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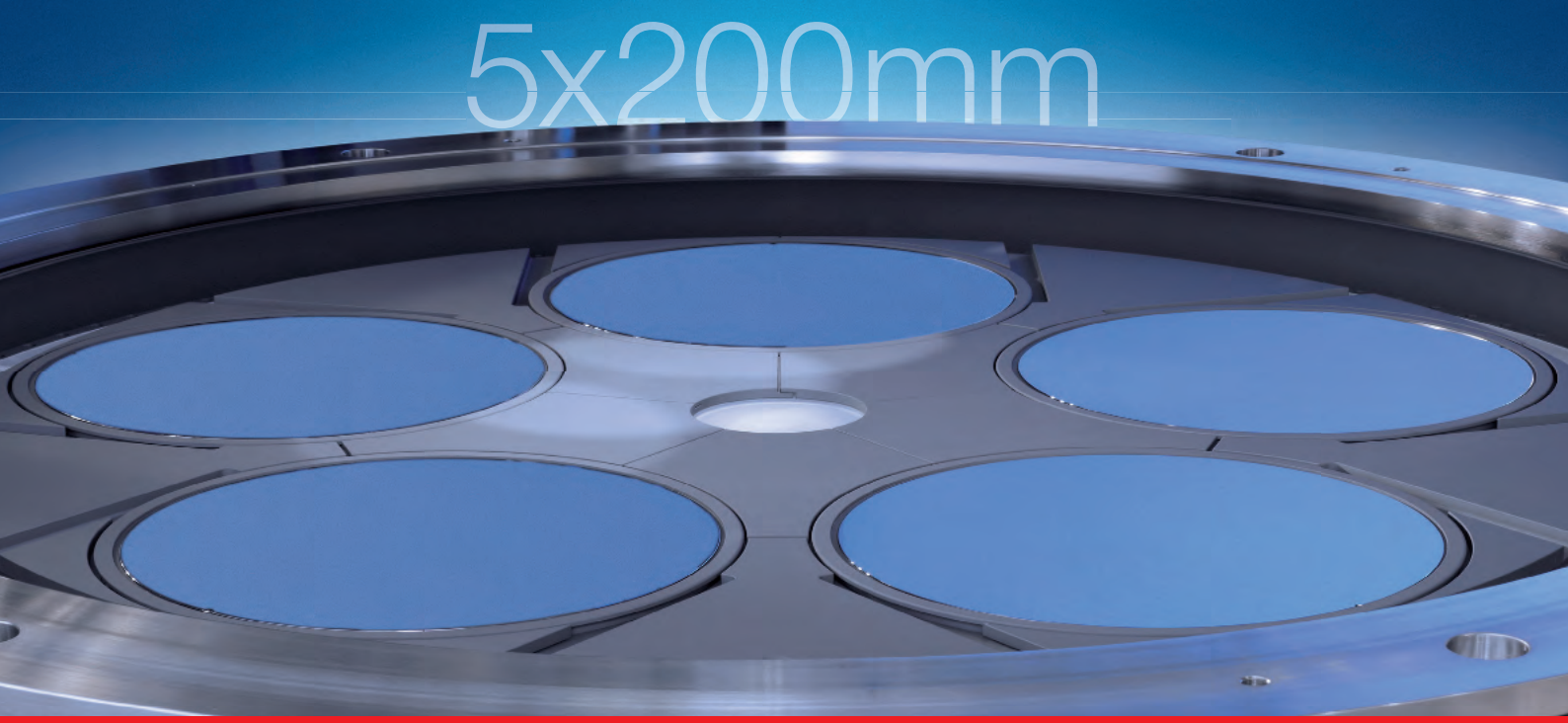

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ALWAYS ONE STEP AHEAD

editorial view

by Dr Richard Stevenson, Editor

Which way forward?

The revolution in solid-state lighting is no longer a question of if, but when. So the big question now must be this: What class of emitter is going to drive the revolution?

I've just arrived back from the big nitride show of the year, the International Conference on Nitride Semiconductors (ICNS), and one of the most important points that I took away from that 900-strong meeting was the wide variety of solid-state emitters that have a strong chance of being used for lighting.

Today, everyone agrees that the cost-per-lumen is too high for mass adoption of solid-state technology, and the devices of tomorrow are going to have to do much better. LEDs are already moving in this direction, with Cree, for example, making gains of about 40 percent per year, based on the lumen-per-watt metric.

Another option for cutting costs is to switch the substrate to silicon: It is cheaper, available in a far larger diameter, and allows processing of the wafers in under-utilised silicon fabs. The problem with GaN-on-silicon LEDs has been a lag in performance over the incumbents, but that gap is closing fast.

According to speakers at ICNS, devices made in the labs of Osram and Samsung are now both within touching distance of their sapphire-based cousins.

It may be that the best way forward is to ditch the blue-LED-and-phosphor-combo, and move to colour mixing of red, green and blue chips. This promises higher efficiencies and colour tunability, but it is held back by the poor efficiency of green LEDs. Maybe this could change, however, following development of nitride-based yellow LEDs at Samsung that feature a very thin AlGaN layer between the wells and barriers. This modification to the active region helps to propel efficiency to almost 20 percent.

By far the most radical vision for the future is being put forward by Sandia National Labs: Use lasers, not LEDs, for lighting. The thinking behind this is that lasers perform better than LEDs at very high current densities, because it is only the latter that suffers from droop – a decline in efficiency as the current is cranked up.

German automaker BMW is already developing laser-based headlights, and it will be interesting to see if any firms in the lighting business start to follow suit in order to trim chip costs. I, for one, bet that the evolution of the solid-state lighting industry is going to take a few twists and turns this decade.

Editor Dr Richard Stevenson richardstevenson@angelbc.com +44 (0)1291 629640

Contributing Editor Dr Rebecca Pool editorial@rebeccapool.com
News Editor Dr Su Westwater suwestwater@angelbc.com
Director of SEMI Publishing Jackie Cannon jackie.cannon@angelbc.com +44 (0)1923 690205

Senior Sales Executive Robin Halder robin.halder@angelbc.com +44 (0)2476 718109

Sales Manager Shehzad Munshi shehzad.munshi@angelbc.com +44 (0)1923 690215

USA Rep: Brun Media: Tom Brun E: tbrun@brunmedia.com Tel: +001 724 539-2404
Janice Jenkins E: jjenkins@brunmedia.com Tel: +001 724-929-3550

Director of Logistics Sharon Cowley sharon.cowley@angelbc.com +44 (0)1923 690200

Design & Production Manager Mitchell Gaynor mitch.gaynor@angelbc.com +44 (0)1923 690214

Circulation Director Jan Smoothy jan.smoothy@angelbc.com +44 (0)1923 690200

Circulation & Subscriptions Assistant Annette Weatherilt annette.weatherilt@angelbc.com +44 (0)1923 690220

Chief Operating Officer Stephen Whitehurst stephen.whitehurst@angelbc.com +44 (0)2476 718970

Directors Bill Dunlop Uprichard – CEO, Stephen Whitehurst – COO, Jan Smoothy – CFO, Jackie Cannon, Scott Adams, Sharon Cowley, Sukhi Bhadal

Published by Angel Business Communications Ltd,
Hannay House, 39 Clarendon Road, Watford, Herts WD17 1JA, UK.
T: +44 (0)1923 690200
F: +44 (0)1923 690201
E: ask@angelbc.com

Angel Business Communications Ltd
Unit 6, Bow Court, Fletchworth Gate, Burnsall Road, Coventry CV5 6SP, UK.
T: +44 (0)2476 718 970 F: +44 (0)2476 718 971 E: info@angelbc.com

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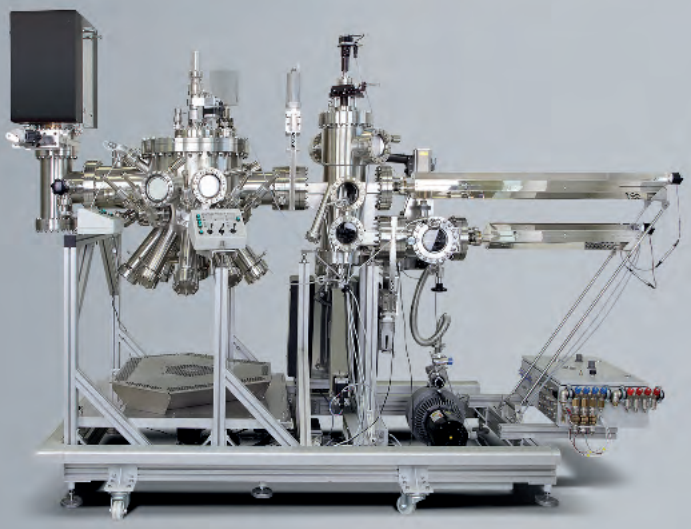

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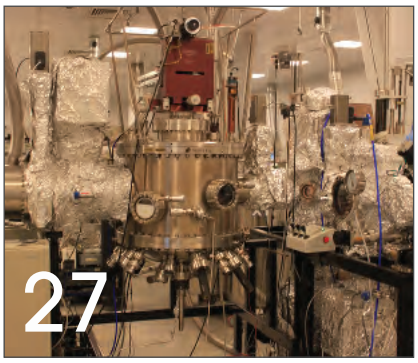

Magazine and Front Cover designed by Mitch Gaynor

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research review

RFMD to convert all GaN processes to 6-Inch GaN-on-SiC

RFMD has introduced what it says is the world's first 6-inch GaN-on-SiC wafers for manufacturing RF power transistors for both military and commercial use.

The company is converting all GaN production and development to 6-inch diameter wafers using its existing high-volume, 6-inch GaAs foundry to reduce platform cost for the growing GaN device market.

"We are pleased to introduce the industry's first 6-inch GaN-on-SiC RF technology on RFMD's existing high-volume 6-inch GaAs manufacturing line," says Bob Bruggeworth, president and CEO of RFMD.

"This merging of production of GaN and GaAs is part of our 'GaN-in-GaAs Fab' strategy to repurpose existing fab capacity to better address growth opportunities from innovative new GaN-based products."

According to industry analyst firm Strategy Analytics, the GaN microelectronics market is expected to more than triple to $334 million by 2017, representing a compound annual growth rate (CAGR) of 28 percent.

This market growth is led by growth in both military (radar, electronic warfare, communications) and commercial (power management, cellular, CATV, land mobile radios) applications.

"By leveraging our technology leadership and high-volume expertise in 6-inch GaAs production, RFMD will now be able to add 6-inch GaN capabilities to deliver new RF Power products that we expect will accelerate revenue growth in our communications, CATV, power conversion, radar, jamming, aerospace and open foundry businesses," comments Jeff Shealy, vice-president of RFMD Power Broadband.

GaN technology supports broad frequency bandwidths and high breakdown voltages in a small area. A 6-inch GaN wafer offers 2.5-times more useable area over competing 4-inch GaN wafer platforms currently available, resulting in 2.5 times more RF power devices per wafer.

Larger area-per-wafer and subsequent lower cost per unit area (in dollars per square millimetre) is critical to enabling affordable, high performance power monolithic microwave ICs (MMICs) for military and commercial applications.

RFMD expects to complete qualification of its 6-inch GaN platforms in 2014.

Oclaro mass producing narrow linewidth InP tuneable lasers

OCLARO has started volume production of its next generation tuneable laser platform.

This new narrow linewidth micro-iTLA (Integrable Tunable Laser Assembly) is specifically targeted for coherent systems, where a high performance laser is needed for both the transmission and the local oscillator laser.

The Oclaro micro-iTLA features high optical output power and off-grid tuning suitable for applications in 100G and next generation 200G coherent networks based on the PM-QPSK and 16-QAM modulation formats.

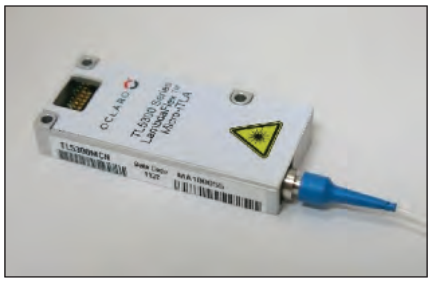
"100G coherent shipments are increasing dramatically, and we expect that shipments in 2014 will be above 40,000 ports," says Daryl Inniss, Practice Leader for Components at Ovum Ltd.

"Each of these coherent ports will require one or two narrow linewidth lasers, and we're excited to see component manufacturers such as Oclaro support the growth of 100G by introducing and ramping production of components such as this narrow linewidth micro-iTLA."

