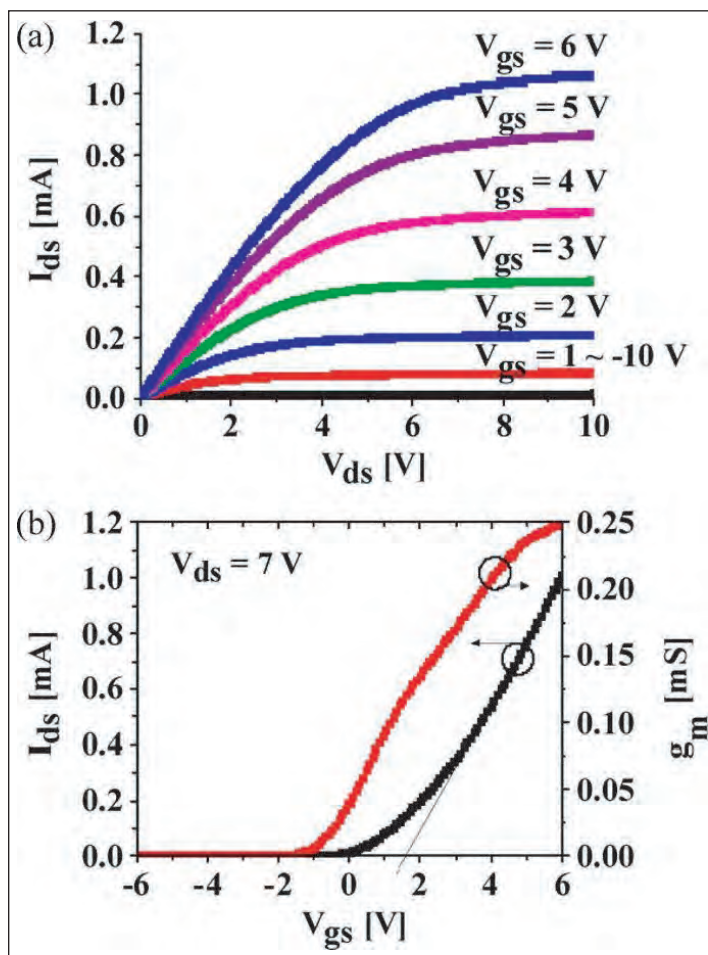


Figure 2. (a) Drain current and voltage characteristics of GaN FinFET with $1 \mu\text{m}$ gate length, 60nm fin width, and five parallel fins. (b) Transfer curves of drain current and transconductance with gate voltage at 7V drain.

the off-state (-3V gate) breakdown voltage was $\sim 280\text{V}$. The researchers believe that the breakdown point could be increased with longer gates, but at the price of lower on-current. Field-plates and gate recessing are other strategies that could increase breakdown voltages.

Gate leakage at -13V gate potential was only 10^{-12}A , despite the extremely thin 20nm Al_2O_3 gate insulation. ■

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Air-bridge to improve field-plate performance for nitride HEMTs

Breakdown voltage increased from 125V to 375V and stability at raised temperature improved compared with conventional design with source field-plate.

Researchers in China and Canada have developed air-bridge field plates for nitride semiconductor high-electron-mobility transistors (HEMTs) that increase the breakdown voltage and offer more stable performance at raised temperatures [Xie Gang et al, Chin. Phys. B Vol. 22, p026103, 2013]. The work was carried out between Zhejiang University, University of Toronto, and University of Electronic Science and Technology of China.

Field plates are used to manipulate electric field distributions in HEMTs. With suitable designs, the peak value of the electric field can be reduced, allowing greater voltages to be sustained. However, such structures can add parasitic side-effects such as increased capacitance between the terminals. The air-bridge field plates were proposed as an attempt to reduce some of these effects.

The researchers produced HEMTs with conventional field plates (CFP, Figure 1a) and air-bridge field plates (AFP, Figure 1b). Both FPs were connected to the source terminal. The aluminium gallium nitride (AlGaN) barrier in the epitaxial structure had 28% Al mole fraction. The sheet carrier density and mobility from Hall measurements were $1.1 \times 10^{13}/\text{cm}^2$ and $1800 \text{ cm}^2/\text{V}\cdot\text{s}$, respectively.