"We are pleased to have successfully completed qualification, and are actively engaged with multiple customers and have completed several design-wins with our new tunable laser platform," adds Yves Hardy, VP of Transmission Product Management at Oclaro.

"With this product offering, Oclaro is simplifying the migration to coherent at both the line card and module level, and the technology is also enabling next generation 100G and 200G pluggable form factors."

The Oclaro micro-iTLA is compliant to the OIF Multi-Source Agreement, and incorporates a form factor which is three times smaller than the standard iTLA and has a significantly reduced power consumption, both of which enable further size reductions in coherent modules to be supported while reducing thermal concerns.



Oclaro Narrow Linewidth Micro-iTLA

The ultra-high optical power output, combined with power and frequency fine tuning, gives greater flexibility to network designers.

The reliability of the InP chip technology and packaging allows customers to be confident that they are manufacturing high reliability systems.

This platform is part of the roadmap of next generation products that builds on the legacy of Oclaro's InP portfolio that is used extensively in the market today.

The micro-iTLA has been shipping to key customers throughout 2013. Oclaro is currently ramping micro-iTLA production to support market demand in the fourth quarter of 2013.

Oclaro sells GaAs Zurich laser diode business to II-VI

OCLARO, a provider of optical communications solutions has sold its Oclaro Switzerland GmbH subsidiary and associated laser diodes business to II-VI Incorporated. The transaction was valued at $115 million. What's more, II-VI acquired an exclusive option to purchase Oclaro's optical amplifier and micro-optics business for $88 million in cash. "The sale of our gallium arsenide laser diode business is an important first step in our plan to restructure the company," says Greg Dougherty, CEO, Oclaro. "The Zurich-based business, including the team and its rich legacy, is a valuable asset and we wish II-VI and the team much future success. We will use the proceeds from the sale to fully repay our bridge financing and to begin restructuring the company for the future. We intend to further simplify our operating footprint, reduce our cost structure and focus our R&D investment in the optical communications market where we can leverage our core competencies."

Of the total transaction value of $115 million, Oclaro received $92 million in cash Oclaro will retain the existing accounts receivable of the business, estimated at approximately $15 million. The remaining $8 million is being held by II-VI subject to traditional post-closing conditions.

As part of the agreement, II-VI has purchased the Oclaro Zurich, Switzerland company, which includes its GaAs fabrication facility, and also the corresponding high power laser diodes, VCSEL and 980nm pump laser product lines, including intellectual property, inventory, equipment and a related R&D facility in Tucson all of which are associated with these businesses ("the Zurich business"). Revenues for the Zurich business were approximately $87 million for the fiscal year ended June 29th, 2013.

Oclaro will continue the back-end manufacturing of the 980nm pump and some high power laser diode products at its Shenzhen, China manufacturing facility and supply them to II-VI under a manufacturing services agreement. The employees of Shenzhen, China will continue to be employed by Oclaro. In addition, various supply and transition service agreements have been established between the companies to ensure a smooth transition.

The option to purchase Oclaro's optical amplifier and micro-optics business, for which II-VI separately paid $5 million in cash, will expire if not exercised within 30 days. If this option is exercised and II-VI purchases the amplifier and micro-optics business, the option price will be applied to the purchase price. If II-VI does not exercise this option, the $5 million payment will be retained by Oclaro.

Total proceeds received by Oclaro were $97 million. Foros and Imperial Capital acted as financial advisors to Oclaro.

Soitec launches 31.8% III-V solar module

SOITEC has announced its latest CPV module featuring a record power-generating efficiency of 31.8 percent. The new module, which is already in industrial volume production, is claimed to deliver the highest efficiency of any commercial product available for multi-megawatt installations.

Using an optimised anti-reflective coating, Soitec's CX-M500 module increases nominal peak power output over previous generations from 2,335 Wp to 2,450 Wp. The new module has been certified according to the International Electrotechnical Commission's (IEC) and Underwriters Laboratories' (UL) standards (IEC 62108, IEC 62688, UL 62108 and UL SU 8703), confirming that it meets product safety, performance and reliability requirements in both the US and European markets.

"With this new product, Soitec is continuing to raise the bar for solar-power efficiency and, looking ahead, the potential for further improvement is significant, " says Gaetan Borgers, executive vice president of Soitec's Solar Energy Division. " Based on our current work in solar-cell development, we are well positioned to achieve even higher module efficiencies in the near future. With our newest commercial modules and their higher efficiencies, we are delivering on our cost-competitiveness roadmap. "

Soitec's new module complies with the California Solar Initiative, so power-plant installations using it can qualify for performance-based incentives from the California Energy Commission (CEC). The module also bears the CE mark, indicating its compliance with the relevant European Union directives, regulations and standards.

Using Soitec's III-V Concentrix technology, each Soitec CPV module comprises a Fresnel lens plate and a bottom plate on which high-performance solar cells are mounted. The Fresnel lenses focus sunlight concentrated by a factor of 500 on the solar cells beneath. The cells are precisely mounted on the bottom plate, enabling the focused sunbeam to align perfectly with the tiny solar cells. In constructing its modules, Soitec uses elements from the circuit board and dual pane window industries, which are both cost effective and have been proven reliable over many years.

The modules are used in assembling Soitec CPV systems. Soitec's tracker-based systems are designed to build high-capacity solar-power plants with low construction and maintenance costs. Soitec's CPV systems can significantly improve the Levelised Cost of Electricity (LCoE) for mid-sized to very large solar-power plants. With installations in 18 countries around the world, Soitec's CPV technology has proven its competitiveness to generate solar power, largely due to its higher production yields throughout the sunlight hours

CPV technology's abilities to operate without cooling water, withstand hot ambient temperatures and have minimal environmental impact make it perfectly suited for use in environmentally sensitive desert areas. Soitec recently announced the signature of a performance-warranty insurance contract with Munich Re, which will ease financing of solar projects using the company's CPV modules.

New process could increase mobility beyond 10nm MOS devices

KULeuven, imec and AIST have developed a solid phase epitaxy process to integrate germanium tin (GeSn) metal-oxide semiconductor field-effect transistor (MOSFET) devices on silicon.

For the first time, operation of depletion-mode junctionless GeSn pMOSFET on silicon was demonstrated, which is a step toward achieving tensile strain in MOSFET devices, and increasing their mobility.

To improve performance in next-generation scaled complementary metal-oxide semiconductor (CMOS) devices, researchers are exploring the integration of novel materials with superior electron mobility. This includes GeSn, a promising semiconductor candidate as channel material, due to its superior physical properties.

GeSn enables increased switching speed of MOSFET devices and can be used in fast optical communication. While most prototype GeSn channel MOSFETs are fabricated on germanium substrates, silicon integration is preferred for CMOS compatibility.

However, epitaxial growth of GeSn on silicon substrates poses several challenges, including limited solubility of tin in germanium (0.5 percent), its compositional fluctuations, tin segregation, and large lattice mismatch (over 4 percent). Therefore, it is critical to suppress these effects to obtain high performance devices with GeSn layers.

Researchers from KULeuven, imec and AIST developed a solid phase epitaxy process, achieving ultrathin (greater than 10nm) single-crystalline GeSn layers on silicon substrates showing tensile strain, attractive for strain engineering of germanium channels.

TEM image of NiGeSn metal S/D MOSFET. TEM is observed along [11-2], the channel direction is [-110] and the surface orientation is (111)

This reduces the difference between the direct and indirect band transition, resulting in acquisition of a direct band gap group IV material. Lastly, due to its non-equilibrium deposition conditions, the new method enables the development of GeSn with high tin concentrations.

By decreasing the channel thickness with reactive ion etching (RIE) from ~30 to ~10nm, the researchers improved the on/off ratio by more than one order of magnitude.

Also, hole depletion in the ultrathin (~10nm) GeSn layers on silicon resulted in good transfer characteristics with an on/off ratio of 84. In the future, research will focus on optimizing the GeSn MOSFET on silicon devices to further increase the channel mobility.

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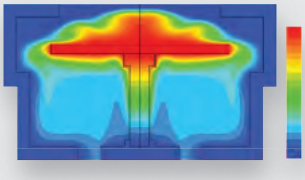

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Cree's new XLamp LED arrays double lumen density

CREE has announced what it says is the industry's first High-Density (HD) LED Arrays - a breakthrough technology that doubles the system intensity of spot lights compared to previous arrays. The new HD class of CXA Arrays provide unrivalled lumen density, enabling reduction in system cost and power consumption. The first HD Array, the CXA1520 LED, enables manufacturers to create a new generation of products that delivers the same intensity and light quality as 39-W ceramic metal halide (CMH) at up to 50 percent lower power.

CXA1520 LED

"The new CXA1520 LED Array delivers an impressive amount of light from a small source. I have not seen another integrated array that can match this level of lumen density," says Mark Groenke, VP of engineering at ConTech Lighting.

"The CXA1520 LED Array enables ConTech Lighting's newest LED fixtures to exceed the efficiency and life of our ceramic metal halide fixture offerings while maintaining intensity and colour quality."

The High-Density Cree XLamp Array extends Cree's CXA family to give lighting manufacturers a single integrated array family to address lighting applications from general-purpose floods to specialty retail spot lights. Cree XLamp CXA1520 LED Arrays deliver up to 3478 lumens at 33 watts, 85°C. Available in ANSI White and four-step EasyWhite binning, the new arrays feature 2700 K through 5000 K CCTs, with 70, 80 and 95-CRI options.

"We have several CXA1507 and CXA1512 LED array designs, and we're excited that the new CXA1520 LED Array shares the same light-emitting size as the CXA1507 and CXA1512 LED Arrays," says Tom Tang, chairman and CEO, Tons Lightology, Inc. "This allows us to address very-high output applications without changing the optics."

New approach for solar cell material

CUBIC SiC may host a new approach for a highly efficient solar cell material. Theory has shown that cubic SiC may act as a highly efficient solar cell material if doped with boron. This has not been explored since this semiconductor material is challenging to produce.

The photovoltaic properties interests the Norwegian research organisation SINTEF which has landed a 0.9 million research grant in the Energy X programme that targets innovative energy concepts. The programme runs under the Norwegian Research Council that selected four projects having breakthrough character among 49 applications.

State of the art quality cubic SiC was shown by the Swedish researchers at Linköping University last year using a method that they have developed. There are great challenges in keeping the stability of this material, and maintain quality while introducing dopants, says Mikael Syväjärvi that initiated the collaboration with the Norwegian organisation.

In Norway there is a lot of experience in solar cell technology, which matches our materials expertise, he adds about the partnership which includes the University of Oslo and Saint-Gobain Ceramic Materials AS. During the last three years, his research team has explored doped SiC for a white LED that has a pure white light and no need for rare earth metal, while at the same time being less influenced by the droop effect.

ABI: GaN to boost microwave RF power market

The gallium nitride power semiconductor market will grow to over $250 million by 2018. Spending on microwave RF power semiconductors has been kick-started by the availability of new GaN devices for 4 to 18 GHz.

Point-to-point communications, SATCOM, radars of all types and new industrial/medical applications will all benefit by the introduction of these high-power GaN devices, finds market intelligence firm ABI Research. "While gallium arsenide devices are presently the backbone of microwave RF power it is gallium nitride that will drive growth going forward," notes research director Lance Wilson. "GaN can operate at much higher voltages and at power levels that were difficult or impossible to reach using GaAs."

In addition to the above mentioned application segments, microwave GaN is finally reaching the performance points that can start to seriously challenge travelling wave tube applications for new designs that have historically used the latter.

"Microwave RF Power Semiconductors" examines Microwave RF power semiconductor devices that have power outputs of greater than 3 watts and operate at frequencies of 4 to 18 GHz. This is a new study, which is part of ABI Research's ongoing effort to track the major changes in the RF power industry.

With the current release, analysis of the six main vertical segments (C-Band GaAs, C-Band GaN, X-Band GaAs, X-Band GaN, Ku-Band GaAs, and Ku-Band GaN) is further expanded to 28 application sub-segments.

These findings are part of ABI Research's High-Power RF Active Devices Research Service , which also includes other Research Reports, Market Data, and analyst inquiry support.

Sol Voltaics wins $9.4 million in funding

SOL VOLTAICS has completed a total of $15.6 million (SEK 102 million) in fresh funding by adding $9.4 million in an equity round to the $6.2 million Swedish Energy Agency loan. This will take its Solink nanomaterial for increasing the performance and energy output of solar panels into pilot production.

The round was led by Umoe, an investment company based in Norway, which had previously made an incubation level investment in Sol Voltaics. Umoe now joins Industrifonden, Nano Future Invest and Foundation Asset Management as the major shareholders of the company. Kent Janér, cleantech investor and CEO of Nektar Asset Management, also became an investor, joining veteran solar industry technologist and executive Erik Sauar, as a new private investor in Sol Voltaics.

With the investment, Sol Voltaics has reached its 2013 funding goals set earlier in the year. In June, the Swedish Energy Agency (SEA), Sweden's national authority for energy policy issues, provided the company a $6.2 million (SEK 41 Million) conditional loan.
Sol Voltaics produces Solink, a GaAs additive for crystalline silicon or thin-film that enables modules to convert more of the sun's light into electricity.

To date, the challenge of advanced materials is that they have been expensive to produce and difficult to implement. Solink will increase efficiency of solar modules by up to 25 percent from current levels using miniscule amounts of these novel nanomaterials. Solink's Aerotaxy process for producing nanomaterials also dramatically reduces the cost of producing these materials while increasing uniformity and volume of production.

Solink is applied to conventional solar panels toward the end of the existing module production process with relatively inexpensive standard equipment.

Solink anticipates producing functional solar cells made from gallium arsenide nanowires for demonstration by the end of 2013. Commercial production of Solink-enhanced modules will begin in 2015 and move into volume production in 2016. Sol Voltaics develops novel nanomaterials for enhancing solar panels and other products.

The company was founded in 2008 and is focused on improving the economics of solar PV applications by generating a higher efficiency.

Sol Voltaics is currently a development stage company and has received venture capital funding from Foundation Asset Management, Industrifonden, Nano Future Invest, Provider Venture, Scatec, Teknoinvest and Umoe. The company is based in Lund, Sweden

GigOptix and MACOM finally bury the hatchet

M/A-COM Technology Solutions Holdings, Inc. (MACOM) and GigOptix, Inc., have agreed to a global settlement of all pending lawsuits between them.

The first lawsuit was filed by GigOptix last year against MACOM subsidiary Optomai, Inc. The filing related to three former employees of GigOptix who founded Optomai, Vivek Rajgarhia, Vikas Manan and Stefano D'Agostino, and MACOM, in Santa Clara County, for alleged misappropriation of trade secrets and breach of contract.

MACOM then hit back with a counterclaim in the Northern District of California, alleging that GigOptix' polymer technology was infringing on two patents in which MACOM claims rights.

The parties have agreed to file joint requests with the relevant courts to fully and finally dismiss both cases, with prejudice.

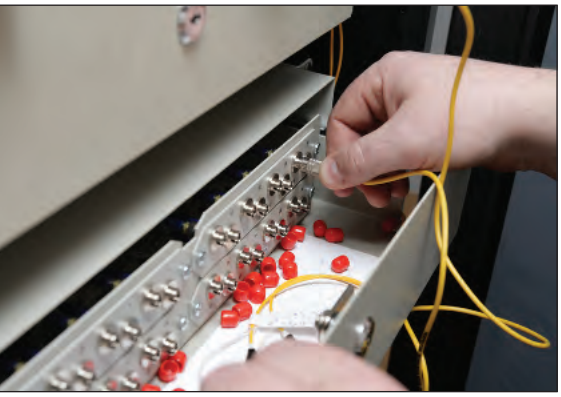
MACOM has agreed to make a one-time settlement payment of $7.25 million to GigOptix concurrently with the filing of the dismissals, which are expected to take place next week. Neither party will admit liability to the other and each side is satisfied with the confidential settlement reached between the parties.

MACOM is a supplier of high performance RF, microwave, and millimetre wave products while GigOptix is a supplier of advanced semiconductor and optical communications components.

TeraXion and Canadia unite on InP telecom research

TERAXION, a designer and manufacturer of optical components and modules, and the National Research Council of Canada (NRC) have formed a strategic partnership.

This will lead to the development and fabrication of TeraXion's new modulator products family and covers its next-generation InP high-speed modulators for coherent transmission systems at 100 Gb/s and beyond. Work will take place at NRC's Canadian Photonics Fabrication Centre in Ottawa. "Today's announcement is another important milestone supporting our strategy for rapidly delivering state-of-the-art high-speed modulators to our customers," says Iain-Jacques Simard, President and CEO of TeraXion Inc. "The Canadian Photonics Fabrication Centre's proven track record for bringing products to a commercialization level has been a key factor in our decision to rely on this partner".



"We are proud of this partnership with TeraXion and believe that combining our world-class process capabilities along with TeraXion's design expertise will deliver results in the marketplace," continues François Cordeau, General Manager of the Information and Communications Technologies portfolio at the National Research Council of Canada.

"The new modulator concept will use a proprietary design to achieve world record low power consumption as well as reaching very high modulation speeds necessary for 100 Gb/s and above transmission," adds Ian Woods, Vice-President InP Platform at TeraXion Inc. "In addition, the form factor of this modulator will be ten times smaller than the competing technologies available today. The new modulator design takes advantage of the unique process capabilities existing at the Canadian Photonics Fabrication Centre," explained Frank Shepherd, the Centre's Technical Manager.

TeraXion's team has previously demonstrated qualified products and so have a strong pedigree and credibility when it comes to modulator product development. Among the catalysts for this TeraXion-NRC partnership are the close geographical location of both partners and the strong photonic eco-system present in the Ottawa region which will contribute to forging a strong and highly effective partnership.
TeraXion designs, manufactures and markets optical components and modules for high-speed fibre-optic transmission networks, fibre lasers and optical sensing applications.
The Canadian Photonics Fabrication Centre provides engineering and manufacturing services, commercial grade prototyping and pilot-run production facilities for III-V semiconductors.

Kyma's AlN template production ramps up

KYMA TECHNOLOGIES has provided an update on its AlN template manufacturing capability.

The company is a domestic supplier of crystalline GaN and AlN template materials, as well as bulk GaN substrates.

Most of these products are fabricated beginning using Kyma's patent protected plasma vapour deposition of nanocolumns (PVDNC) crystal growth process which is implemented on Kyma's patented and proprietary PVDNC crystal growth tools.

The AlN templates are produced both for commercial sale and for use internally for fabricating GaN templates, bulk GaN substrates, and related products.

Until 2011 Kyma's PVDNC effort relied on early-generation PVDNC crystal growth tools which were especially useful for the company's R&D stage but were not designed for high volumes.

To keep up with growing demand for Kyma's AlN and GaN products and the growing interest in larger diameter products, in 2011 Kyma designed and built their first PVDNC production tool which featured a larger diameter platter and much faster growth cycle time.

Related company announcements made in 2011 and 2012 include those of 1) the expansion of AlN template manufacturing capacity, 2) the demonstration of a 12" AlN on silicon template, and 3) the demonstration of a 10" AlN on sapphire template.

Primary applications for Kyma's AlN templates are for visible LEDs and power switching electronics. Recently demand has also grown for ultra-violet (UV) LED applications. Customers are interested in both AlN on sapphire and AlN on silicon for the LED applications; power electronics customers are focused mostly on AlN on silicon.

Ed Preble, Kyma's Chief Marketing Officer, and Tamara Stephenson, Kyma's Technical Sales Engineer, just completed a sales and marketing trip in the Asian Pacific focusing on application of Kyma's materials for LED applications.

Preble notes, "Over the past two weeks we were told by multiple customers in multiple nations that we have by far the best AlN templates on the market. Such customer input validates our PVDNC process as the technology of choice for creating a high quality nucleation surface for our customers' device wafer epitaxy processes."

Shrinking GaN power transistors and improving efficiency

HIGHLY MODERN power transistors based on GaN enable power electronic switches to operate at much higher switching frequencies compared to those based on silicon.

An increased power density per volume and per weight, reduced costs, less material use and, in the case of a mobile system, increased system efficiency are among the advantages. Solutions and concepts for high-frequency power electronics of the future shall be developed in the collaborative project "GaN-resonant - Efficient, highly compact high frequency power electronics with GaN transistors," which is sponsored by the German Federal Ministry for Education and Research (BMBF).

"GaN-resonant" was launched on July 1st, 2013 and will be funded with around €1.2 million over the next three years by the BMBF in the context of its funding announcement, "Leistungselektronik zur Energieeffizienzsteigerung (Power Electronics for Increasing Energy Efficiency)".

The Fraunhofer Institute for Solar Energy Systems ISE, the SUMIDA Components & Modules GmbH and the Liebherr Elektronik GmbH are all involved in the collaborative project "GaN-resonant".

The project goal is to develop a resonant DC/DC converter with GaN transistors, which is to operate with switching frequencies well above 1 MHz and a nominal power of 3 kW.

The simultaneous occurrence of extremely high switching frequencies and high transmitted power requires the use of special, innovative inductive components.

The development of such devices makes up a significant part of the collaborative project. Due to high power losses, the solutions available today limit the technically practical switching frequency.

Thus, the existing solutions are not suitable for future applications, which demand both a substantially higher power density and a higher efficiency at the same time.

This accomplishment can only be realised by innovations in the area of inductive components (core materials and geometries, winding structures and cooling concepts).

In the area of control, synchronous to the applied switching frequency, new problems arising due to the higher frequencies will be addressed in the collaborative project.

In order to exploit the advantages of a high switching frequency, the computing power used to control the DC/DC converter must be increased by a similar amount as the switching frequency or parts of the control must be carried out with analogue devices.

Wireless market drives record results for IQE

IQE PLC, a global supplier of advanced wafer products and wafer services to the semiconductor industry, has announced its half year results for the six months to 30th June 2013. Revenues were up 84% to £63.0 million as compared to the first half of 2012 (H1 2012), where revenues were £34.3 million. The figure for this year was boosted by acquisitions including the purchase of Kopin Wireless.

EBITDA for H1 2013 was up 162% to £10.5 million as compared to the same period last year when it was £4.0 million. Adjusted Profit Before Tax (PBT) increased tenfold from £0.5 million to £5.1 million (reported PBT was £2.5 million). Adjusted basic Earnings Per Share (EPS) increased from 0.13p to 0.82p (reported basic EPS was 0.39p). EBITDA and adjusted profit measures exclude non-cash charges for share based payments, non-cash acquisition related charges and exceptional items.

Net debt increased from £15.5 million in December 2012 to £37.7 million at the end of June 2013.

Drew Nelson, who is IQE Chief Executive made a statement commenting on the results. He said "These record financial results are a clear testimony to the transformation we've achieved over the last 18 months. Our two strategic wireless acquisitions have been successfully integrated and are performing very strongly. These deals represented the final building blocks in our wireless strategy, and we are now firmly focussed on delivery."

"Although the recent weakness in the global smartphone market, ahead of new product launches, has injected a greater degree of uncertainty in the short term, the overall wireless story remains as exciting as ever. The demand for greater connectivity, the increasing complexity of wireless communications and the explosion in data traffic continue to drive increasing demand for compound semiconductors. We are uniquely positioned to exploit this long term growth trend as the clear leader in providing a broad range of high performance wireless products."
"The advanced properties of compound semiconductors go far beyond just wireless communication. We have built a strong IP portfolio and are primed to exploit the adoption of compound semiconductors in a number of mass market applications. These include advanced solar (CPV), Power Semiconductors, LED lighting as well as a range of consumer and industrial applications utilising advanced lasers (VCSELs)."

"Advanced solar (CPV) is a disruptive technology which is gaining traction in the energy market. Advances in cell and system efficiency are accelerating the adoption of CPV, which is widely expected to be a $200-500 million market for compound semiconductor materials in the next three to five years. Having successfully hit all major technical and operational milestones, and recently posted new world record efficiencies from our production platform, we are now qualified for high volume manufacturing to commence over the coming months."

"Our significant progress in strengthening and broadening the wireless business, whilst building a solid platform of technologies which are poised for strong growth in our other target markets, mean we remain confident of achieving market earnings expectations for the full year. The operational leverage of our business model should create significant earnings growth as our revenues increase."

Currently, approximately 85% of the Group's sales are into the wireless communications market. This market has enjoyed strong and sustainable growth driven by the proliferation of wireless communication devices, and the requirement for more compound semiconductor chips per device as wireless communication becomes increasingly complex.