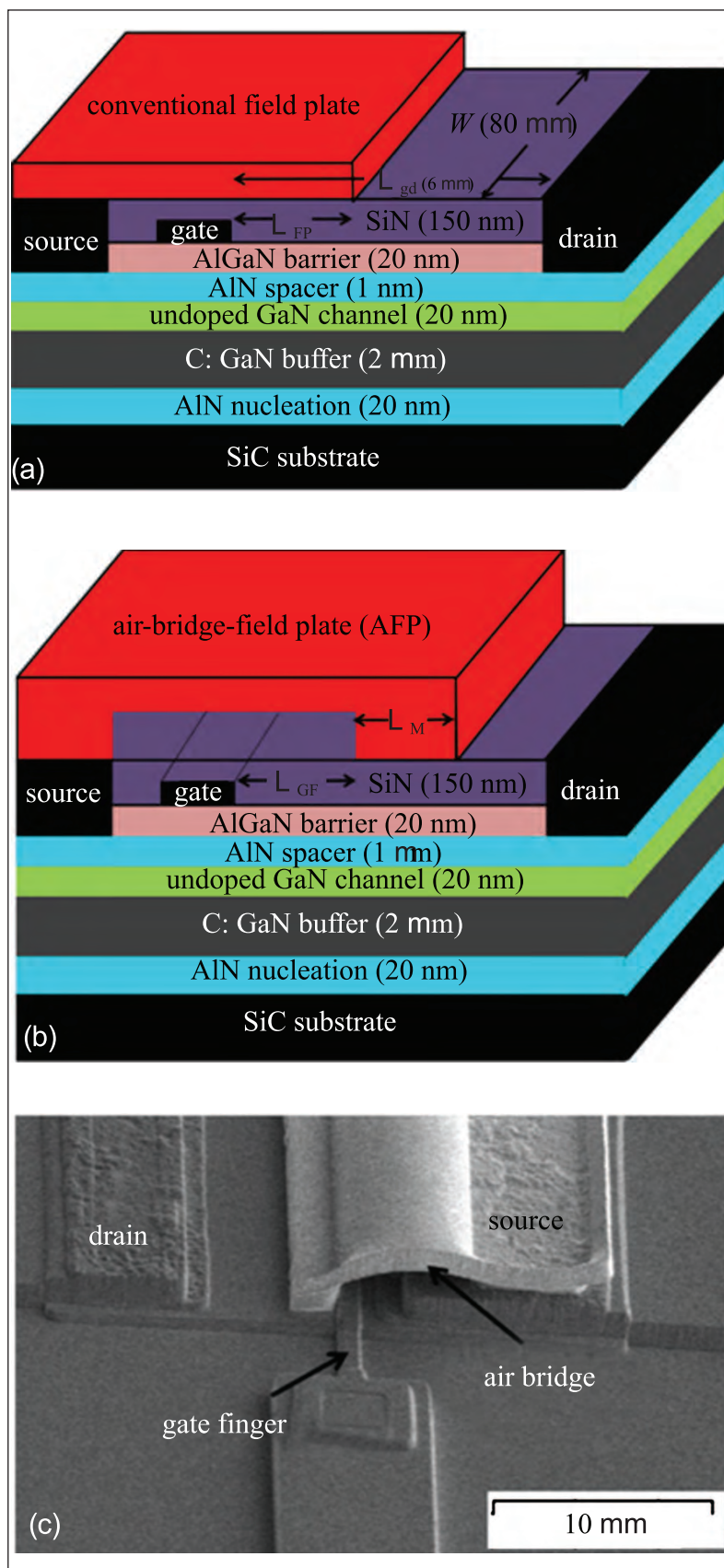


Figure 1. Cross-sectional view of proposed HEMT structure: (a) with a CFP, where L_{FP} is FP length. (b) AlGaN/GaN HEMT with novel AFP, where L_{GF} , L_M and L_{GD} are the gate-to-air-bridge field-plate distance, air-bridge footprint width, and gate-drain distance (drift region), respectively. (c) SEM view of fabricated novel AFP HEMT.