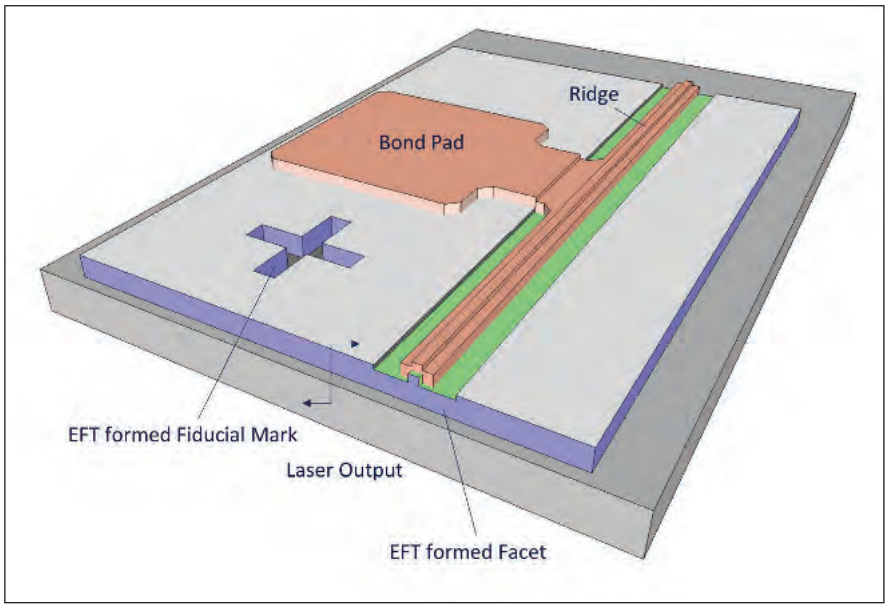
The Group expects these factors to continue to drive growth in demand for compound semiconductors for many years to come. IQE's key end markets are wireless, photonics (incorporating advanced solar, high resolution infrared, and opto-electronics), electronics (advanced technologies) and the power switching and LED lighting industry.

BinOptics eyes silicon photonics

As photonics integration on silicon gathers momentum, US-based BinOptics is set to break into the market with its etched facet lasers

WITH THE FUTURE of computer technology hinging on ultra-fast data transfer between and within microchips, all eyes are on silicon photonics as an option to keep traffic moving. One company keen to cash in on this rapidly growing field is US-based manufacturer of etched facet lasers, BinOptics. Using its so-called Etched Facet Technology, the company has fabricated and recently incorporated InP based lasers and other photonics components for use in silicon photonics applications.

"We've seen the level of interest in silicon photonics rise very dramatically over the last twelve months," says chief executive Alex Behfar. "This is an exciting time for silicon photonics and I think we will see some applications – people have talked about the use of silicon photonics in active optical cables – in the coming year."



EFT can be used to etch fiducial marks to the laser and silicon photonics chip, aiding low-cost passive alignment

Mechanical cleaving of semiconductor epiwafers is the usual way to define reflective mirrors or facets at the ends of edge-emitting diode lasers. However, this process can be imprecise and incompatible with monolithic integration. With this in mind, Behfar started developing an alternative method while at Cornell University in the late 1980s, and has since commercially developed his process, known as etched-facet technology (EFT).

Based on photolithography and chemically assisted ion-beam etching to form facets, the process has since been used to mass manufacture millions of edge emitters and surface-emitting lasers, known as horizontal cavity surface emitting lasers, HCSELs, as well as integrated photonic devices for Ethernet and Gigabit Passive Optical Networks.

And having bagged a healthy $13.3 million in new investment in late 2011 to fund development in new markets, the company is ready to fabricate edge facet InP lasers for hybrid silicon photonic circuits. According to Behfar, his company can use EFT to fabricate edge emitters or HCSELs, depending on the silicon photonics platform to be used. But why turn to an edge facet laser?

A clear advantage of BinOptics' lasers is that edge facet technology enables the etching of angled facets that allow light to emerge at an angle or perpendicular to the surface of the InP chip, aiding coupling to grating couplers on silicon photonic chips. But why not use a VCSEL then?

As Behfar highlights, his InP lasers typically emit at 1270 nm, 1290 nm, 1310 nm and 1330 nm, as well as across the optical C-Band, 1525 nm to 1565 nm. VCSELs are usually based on GaAs wafers and emit from 650 nm to 980 nm with the fabrication of long-wavelength InP VCSELs having barely left the research lab. What's more, silicon photonics applications demand power levels that are difficult to achieve with VCSELs. And as the chief executive is quick to highlight, while facet cleaving and subsequent coating operations can cause device failures, EFT followed by the company's proprietary passivation technology circumvents this problem and also eliminates the need for hermetic packages.

"EFT laser chips have successfully passed 5000 hours reliability in 85°C and 85 percent relative humidity," he says. "You can just put these chips down and they operate in a non-hermetic environment, unlike photonic devices that need expensive TO-can or butterfly-type packages."

But crucially, EFT enables manufacturers to use low-cost passive alignment, rather than more expensive active alignment, when coupling either a edge facet-fabricated edge emitter to a silicon photonics waveguide or a HCSEL to a grating coupler on the silicon photonics chip. As Behfar highlights, EFT-formed fiducial marks or cross-hairs, applied to the EFT laser chip and silicon photonics chip, can be used to position one with respect to the other to an accuracy of $\pm 0.1\ \mu$m. In contrast, mechanical cleaving has limited the the accuracy of passive alignment to around $\pm 2\mu$m in high throughput manufacturing. As a result many manufacturers – worried that this level of accuracy is insufficient for high performance communications – have turned to active alignment, using precision instruments.

The accuracies may be greater, but as Behfar asserts: "Active alignment involves powering the laser as well as a relatively long alignment time to optimise the coupling to a waveguide. This makes the process generally expensive, and at least one order of magnitude higher in cost, than passive alignment. The economics of active alignment just don't work."

"With EFT, you still get the precision and optical coupling you need without having to resort to active alignment," he adds.

And with his sights set on near-term silicon photonics applications, Behfar also hopes his lasers will be snapped up for the chip-to-chip and on-chip applications of tomorrow. "These applications are still a few years away but they are extraordinarily exciting, and we hope to contribute to that with our technology," he says.

Seren moves on

Once intent on lighting up the LED industry with its novel process to fabricate nano-rod LEDs, Seren Photonics is now focusing on large semi-polar GaN templates for a brighter light.

WHILE AROUND HALF of start-up businesses will have shut up shop within four years of launch, UK-based Seren Photonics remains safe and sound. Established in late 2009, the high brightness LED developer has since won nearly £2.5 million in equity and research funds, and has recently entered a second funding round. But change is afoot.

Known for its process to fabricate high efficiency InGaN/GaN nano-rod LEDs – pioneered by founder and chief technical advisor Tao Wang, an academic at Sheffield University – Seren is now touting a second technology; 2-inch non-polar and semi-polar GaN templates. Claimed to enhance light output and reduce droop, enabling efficient green LEDs and laser diodes, the templates boast lower defect densities than equivalent products as well as low wafer curvature.

As Seren chief executive, Carl Griffiths, explains, the template process is derived from the same basic physics as the original nano-rod LED technology. To date, only relatively small size (10 mm x 10 mm) semi-polar GaN substrates have been available as manufacturing has been via sawing from GaN boules grown by HVPE or ammonthermal techniques.

However, the company has now used its growth-on-nanorod and AlN buffer layer approach to grow 2-inch non-polar and semi-polar substrates. Here, nano-rod structures are created using the company's self-organised nickel nano-mask technique followed by a plasma etch. The purpose of the nano-rods is to rapidly block defects, thus creating a low defect density layer in less than 5 μm of GaN.

"We arrive at a very low defect density in a very very thin GaN layer so the amount of wafer bow on our product is negligible," explains Griffiths. "This is key at larger diameter substrates."

And while the process is similar to other nano-column based concepts – IQE acquired UK start-up NanoGaN in 2009 to exploit its proprietary nano-column process for producing GaN substrates – the results are different. As chief development officer, Bedwyr Humphreys, highlights: "Our process is similar to other concepts using nano-columns but there are fundamental differences in the way re-growth takes place, which reduces defect density on our templates."

So where next for the company? As Griffiths asserts, it has always been about creating high value IP and licensing that IP to manufacturers, but its next generation templates are a little different.

"We need to go further along the supply chain with this," he says. "We intend to do some small-scale production first and then look for a large manufacturing partner to engage with or license the technology to."

> "We see the future more lying in line with the semi and non-polar templates so we want to raise capital to facilitate small-scale manufacturing before engaging fully with volume manufacturers. We anticipate ramping up volumes in 18 to 24 months' time as well as proceeding from 2-inch to 4- and 6-inch substrates."

And so templates have already been passed on to tier one companies – Seren awaits feedback – and the company also hopes to join forces with a large-scale epitaxy manufacturer to transfer the technology and ramp up volumes.

"We see the future more lying in line with the semi and non-polar templates so we want to raise capital to facilitate small-scale manufacturing before engaging fully with volume manufacturers," explains Griffiths. "We anticipate ramping up volumes in 18 to 24 months' time as well as proceeding from 2-inch to 4- and 6-inch substrates."

But the plans don't stop at sapphire. With manufacturers now eyeing silicon as a potential cheap substrate for LEDs, research is underway at Seren to deposit its template layers on silicon. "Moving onto this second platform would certainly be beneficial in opening up the power semiconductor market for us, so silicon is definitely on our roadmap," says Humphreys.

The end of nano-rod LEDs?

But what about the company's original aim to 'unlock the full potential of nitride-based, ultra high-efficient, white LEDs' with its nano-rod based process? Griffiths asserts work is ongoing, and we may see more yet.

"There is such an incredible overlap in the fundamental technology of our two [technologies] that we certainly won't be stopping [the nano-rod work]," he says. "Professor Wang is currently working on two or three new technologies that rely on the capability to make the nano-column structure."

Griffiths will not be drawn on details, only to say his researchers "have spent a lot of time in the last six months understanding the different process steps, such as the exact nano-column size you need."

At the same time, the company has been busy fostering relationships with manufacturers and government in China. Griffiths believes that at this point in time, the template technology is more appealing to companies in the West as Asia-based counterparts focus on driving down LED manufacturing costs in response to the recent deluge of LEDs on the market. But he expects this will change.

"Right now the emphasis for us is to work with the tier one players that have a long reach into research as these are the guys what will bring the technology forward and make it applicable," he says. "But I think in two to three years' time as the technology matures, these templates will migrate over to China where Asia-based manufacturers can then drive the costs down."

BluGlass raises LED ambitions

Following federal funds, BluGlass is eyeing GaN on silicon LED markets.

IN JULY THIS YEAR, Australia-based semiconductor process developer, BluGlass, won Aus$3 million in federal government funding to demonstrate high efficiency, low cost GaN LEDs.

The start-up has spent years honing the low temperature growth of GaN, and more recently the growth of *p*-GaN layers, on MOCVD GaN templates but will now ramp up efforts to grow entire LED structures on silicon substrates as well as sapphire wafers.

"Our lower temperature remote plasma CVD has the potential to reduce the bowing and cracking problems of traditional high-temperature MOCVD... and we can see emerging opportunities in GaN-on-silicon markets,"explains company chief technology officer, Ian Mann.

To achieve low temperature growth, BluGlass replaces the ammonia source of a typical MOCVD system with nitrogen gas, passed through an electrical coil to generate a plasma. During conventional MOCVD, temperatures of up to 1200 °C dissociate nitrogen from ammonia, and GaN layers are grown. But by directly supplying nitrogen via a plasma, BluGlass deposits the semiconductor layers at much lower temperatures.

To date, the company has not revealed actual growth temperatures but earlier this year it showcased *p*-GaN films, grown via RPCVD on MOCVD GaN templates, that met industry electrical performance benchmarks. Mann claims the process is cheaper than MOCVD as large amounts of ammonia are not used, although a RPCVD deposition tool will cost about the same as an MOCVD system. His team is now working towards growing *p*-GaN layers at low temperatures and aims to grow at temperatures matching those used in MOCVD growth of multi-quantum wells.

"Today we buy multi-quantum well layers made on an MOCVD machine and we grow *p*-GaN layers on top of these," says Mann. "But with our technology, some of the real value will come from growing the multi-quantum wells and then the *p*-type GaN layers at the same temperature all via RPCVD. We believe this is achievable. And crucially, as Mann highlights: "A low temperature *p*-GaN layer has the potential to be less damaging to the MQW and therefore improve the efficiency of an LED."

The recent funding has enabled the firm to buy a second, larger MOCVD system, that Mann and colleagues will now retrofit to a RPCVD system. The CTO emphasises that the system will be smaller than the size of a production facility in a tier one fab, but will allow the team to work with single, 8-inch wafers.

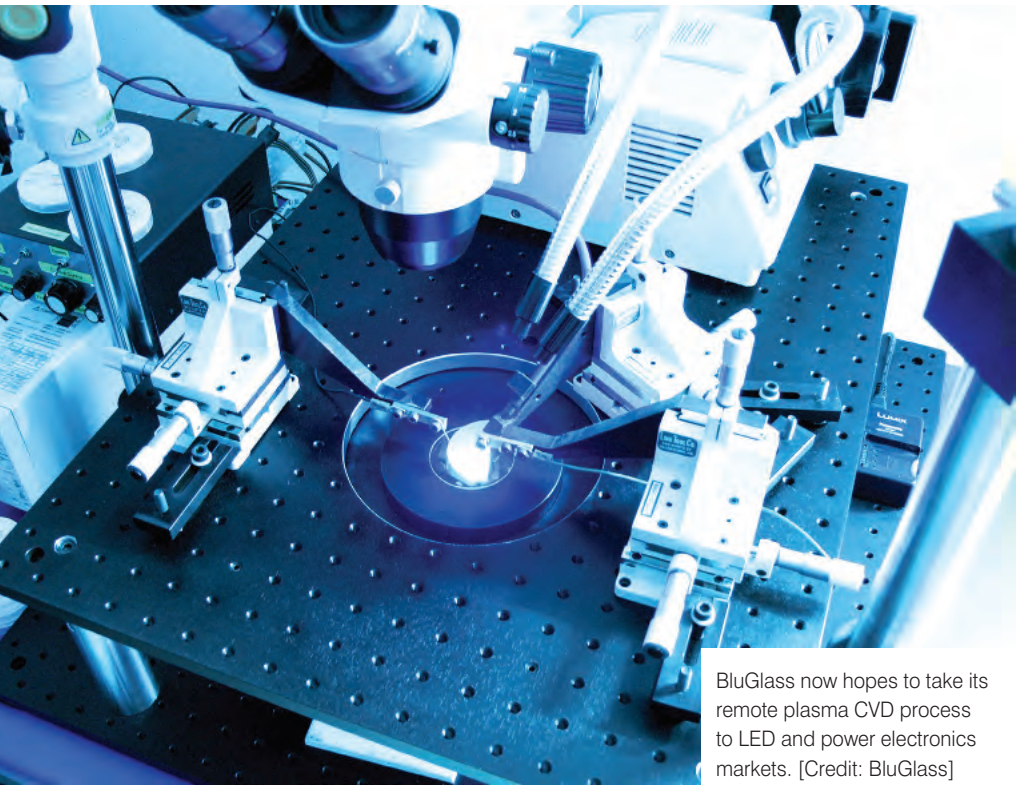
"The system will allow us to demonstrate 8-inch silicon, which is a must-have and isn't something we can do with our current development equipment," he says. The team is currently developing nucleation and multi-quantum well layers, and while the RPCVD process will differ from conventional MOCVD, Mann asserts: "We will use RPCVD to grow a full structure in the same way that MOCVD can grow a full structure."

"At the same time we are also looking to commercialise as fast as we can and will draw on other resources, potential partnerships and other funding to accelerate this," he adds.

But what of the company's starting technology – blue light emission from GaN deposited on glass?

According to Mann, BluGlass is now focused on the conventional substrates that the LED industry is familiar with. And the company doesn't expect to stop at LEDs, but intends to take its technology to power electronics markets.

"Clearly the power electronics market is an emerging market as well," highlights Mann. "And from a technology point of view, getting good quality GaN growth on silicon is important for both power electronics devices and LEDs."



BluGlass now hopes to take its remote plasma CVD process to LED and power electronics markets. [Credit: BluGlass]

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IQE

Front Ends for Mobile Devices

Handset front-ends are becoming more complex, due to an ever-increasing number of bands used for mobile communication. Will this trend play into the hands of GaAs chipmakers? Or is silicon CMOS technology going to grab market share?

Keynote presentation: Jeremy Hendy
Envelope tracking - transforming the performance of CMOS and GaAs PAs

nujira

Other speakers

Asif Anwar
Coming full circle - will Si CMOS burst the GaAs bubble?

STRATEGY ANALYTICS

Thomas Meier
GaAs & Silicon: Co-existence in a wireless world

TriQuint Reach Further · Reach Faster

Brendan Timmins
Minimizing the cost of precious metals used in compound semiconductors

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* All speakers and presentations are subject to change.

Wide Bandgap RF Devices

GaN and SiC have a great set of attributes that make them very promising materials for producing RF devices. But are they now fulfilling their potential and netting substantial sales?

Keynote presentation: Andrew Barnes
Overview of GaN reliability improvement activities at the European Space Agency

Other speakers

Chris Horton
Enabling material solutions for GaN in the RF arena

Mike Mallinger
Microsemi's SiC or long-range radar

Marc Rocchi
100nm GaN/Si mmW foundry service and MMICs

Solar

Triple-junction solar cell efficiencies are increasing steadily. Will this help to spur rapid growth in the concentrating photovoltaic sector, or will it be more valued by those requiring a power source for satellites?

Keynote presentation: Vijit Sabnis
Setting a new benchmark for space solar cell performance

Other speaker

Rainer Krause - Soitec
Wafer bonded 4-junction GaInP/GaAs//GaInAsP/ GaInAs high performing concentrator solar cells

LEDs

LEDs are the dominant source for backlighting screens of all size. So, to penetrate new markets and grow revenues, can chipmakers now trim the cost-per-lumen of the LED or equip the device with additional features?

Keynote presentation: Young Soo Park
Slashing LED costs with 200 mm silicon substrates

Other speakers

William Henry
Applications and opportunities for MicroLED emitters

Pallavi Madakasira
LED light bulbs: When and how will the lighting of tomorrow become the lighting of today

Ulrich Steegmueller
Success factors in the increasingly competitive LED ecosystem

Continues on next page

Power Electronics

Silicon has dominated the power electronic market for decades, but wide bandgap semiconductors will soon replace this material. What's the primary role for SiC, and where will GaN feature?

Keynote presentation: Ming Su
Can GaN or SiC make an impact in electric vehicles?

Keynote presentation: Mike Briere
Pioneering GaN on Si power devices on large diameter substrates

Other speakers

Michael Weirich
Why JFETs can be a success in the power electronics market

Philippe Roussel
Vertical integration vs outsourcing in the wide bandgap sector

Marcus Behet
SiC and GaN/Si for power electronics – niche forever?

Denis Marcon
200mm GaN-on-Si CMOS compatible technology for power electronics

Laser and PICs

Rocketing levels of internet traffic are putting greater and greater strain on optical networks and data centres. Can this be addressed by advancing the performance of conventional lasers, or does the market need to turn to greater use of PICs?

Keynote presentation: Michael Lebby
Photonic integration in InP: A regrowth-free platform for fabless manufacturing model

Other speakers

Gregory Fish
III-V Heterogeneous photonic & electronic integration on silicon

Dr. Thorsten Matthias
Direct wafer bonding: Enabling technology for future photonic and electronic integration

Petteri Uusimaa
RGB laser solutions to display and projection application

Hong Lin
Bulk and free-standing GaN substrate technologies and industry status in the LED, laser diode and power applications

Integration of CMOS and III-Vs

Silicon is running out of steam, and the future is widely tipped to be high-mobility channels made from germanium and III-Vs. But how will these materials be introduced in the world's leading silicon foundries?

Keynote presentation: Dr Jean Fompeyrine
Co-integration of III-V and Ge CMOS

IBM

Other speakers

Shinichi Takagi — The University of Tokyo
III-V and germanium FET technologies on Si platform

Aaron Thean
Extending Moore's Law with III-V and germanium

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Slashing defect densities

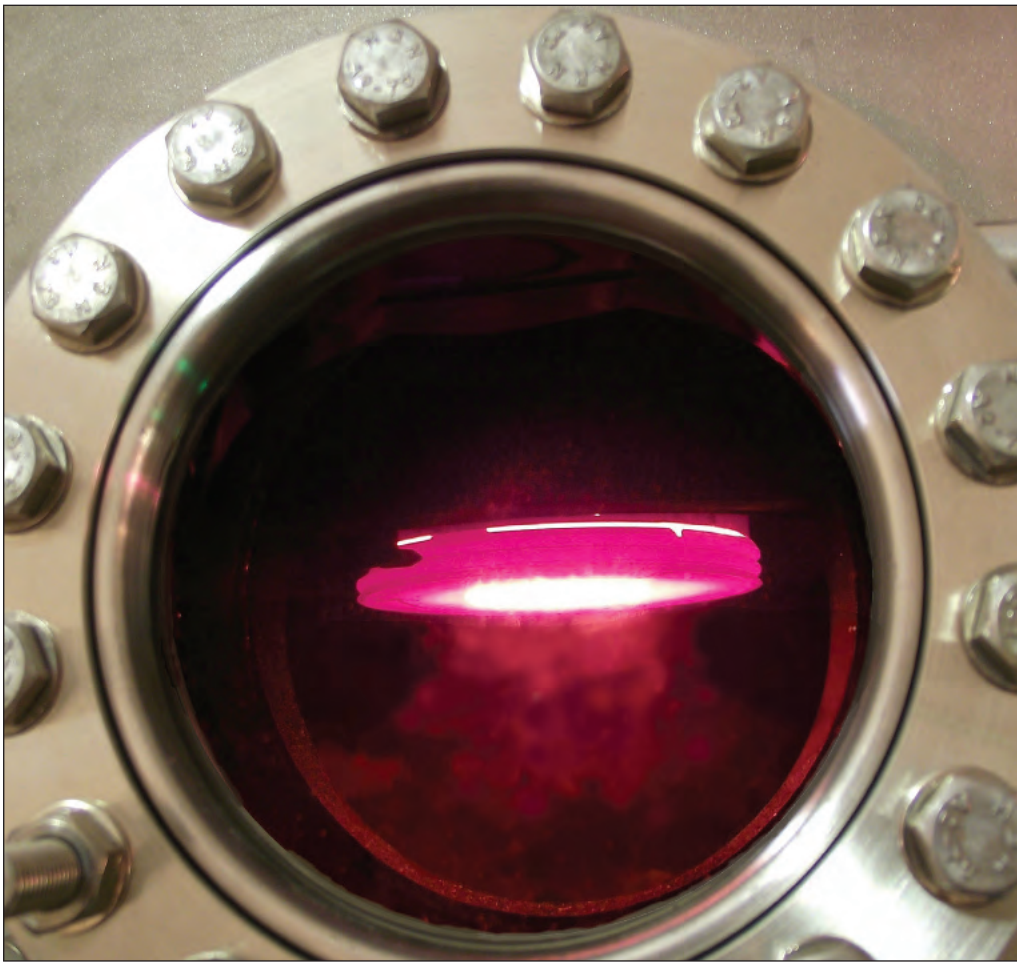
in nitride films grown by high temperature ammonia MBE

Grown in an MOCVD reactor, nitride films tend to yield fewer defects than when they are formed in MBE chambers. But this gap in material quality can disappear with high-temperature ammonia MBE, which produces epitaxial structures with outstanding electrical characteristics, argues Alexey Alexeev and Stanislav Petrov from SemiTEq.