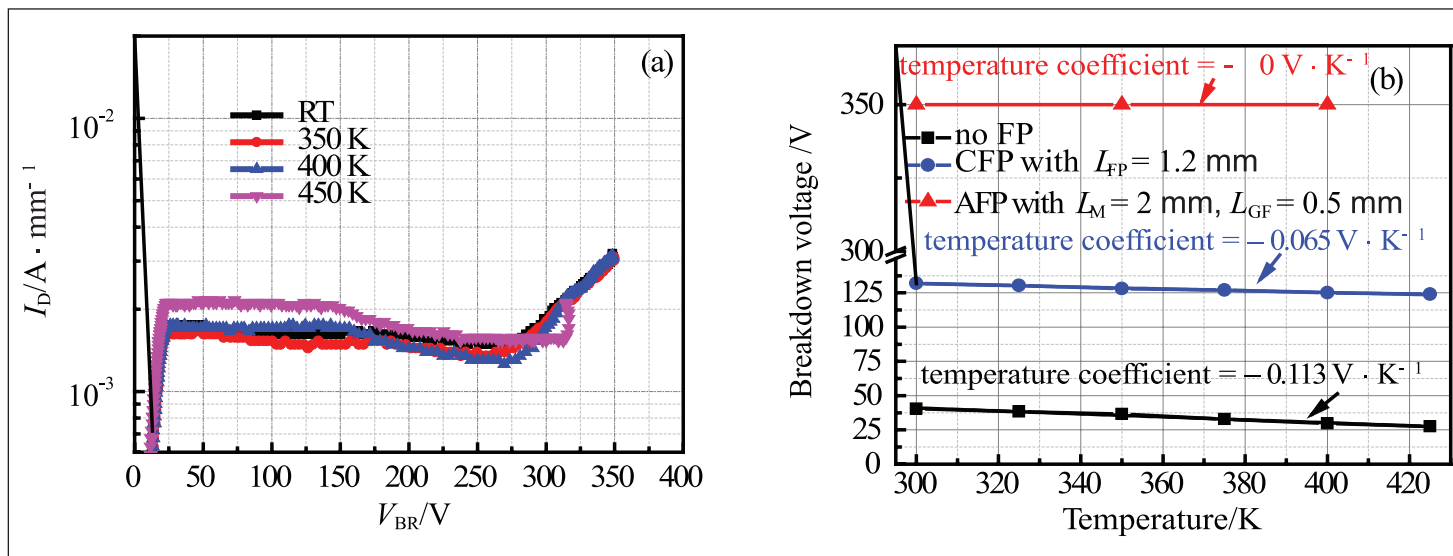


Figure 2. Measured breakdown voltage with different temperatures for (a) HEMT with AFP, (b) temperature coefficient of breakdown voltage for conventional HEMT (no FP), HEMT with CFP, HEMT with AFP, respectively.

The ohmic source–drain contacts of the devices consisted of titanium/aluminium/nickel/gold annealed at 850°C for 30 seconds in nitrogen. The Schottky gate electrode was platinum. Silicon nitride passivation was applied using plasma-enhanced chemical vapor deposition (PECVD). The field-plate structures were made from 1000nm-thick gold.

“The fabrication process for the AFP HEMT is fully compatible with the commercial RF GaN technology without the need for any additional photolithography or processing steps,” the researchers report.

Using an air-bridge greatly reduced the gate–source capacitance compared with conventional field plates due to air having the lowest dielectric constant of essentially 1.

Measurements and simulations with varied field-plate parameters suggested optimum values of 2 μm for the AFP footprint (LM) and a gate–FP distance of 0.5 μm (LGF). For the CFP devices, the optimum FP length (LFP) was 1.2 μm . The effects of varying these parameters in simulations were to alter the heights of field peaks near the gate and field-plate edges. It is these field peaks that are responsible for device breakdown.

The other device parameters were a source–gate distance of 1.1 μm , gate length of 0.8 μm , gate width of 80 μm , and gate–drain distance of 6 μm .

The off-state breakdown (–5V gate potential) was 37V for a HEMT without FP, 125V with optimum CFP, and 375V with optimum AFP. The drain leakage for the HEMT without FP was 10^{-2}A/mm before breakdown. A similar current level was seen with the CFP. However, for the AFP device, the drain leakage was one order of magnitude lower.

The researchers also carried out measurements at raised temperatures (Figure 2). The breakdown performance with AFP is almost constant up to 400K. The researchers believe that this is because the AFP suppresses the drain-side gate-edge electric-field-induced gate-to-channel hot carrier injection. Increasing the temperature to 450K reduced the breakdown to 320V. The lower breakdown was attributed to increased gate leakage at higher temperatures.

By contrast, HEMTs without FP and with CFP showed degraded breakdown with raising the temperature at rates of –0.113V/K and –0.065V/K, respectively. ■

<http://iopscience.iop.org/1674-1056/22/2/026103>

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Diode embedding in nitride transistor to reduce parasitic inductance

A nitride transistor with an embedded Schottky barrier diode shows promise for monolithic high-efficiency energy converters and inverters.

South Korea's Hongik University has developed a nitride semiconductor device on silicon with an embedded Schottky barrier diode (SBD) [Bong-Ryeol Park et al, Appl. Phys. Express, vol6, p031001, 2013].

The device was designed as a normally-off switching transistor in forward operation and as a diode in reverse operation. One such component was able to withstand voltages up to 966V before breakdown. The research team suggests that two such switching devices could be used to implement a single-phase half-bridge DC-AC inverter circuit. Other possible applications include DC-DC energy conversion.

"The proposed device is very promising for use in high-efficiency monolithic converter

and inverter ICs; eliminating the external diode can dramatically reduce the chip size, minimizing the parasitic inductance and thus allowing fast switching