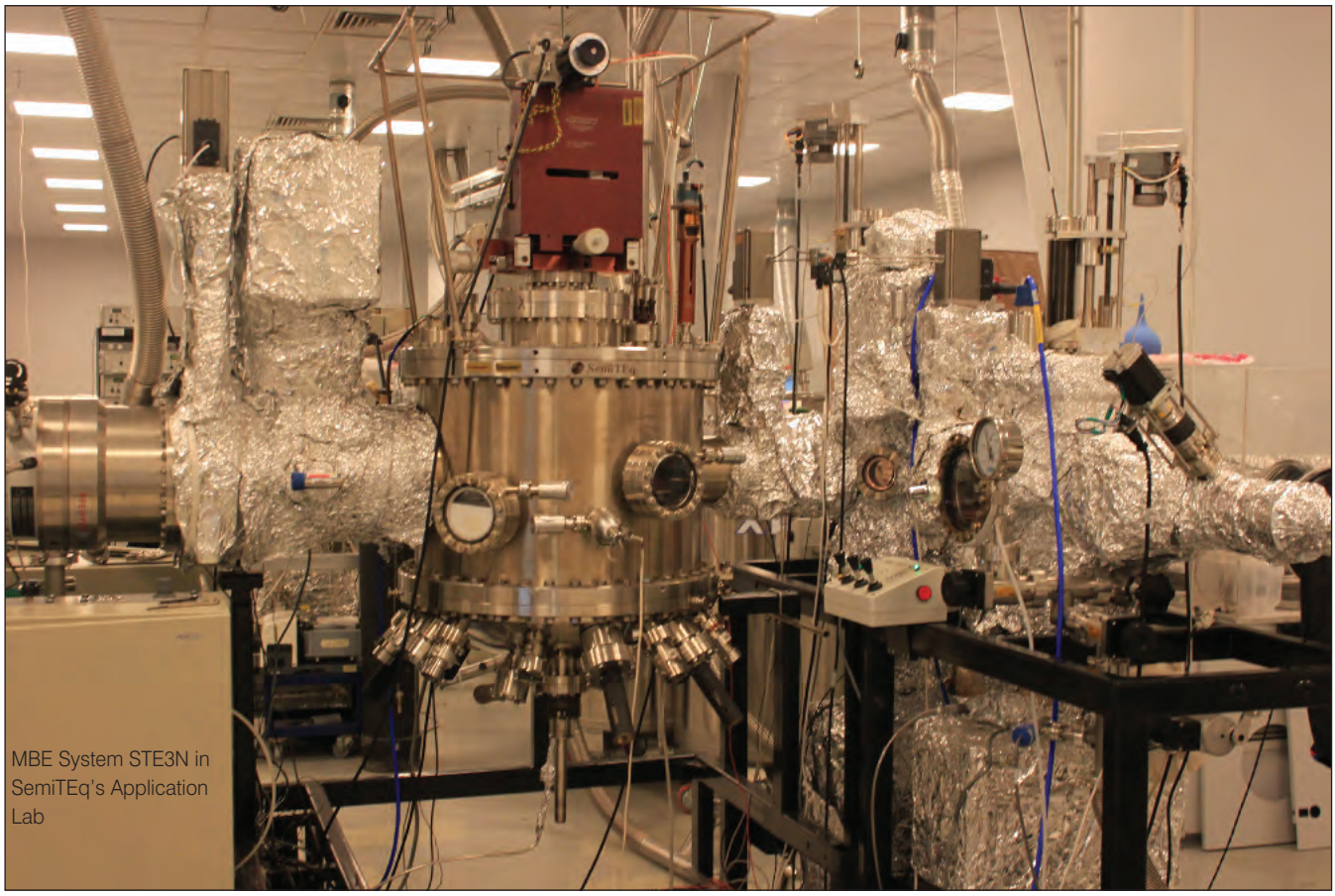
THERE IS A FUNDAMENTAL difference between the growth of most nitride devices and those based on the arsenide and phosphide families. While the latter are grown on native substrates with very low defect densities, nitride devices tend to be formed on the likes of sapphire, silicon and SiC, because GaN substrates are so difficult to make, pricey, limited in availability, and – in relative terms – not of that high a quality.

The biggest downside of growth on mismatched substrates is that it leads to high dislocation densities. If the more widely used deposition technology, MOCVD, is deployed, dislocation density in GaN films is typically in the range 10^8-10^9 cm^{-2}. However, if this approach is combined with an epitaxial overgrowth technology, dislocation density can fall towards 10^7 cm^{-2}. In comparison, due to the lower temperature traditionally associated with MBE, this growth technology leads to a lower surface mobility of adatoms and ultimately an inferior material quality. Dislocation densities for nitride samples grown by MBE are typically 10^9-10^{10} cm^{-2}.

Although MBE tends to yield inferior dislocation densities, it does offer several advantages over MOCVD. Some of them occur for all material



SemiTEq's approach to slashing defect densities in nitride films



MBE System STE3N in SemiTEq's Application Lab

systems: the opportunity for *in-situ* monitoring offered by reflection high-energy electron-diffraction, which can be used to identify the transition from three-dimensional to two-dimensional growth and provide surface reconstruction; the growth of sharper hetero-junctions; and a safer, easier route for the research and development of material systems and devices.

In addition, there are benefits associated with MBE growth that are unique to nitrides. In its most common form of MBE, plasma-assisted (PA) MBE, growth is relatively simple and hydrogen is absent from the growing surface. What's more, deposition at low temperatures can be advantageous – incorporating indium in binary and ternary nitrides is easier at low temperatures, so this technique is good for the growth of InN, InGaN and InAlN with a high indium content. In addition, low temperatures aid effective *p*-type doping.

If epiwafer growers select PAMBE, they are benefitting from the continuous development over the last decade of not only this technology, but also that of the plasma sources. By optimising growth conditions at the initial stage and during the deposition process, it is possible to improve material quality. Examples of this approach, which includes using migration-enhanced epitaxy, have paid dividends in several groups, including Jim Speck's team at the University of California, Santa Barbara, and Valentin Jmerik's group at Ioffe Physical Technical Institute. However, the growth temperature is still limited with PAMBE.

> "At SemiTEq, a brand within the Russian Joint Stock Company Semiconductor Technologies and Equipment, we are now offering equipment that is capable, in MBE terms, of growth of GaN and AlN at very high temperatures."

Consequently, dislocation density is high, due to insufficient surface mobility of adatoms and inferior coalescence of nucleation blocks at the initial growth stage. What's needed is to increase the growth temperature in order to slash the defect density, while retaining the advantages that MBE has over MOCVD.

At SemiTEq, a brand within the Russian Joint Stock Company Semiconductor Technologies and Equipment, this has been the goal for more than a decade. We are now offering equipment that is capable, in MBE terms, of growth of GaN and AlN at very high temperatures.

This range of tools is selling well into our domestic market, enabling engineers to produce epistructures that combine excellent electronic attributes with very impressive levels of crystal quality.

Working with ammonia

Our tools are not based on the most common form of nitride MBE growth, PAMBE, but are based on an alternative approach known as ammonia MBE. We are not the sole pioneers of this deposition technology, but use far higher temperatures and III-V ratios than is normal with this technique.

The typical approach is to use growth temperatures that are 100-200 °C higher than those associated with PAMBE and III-V ratios a little higher. With these conditions, growth rates are 1 μm/hr or more. In this regime, researchers don't tend to crank up the III-V ratios, which restricts growth temperatures to levels considerably lower than those found in MOCVD tools, where they are often above 1000 °C.

A major downside of keeping the temperatures below this is the high density of dislocations arising in nitride films – they tend to be more than an order of magnitude higher than those produced in epiwafers grown by MOCVD.

In comparison, our tools can get very close to MOCVD growth temperatures. This was a primary goal of ours when we started developing an MBE reactor for nitride growth in the late 1990s. Back then, we already had a great deal of experience in the growth of epiwafers for high power InAlGaAs laser diodes, and we were well aware that higher growth temperatures lead to better devices.

We were also aware of a 'gap in the market' when we commenced our development of a GaN tool. At that stage, there were no commercially available MBE systems that were capable of the growth conditions that we believe are best for nitride growth. That led us to think that there were sizeable rewards available for trying to realise an MBE system that could operate reliably in such extreme process conditions.

Initially, we focused on increasing the growth temperature of GaN that is, of course, limited by thermal decomposition on the wafer's surface. Since nitrogen is more volatile than gallium, thermal decomposition of GaN is governed by the ammonia flux that flows onto the surface of the growing film.

To realise extremely high ammonia flows, we developed a special MBE system that features an increased area of liquid-nitrogen-cooled cryopanels. The pumping system based on these cryopanels, which is used in conjunction with a high-speed turbo molecular pump, can produce a high vacuum in the growth chamber even with very high ammonia flow rates.

Thanks to these features, our prototype system enabled the GaN growth temperature without thermal decomposition to increase to 970 °C, while using an ammonia flow of 400 sccm. This temperature is even significantly higher than the highest values reported for ammonia MBE – about 900 °C – while the vacuum in the growth chamber is typical for ammonia MBE, staying below 5 x 10^{-3} Pa. Armed with these new growth conditions, engineers can improve the structural quality of GaN. However, the dislocation density is still higher than that for MOCVD-grown layers.

Slashing dislocation densities

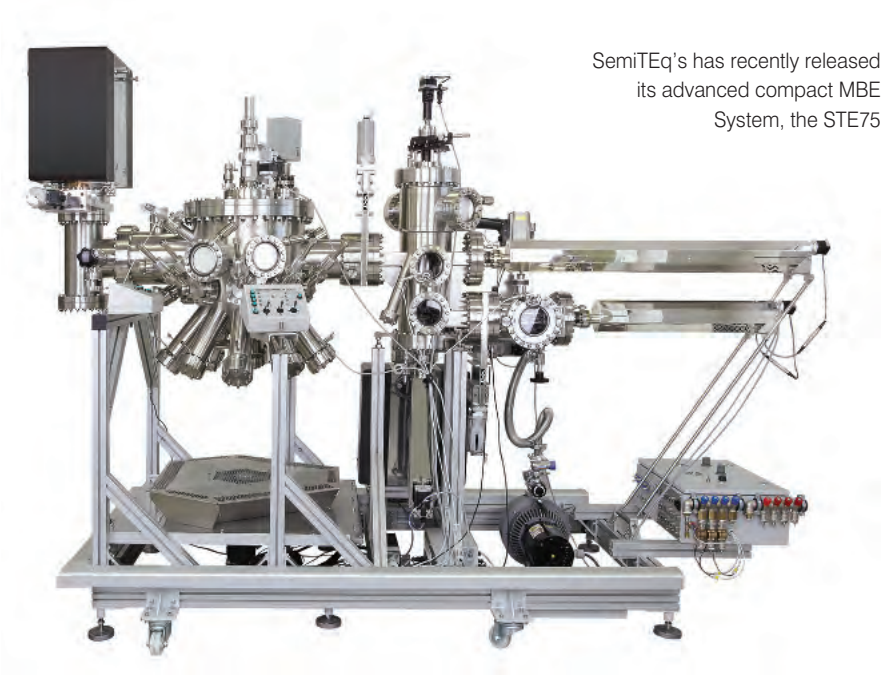
To significantly slash the dislocation density with ammonia MBE, we performed a series of experiments that revealed that the key is to grow an AlN buffer layer at an extremely high temperature – more than 1000-1100 °C. This type of buffer improves material quality by increasing coalescence, so nitride film deposition quickly moves to the two-dimensional growth mode.

Our tools show that with ammonia MBE, rather than plasma-assisted MBE, it is possible to grow AlN and high-aluminium-content AlGaN with a high substrate temperature and V/III ratio in excess of unity (N-rich mode). Alternately, growth at high temperatures in PAMBE is very tricky, because the aluminium-rich mode is essential for two-dimensional growth of the AlN buffer, while aluminium desorption is significant at substrate temperatures of 900 °C or more.

To realise the extremely high substrate temperatures for AlN buffer layer growth we had to develop a specialized MBE system. In this system, ammonia flows are lower for the growth of an optimal AlN layer than for GaN growth, while large area cryopanels enable typical vacuum levels for MBE, even at extremely high substrate temperatures.

This vacuum level, combined with an aluminium effusion cell, rules out the possibility of unwanted, difficult-to-address parasitic reactions that typically occur in the MOCVD reactor between tri-methyl-aluminium and ammonia.

Another of our tool's features is that it opens the door to the growth of high quality structures for microelectronics or optoelectronics that feature an active region grown by either ammonia or PAMBE. Such structures, which can be grown in a single run, can be used to make ultraviolet emitters and detectors and microwave transistors. These devices demand very high quality layers of AlN and high-aluminum-content AlGaN.



SemiTEq's has recently released its advanced compact MBE System, the STE75

Reactor portfolio

Our STE3N* series of MBE reactors that we released in 2003 combine an extremely high temperature on the substrate – it can be up to 1200°C with a high N/III ratio and an ammonia flow rate of up to 1000 sccm. The heating stage is highly reliable during a long growth run, aiding deposition of structures featuring thick AlN/AlGaN buffer layers and active layers with extremely low dislocation densities.

The STE3N* is available in either a two or three chamber format (the STE3N2 and STE3N3, respectively), with the latter equipped with a buffer preparation chamber.

The STE3N* systems can be configured to combine the ammonia injector with a nitrogen plasma source, which can be used in combination with ammonia MBE for growing active layers of InGaN, InAlN and magnesium-doped AlGaN. Both systems have specially designed indium, gallium and aluminium effusion cells for providing long-term life and growth rates of up to 2 μm/hr, when operating as ammonia MBE tools.

Other features of our STE3N* growth tools are the patented design of the substrate holder and the heating stage of the growth manipulator. This enables high heating uniformity, regardless of substrate material, and wafer diameters of up to 100 mm, allowing this tool to fulfil the requirements of engineers in R&D labs and those responsible for pilot production.