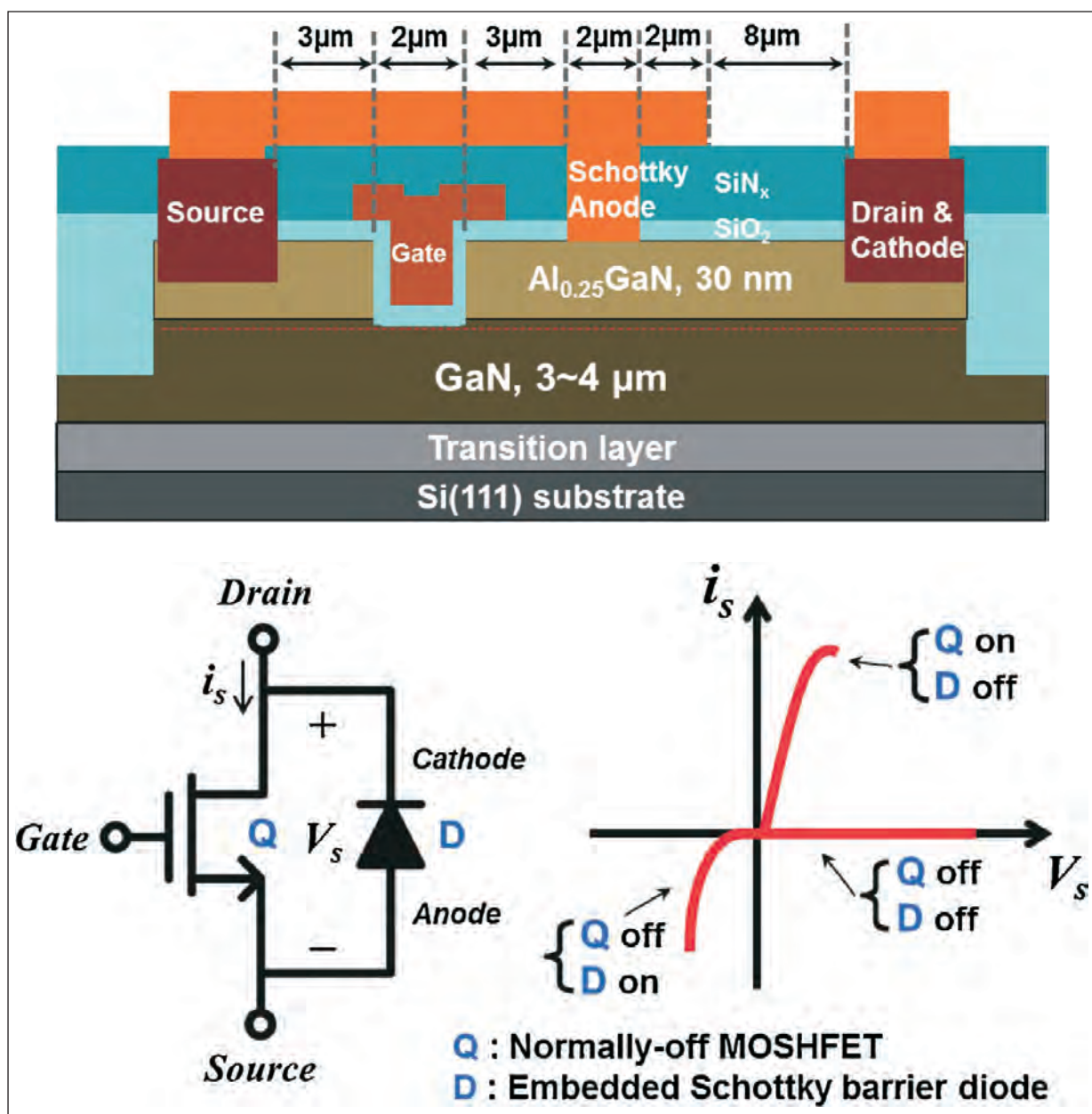


Figure 1. Cross-sectional schematic, equivalent circuit, and current-voltage (I-V) characteristics of SBD-embedded AlGaN/GaN-on-Si power switching device.

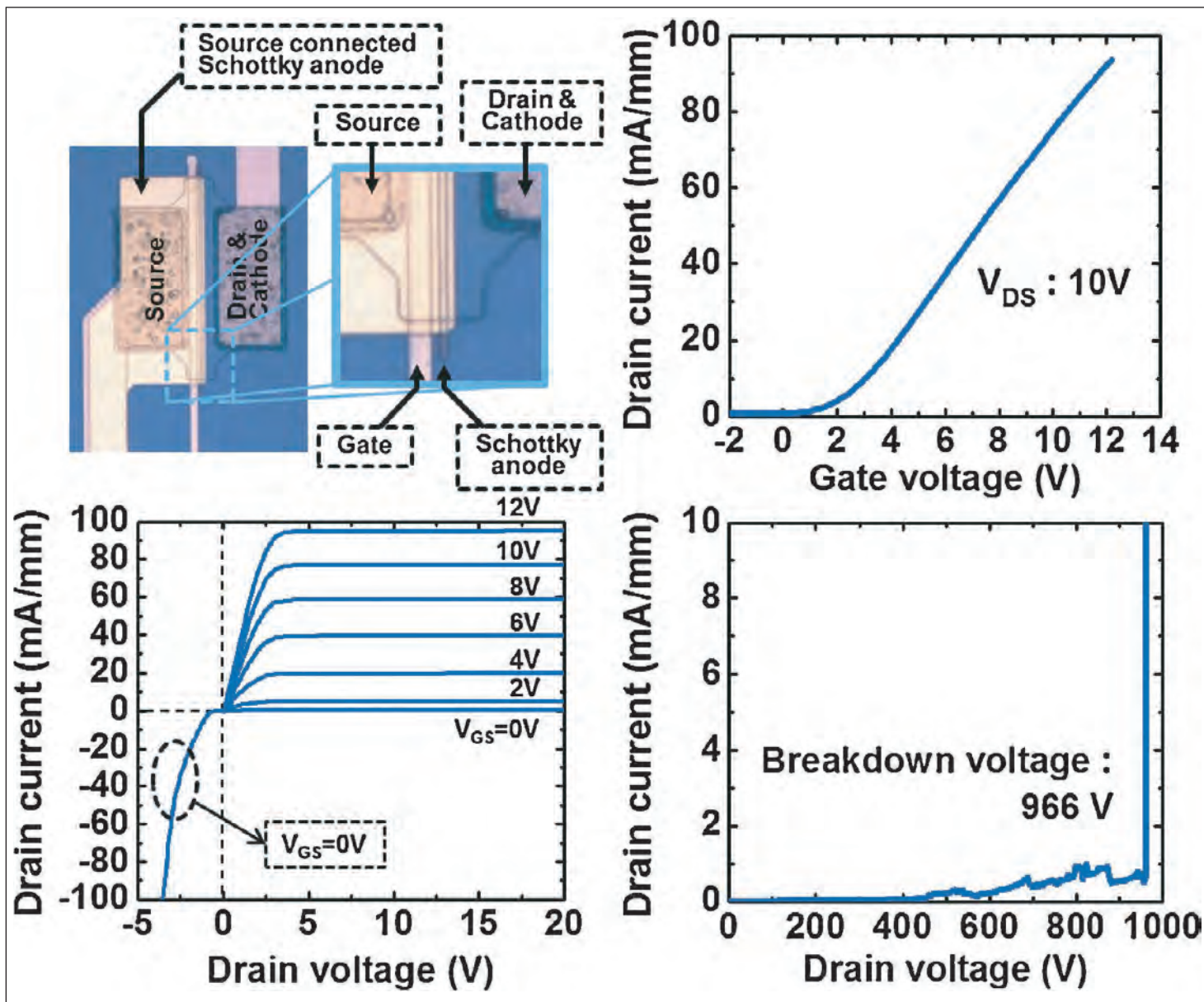


Figure 2. (a) Microscopy image of fabricated device, (b) transfer and (c) forward and reverse I–V, and (d) off-state breakdown characteristics of a fabricated device.

operation,” they write.

The epitaxial structure was created on p-type (111) silicon (Figure 1). The devices were isolated using low-damage mesa inductively coupled plasma (ICP) reactive ion etch. Normally-off operation of the transistor was achieved by etching through the aluminium gallium nitride ($Al_{0.25}Ga_{0.75}N$) barrier. The etched structure was covered by 30nm of silicon dioxide (SiO_2) insulation using ICP chemical vapor deposition (CVD). The ohmic source–drain metals were silicon/titanium/aluminium/molybdenum/gold annealed at 850°C for 30 seconds. The gate and pad regions were nickel gold.

A further 180nm insulation layer of silicon nitride (SiN_x) was applied. The Schottky anode and cathode regions of the embedded diode were then ICP reactive-ion etched into the SiN_x . The anode was electrically connected to the source terminal of the transistor. The cathode was overlaid on top of the drain terminal.

The metallization for the embedded diode consisted of nickel/gold.

The transistor turned on at 2V with an on-resistance of $5.2m\Omega\cdot cm^2$. The 1mA/mm forward turn-on voltage of the Schottky barrier diode was 0.8V. A device with 10 μm anode-cathode distance had off-state (0V gate) breakdown at 966V (Figure 2).

The researchers see an advantage of their device as being the ability to independently adjust the turn-on voltages of the transistor and diode. The transistor turn-on is affected by the recess depth and the gate insulator thickness. The diode turn-on is determined by the Schottky metal structure. This variability could allow optimization of the epitaxial design and device structure to improve performance characteristics. ■

<http://apex.jsap.jp/link?APEX/6/031001>

Author: Mike Cooke

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Fax: +1 919 789 8881
www.kymatech.com

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Fax: +1 480 899 0779
www.nikkomaterials.com

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Fax: +49 (0) 9131 / 73 22 37
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sp3 Diamond Technologies

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www.sesmi.com

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The Fox Group Inc

(see section 3 for full contact details)

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Fax: +33 (0)1 69 31 61 79
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Mining & Chemical Products Ltd (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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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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9 Materials & metals

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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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14 Chip test equipment

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SUSS MicroTec Test Systems

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Waterbury Center, VT 05677,
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www.suss.com

15 Assembly/packaging materials

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Fax: +1 512 231 8183
www.epak.com

Gel-Pak

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Wafer World Inc

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16 Assembly/packaging equipment