Our latest addition to the nitride MBE portfolio, the STE75, is also capable of the same growth conditions for high-temperature deposition of AlN buffer layers, but features more compact cryopanels for a limited number of samples per growth series.

Superior samples

We have used our ammonia MBE tools to develop a complex, very special AlN/AlGaN buffer layer that holds the key to the growth of extremely low dislocation density films on several types of mismatched substrates. Using *c*-plane sapphire, for example, we can form a buffer comprising 200-400 nm-thick AlN grown at a substrate temperature of 1100-1150 °C, followed by an AlGaN/AlN superlattice and $Al_xGa_{1-x}N$ (x=0.1-0.3) transition layers deposited at 900-920 °C.

According to scanning transmission electron microscope images, the dislocation density in these samples is 2-4 x 10^{10} cm^{-2} in the AlN buffer, falling to 4-6 x 10^{9} cm^{-2} in the AlGaN layer grown after the superlattice (see Figure 1). Meanwhile, dislocation density in the top GaN active layer is just 9-10 x 10^{8} cm^{-2}. The latter value is comparable to GaN grown on sapphire by MOCVD, and far lower than that associated with conventional MBE.

The improvements to material quality have produced a substantial increase in electron mobility, which reaches a maximum value of 600-650 cm^2 $V^{-1}s^{-1}$ in a 1.5-μm-thick, lightly doped GaN top layer (silicon doping of 3-5 x 10^{16} cm^{-3}). This value is comparable to that of good quality, MOCVD-grown GaN, and in good agreement with calculations determining the relationship between mobility and dislocation density.

The GaN layer can be capped with an $Al_xGa_{1-x}N$ barrier layer with variable composition. By changing the value of x from 0.25 to 0.4, electron sheet density can be varied from 1.0-1.8 x 10^{13} cm^{-2}, while mobility is adjusted from 1300-1700 cm^2 $V^{-1}s^{-1}$. This enables the channel sheet resistance for the two-dimensional electron gas to be tuned between 230-400 Ohm/sq. Higher electron sheet densities are possible by replacing the AlGaN barrier with lattice-matched InAlN – this yields an electron sheet density of 2.3-2.5 x 10^{13} cm^{-2} and a mobility of 1200-1300 cm^2 $V^{-1}s^{-1}$.

Historically, only PAMBE could be used to grow the high-quality, lattice-matched InAlN layer, which requires an indium content of 18 percent. The lower temperature limit for ammonia MBE is determined by ammonia cracking efficiency, and this is negligible at temperatures lower than 500 °C.

Increase the temperature above this value and typical ammonia flow leads to very low indium content – it is insufficient for growing InAlN lattice-matched to GaN.

However, Speck's group have shown recently that if the ammonia flow is increased to 1000 sccm, growth of InAlN that is lattice-matched to GaN is possible. Motivated by this result, we have tried to grow such structures by PAMBE and ammonia MBE, realising good results in both cases. It is worth noting that thanks

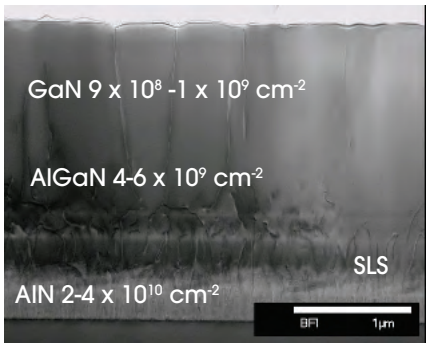


Figure 1. An scanning tunnelling electron microscopy image of an AlN/SLS/AlGaN/GaN heterostructure reveals that the dislocation density in nitride films grown by MBE can rival those found in MOCVD-grown samples

to the special cryopanels and pumping system design, the vacuum levels are almost unchanged when ammonia flow hits 1000 sccm! This attribute of our tool will make it very attractive for producing many device structures.

Several Russian research centres and companies have employed our MBE tools to grow DHFET epiwafers, which have been used to make prototypes of advanced high power microwave transistors. Testing of these devices reveals a high quality active region and absence of the current collapse effect, thanks to the adoption of a double heterostructure design that is significantly different from that of a conventional GaN/AlGaN FET.

What is also very encouraging for us is that the high power transistors produced from wafers grown in our STE3N* MBE system are very robust, according to long-term ageing tests.

Our efforts have meant that within a relatively short space of time, we have come a long way from a small R&D company to being the sole Russian MBE manufacturer, competing successfully with world-leading companies. One of the biggest factors behind this success is our continuous work with partners and customers. We offer not only technical training, but enhanced process training, including development and implementation of client-oriented processes. Creating a strong relationship with our customers and the constant monitoring of their work allows us to continuously improve our equipment.

Cranking up the efficacy of Green LEDs

Green LEDs don't deliver the same level of performance as their red and blue cousins. However, by decreasing the current density with a larger chip and optimising growth conditions to reduce dark spots it is possible to close that gap with LEDs that hit 190 lumens per watt at a 100 mA drive current, says Osram's Andreas Löffler and Michael Binder.

AFTER PRICE, imperfect colour quality is the biggest criticism levelled at the LED light bulb. This downside stems from the way that the white light is generated: A GaN-based, blue-emitting chip pumps a yellow phosphor, and the mixing of these two colours produces white light. With this approach, the output does not feature a significant contribution from the red region of the visible spectrum.

A superior approach for making lighting products – that is also an option for solid-state projection displays – is to generate white light by mixing the emission from red, green and blue LEDs. Advantages of this approach are not limited to a higher colour-rendering index, and also include the opportunity for higher efficacy and flexible colour steering.

To produce a high-efficacy system with this form of colour mixing, efficient sources must be employed. Blue and red LED performance is already impressive, with recent improvements spurring peak power conversion efficiencies beyond 81 percent and 70 percent, respectively, but the green cousin is lagging far behind. This particular species suffers from a problem commonly known as the green gap.

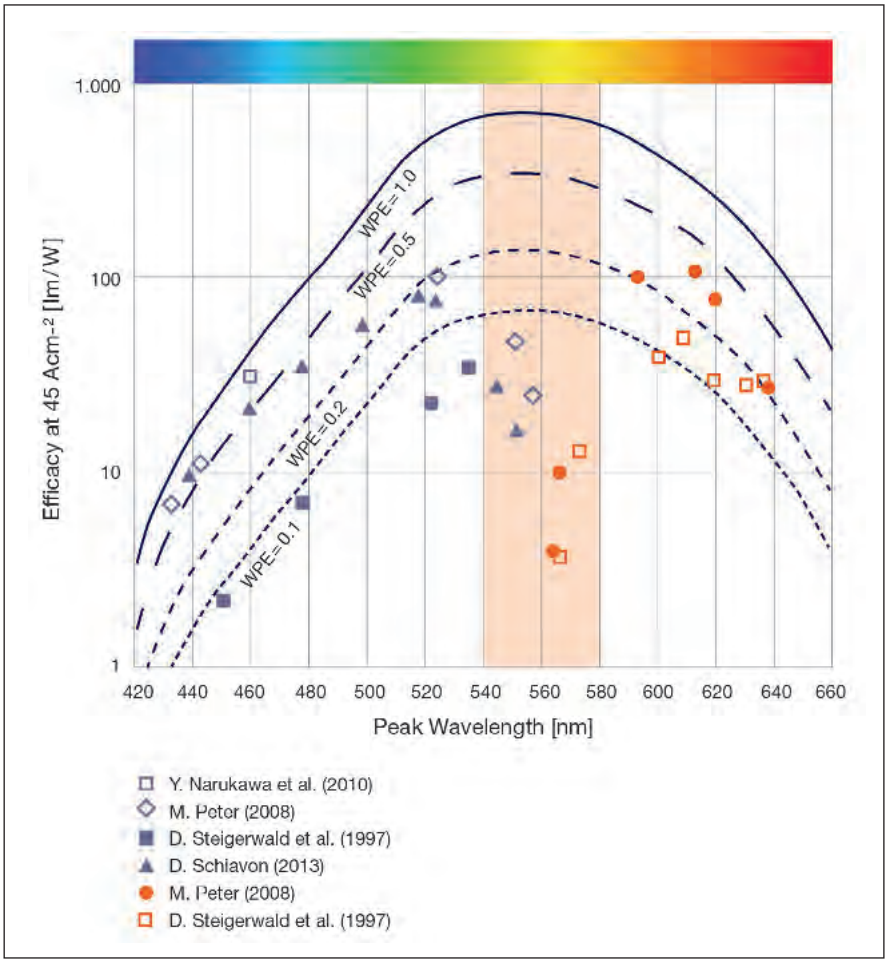
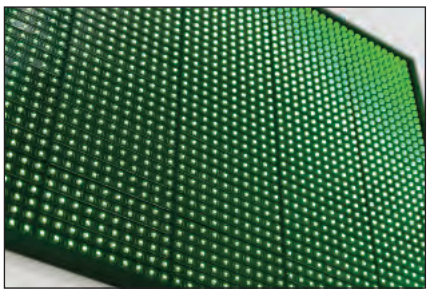


Figure 1: Efficacy of III–nitride (green data points) and III–phosphide (red data points) LEDs with different wavelengths (data taken from recent publications). The blue lines represent the CIE 1924 luminosity function multiplied by the corresponding value of the wall plug efficiency (WPE). Marked in yellow is the green–yellow range, which is not adequately covered by either the III–nitrides or the III–phosphides. This is the essence of the green gap problem

Going green

The big challenge associated with trying to make an efficient green LED is that there is not an ideal, mature material system to work with. The III-N family that is used to create powerful blue LEDs is far less efficient at longer wavelengths, and a similar problem plagues the III-phosphides that are very efficient in the red range; extend emission of this class of LED to shorter wavelengths and efficiency plummets. So, in short, both material systems present low efficiencies in the green-yellow spectral range (see Figure 1).



Applications for high efficiency green LEDs vary from projection systems to backlighting, video walls and solid-state lighting with a high colour-rendering index

With the III-phosphides, the falling efficiency as emission is propelled to the green is a fundamental limitation of the material system. Altering the composition of AlInGaP so that it emits in the green – rather than red, orange, or yellow – leads to insufficient carrier confinement, due to the relatively low band gap of this material system. This rules out efficient radiative recombination.

In comparison, for III-nitrides, the barriers to high efficiency may be very tough, but they are not insurmountable. With this material system, two factors are behind the decline in efficiency as emission stretches to the green: a fall in external quantum efficiency and a decrease in electrical efficiency.

The first weakness has its origins in the need to apply an extraordinarily high forward voltage to green LEDs. These devices feature extremely high internal piezoelectric fields. So, for a given current, the voltage that has to be applied to this type of LEDs is even higher than that for a blue variant, despite

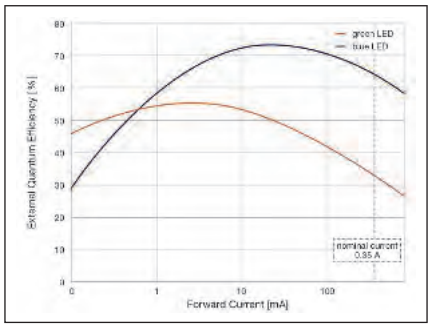


Figure 2: Comparison of the current dependent external quantum efficiency (EQE) of a blue and green 1mm² InGaN/GaN LED emitting at 442 nm and 530 nm, respectively

the lower bandgap. This higher drive voltage drags down power conversion efficiency. The second weakness is given by the fact that green LEDs are plagued by droop, the steady decline in internal quantum efficiency at increasing current densities. Droop occurs in blue LEDs, but its impact is far greater in green ones, leading to very low efficiencies at common operating currents (see Figure 1 and 2).

The cause of droop is a hotly debated topic within the nitride community. Since the loss rate that causes droop exhibits a cubic dependence on charge carrier density under both electroluminescence and photoluminescence excitation, Auger recombination (direct or phonon-assisted) in the active layer is one of the main suspects.

However, this is by no means the only conjecture for the cause of droop – there have been attempts to explain the origin of this mysterious malady with theories involving either dislocations, carrier spill-over (thermionic, ballistic and Auger-induced spill-over) or electron leakage. The latter is enhanced by high internal piezoelectric fields.