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Fax: +1 215 784 6001
www.kns.com

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17 Assembly/packaging foundry

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www.quikicpak.com

18 Chip foundry

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www.csmantech.org

2–5 June 2013

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Technology Centre in Aachen, Germany

E-mail: ewmvpe2013@jara.org

www.jara.org/index.php?id=606

2–7 June 2013

IEEE MTT-S 2013 Microwave Week, including: International Microwave Symposium (IMS); Radio Frequency Integrated Circuits (RFIC) Symposium

Seattle, WA, USA

E-mail: tom@seaporttech.com

www.ims2013.org

5–6 June 2013

SEMICON Russia 2013

Moscow, Russia

E-mail: eweller@semi.org

www.semiconrussia.org/en

9–11 June 2013

International SiC Power Electronics Applications Workshop (ISiCPEAW 2013)

Stockholm, Sweden

E-mail: karin.pagard@acreo.se

www.b2match.eu/isicpeaw2013

11–14 June 2013

2013 Symposia on VLSI Technology and Circuits

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www.vlsisymposium.org

24–25 June 2013

euroLED 2013

The ICC, Birmingham, UK

E-mail: info@euroled

www.euroLED.org.uk

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9–11 July 2013

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www.greenworldconferences.com

1–3 August 2013

SOLARCON India 2013

KTPO Exhibition Complex, Bangalore, India

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www.solarconindia.org

4–10 August 2013

15th Summer School on Crystal Growth (ISSCG-15)

Gdansk, Poland

E-mail: isscg15@mif.pg.gda.pl

<http://science24.com/event/isscg15>

5–6 August 2013

SolarTech Expo Spain 2013

Valencia, Spain

E-mail: ds@greenworldconferences.com

www.greenworldconferences.com

11–16 August 2013

17th International Conference on Crystal Growth and Epitaxy (ICCGE-17)

Warsaw, Poland

E-mail: iccg17sec@mail.unipress.waw.pl

<http://science24.com/event/iccg17>

25–29 August 2013

SPIE Optics + Photonics 2013

San Diego Convention Center, CA, USA

E-mail: customerservice@spie.org

<http://spie.org/optics-photonics.xml>

4–6 September 2013

SEMICON Taiwan 2013 and LED Taiwan 2013

TWTC Nangang Exhibition Hall, Taipei, Taiwan

E-mail: ali@semi.org

www.semicontaiwan.org/en

8–12 September 2013

IEEE Photonics Society's annual Photonics Conference (IPC-2013, formerly the IEEE LEOS Annual Meeting)

Hyatt Regency Bellevue Hotel, Seattle, WA, USA

E-mail: m.hendrickx@ieee.org

www.ipc-ieee.org

22–26 September 2013

39th European Conference on Optical Communications (ECOC 2013)

ExCeL London Exhibition Centre, London, UK

E-mail: carina.meakins@nexusmediaevents.com

www.ecoc2013.org

23–26 September 2013

SPIE Remote Sensing 2013, co-located with SPIE Security+Defence 2013

Internationales Congress Centre Dresden, Germany

E-mail: info@spieeurope.org

<http://spie.org/remote-sensing-europe.xml>

<http://spie.org/security-defence-europe.xml>

23–26 September 2013

5th International Conference on One dimensional Nanomaterials (ICON 2013)

Annecy, France

E-mail: icon2013@grenoble.cnrs.fr

www.icon2013.fr

24–26 September 2013

3rd International LED professional Symposium + Expo (LpS 2013)

Bregenz, Austria

E-mail: symposium@led-professional.com

www.led-professional-symposium.com

30 September – 4 October 2013

28th European Photovoltaic Solar Energy Conference and Exhibition (EU PVSEC 2013)

Parc des Expositions Paris Nord Villepinte, Paris, France

E-mail: press@wip-munich.de

www.photovoltaiac-conference.com

1–2 October 2013

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Mexico City, Mexico

E-mail: ds@greenworldconferences.com

www.greenworldconferences.com

1–3 October 2013

IEEE Photonics Society's Avionics, Fiber-Optics & Photonics Conference (AVFOP 2013)

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