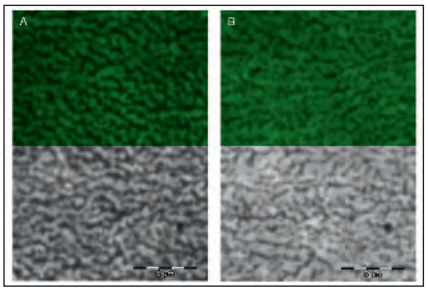


Figure 3: Microphotoluminscence images of a device from a production (a) and a research and development sample (b). For a better contrast, the lower part of the images are shown in levels of grey only

Moving in the right direction

At Osram Opto Semiconductors of Regensburg, Germany, we have been steadily improving the efficacy of our green LEDs. In 2008, our colleagues, led by Matthias Peter, reported a 1 mm², ThinGaN 527 nm chip producing 100 lm at 350 mA. This corresponds to 73 lm/W. Two years' later, we increased efficacy to 100 lm/W at 350 mA, using an optimised 1 mm² chip housed in a Golden Dragon Plus package. At this drive current, luminous flux is 117 lm, while cranking up the current to 1 A increases output to 224 lm.

More recently, we have raised the bar for green LED performance again. Higher efficacies have been possible with MOCVD-grown LEDs formed on *c*-plane sapphire that feature an active region with five to seven InGaN quantum wells embedded in GaN barriers. A 5 μm-thick, silicon-doped GaN buffer layer underpins this active region, which is covered with a 30 nm-thick, *p*-type magnesium-doped AlGaN electron-blocking layer and a 140 nm-thick, magnesium-doped GaN contact layer.

We have compared the photoluminescence produced by the active region of this structure with that of a device coming off our production line (see Figure 3). With the high-volume device, micro-photoluminescence reveals strong inhomogeneity in intensity, with a pattern of dark spots appearing against a meandering, bright background. The density of the dark spots corresponds to the hexagonal crystal defect (V-pits) density, leading us to suspect that there is a strong correlation between these spots and the V-pits. This view is supported by several studies by other groups, which confirm a point-to-point correlation.

Lowering the growth rate in the active region significantly improves quantum well material quality, according to micro-photoluminescence imaging. The density of the dark spots is similar to that of the sample from the production line, but the affected area is far smaller. This increases the proportion of bright areas, leading to a more homogeneous luminescence pattern.

This improvement, which results from an increase in material quality that enhances internal quantum efficiency and transport characteristics, leads to better-performing LEDs. Recent samples that have been

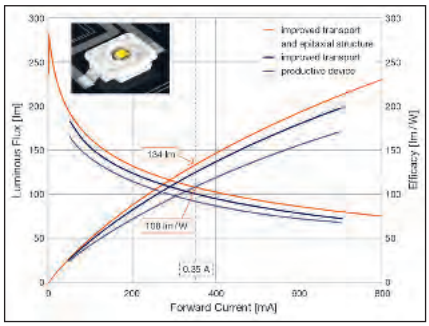


Figure 4: Electro-optical characteristics of a 1mm² ThinGaN chip in a Dragon package: device from production (blue), device with improved transport (black) and optimized epitaxial structure (orange)

mounted in a Dragon package with a spherical lens produce 114 lm at 350 mA, corresponding to an efficacy of 100 lm/W (see Figure 4). In comparison, devices from the production line emit just 108 lm under the same drive current. Even better results are possible by by removing quantum wells that do not contribute significantly to light generation. In our case, that means trimming the number of wells from seven to five, and therefore improving carrier transport. With this refinement, output from the 532 nm-emitting, 1 mm² ThinGaN chip hits 134 lm at 350 mA, corresponding to an efficacy of 108 lm/W.

The key to further improvement in these green-emitting LEDs is to combat droop by cutting carrier density, through either an increase in chip size or the number of emitting quantum wells. The efficacy curves of Figure 4 allow us to estimate that cutting the current density by a factor of two or four increases efficacy by 25 percent or 60 percent.

We have adopted this approach, increasing chip size to 2 mm². This increased output power for a green LED

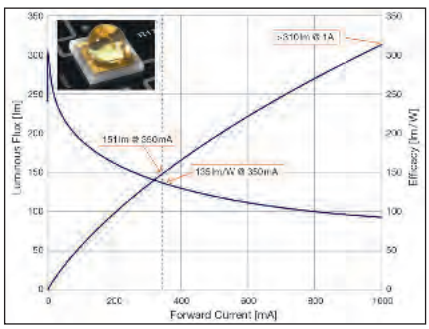


Figure 5: Electro-optical characteristics of a 2 mm² ThinGaN chip in an OSLON package with an improved carrier transport and an optimized epitaxial structure

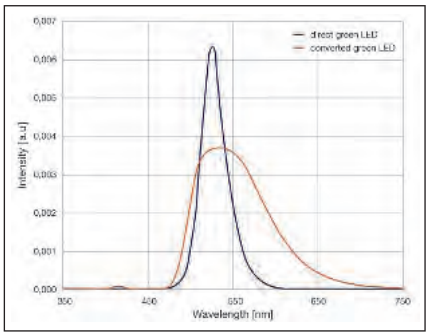


Figure 6: Spectra of two different approaches for green LEDs. The emission generated by the phosphor is broader than that resulting from a direct green, InGaN-based LED

to a record 150 lm (280 mW) at 350 mA (see Figure 5 for plots of this 533 nm LED). This corresponds to an efficacy of 135 lm/W – compared with 108 lm/W for the 1 mm^2 chip.

Increasing currents to higher values leads to far greater output at slightly shorter wavelengths: Driven at 700 mA, the chip emits 248 lm and 480 mW at a peak wavelength of 531 nm; and cranking up the current to 1A propels the output to 313 lm and 620 mW, with peak wavelength shifted to 529 nm. The latter figure, which equates to more than 310 lm (600 mW) at a current density of 50 A cm^{-2}, is an enabling technology for high-performance projection systems based on red, green and blue LEDs. Efficacies at very low drive currents are particularly impressive. They exceed 190 lm/W at 100 mA, and are in excess of 300 lm/W below 2 mA.

Pumping phosphors

An alternative approach for making a green emitter is to take a blue LED and add a green phosphor. We have investigated this, using a ceramic platelet of the green phosphor lutetium aluminium garnet (LuAG). This pumping approach creates a significantly different green emission profile: the emitter features a 531 nm peak wavelength, a Gaussian peak at 525 nm and a full-width half maximum (FWHM) of 33 nm; while the chip-phosphor combination produces a peak wavelength of 529 nm, has a central wavelength of 557 nm and produces a FWHM of 99 nm (see Figure 6). A broader emission profile has its pros and cons. It's favourable for general lighting because it offers a high CRI, but a narrower emission is preferred in applications such as projection. There, the smaller spectral bandwidth of direct-green LEDs quashes cross talk, leading to higher system efficiency. What's more, if direct-green LEDs are used for projection, they can cover a wider colour range than a converted green solution (see Figure 7).

However, a blue LED and a green phosphor is still an attractive option, because it avoids issues associated with the green gap. Although there are inevitable losses associated with the Stokes shift, pumping a phosphor with a blue chip leads to higher efficiencies, because droop is not as strong at shorter wavelengths (see Figure 8). In addition, internal piezoelectric fields are weaker in blue LEDs, leading to lower electrical losses. We have compared the luminous flux and the efficacy of the two different

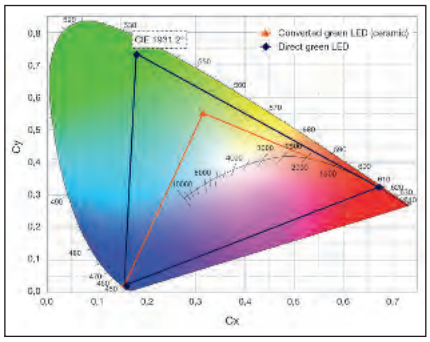


Figure 7: The CIE 1931 colour space chromaticity diagram shows two red-green-blue approaches with given red (610 nm) and blue (450 nm) LEDs used in combination with a direct green InGaN LED or a phosphor-converted green LED. The narrower emission spectra of a direct green InGaN LED, compared to green generated by phosphor conversion, makes this device better suited to projection

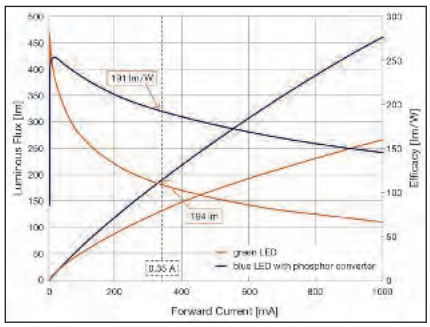


Figure 8: Current-dependent luminous flux and efficacy of two different approaches to generate green light. Whereas the green InGaN/GaN LED shows significant droop at high operating currents, a blue LED in combination with a phosphor converter yields higher efficacy and luminous flux at a typical driving current

approaches, using ThinGaN chips 1mm^2 in size. At lower current densities, the green LED is more efficient than its blue cousin, there are no conversion losses, and efficacy is 291 lm/W at 1 mA. However, efficacy falls rapidly as current increases, and is just 108 lm/W and 66 lm/W at 350 mA and 1 A, respectively. Blue LEDs, in comparison, are more efficient at higher current densities, with efficacy peaking at a current of 20 mA. Driven at 350 mA, the blue LED and green phosphor combination emits 194 lm at 191 lm/W, and at 1A delivers 462 lm at 145 lm/W.

Several routes are available for increasing the efficiency of the direct green LED, so that it closes the performance gap with the blue-chip-and-phosphor combination: Carrier density could be cut by increasing the volume of the active region via the addition of more wells; internal quantum efficiency could be increased through improvements to material quality; and the active area could be increased by optimising the design of the chip and its dimensions. In our view, the pathway with most potential is to improve the epitaxial growth process, because this could lead to a lower forward voltage and superior carrier transport.

We gratefully thank the German Federal Ministry of Education and Research (BMBF) for financial support (grant number 13N9974, ''High Quality LED'') for the development of direct green LEDs. We also appreciate the support of numerous colleagues at Osram and Osram Sylvania.

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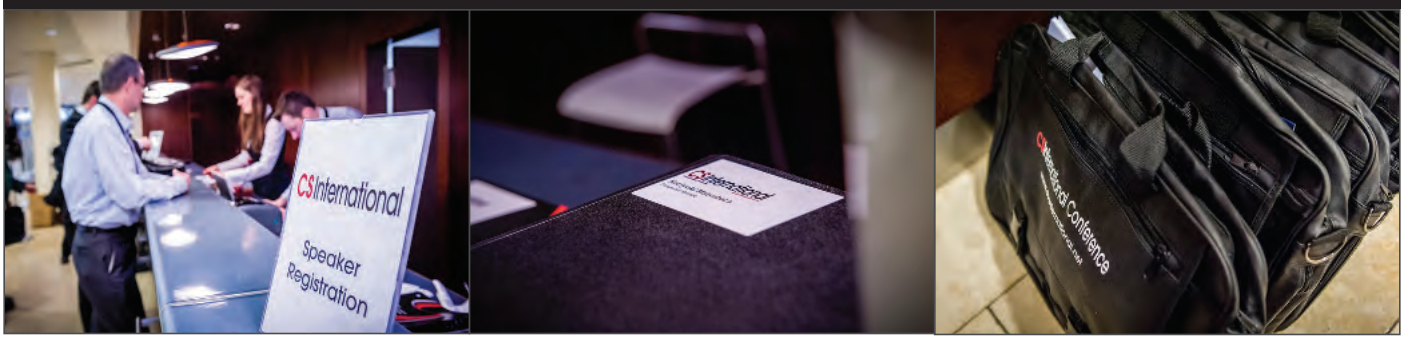

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Pursuing pathways to widespread adoption of solid-state lighting

The solid-state lighting revolution will be spurred by plummeting LED costs and improvements to the quality of emitted light. Success on these fronts could be aided by refinements to existing technologies; the introduction of GaN-on-silicon LEDs; a move to colour mixing of red, green and blue LEDs; and a switch from LEDs to lasers as the primary lighting source. All options were discussed at the International Conference on Nitride Semiconductors. Richard Stevenson reports.

IT CAN BE ARGUED that the nitrides, like graphene, are worthy of the moniker 'the wonder material'. Attributes of GaN and related alloys include incredibly efficient emission in the violet and blue, a very high electric field strength that has led many to tip this material as the future for power electronics, and the capacity to form chips with a power density that is far greater than that produced with the likes of GaAs and InP.

However, that is not to say that the III-Ns are faultless. This family of materials have a significant lattice mismatch with one another, which hampers the development of many devices, particularly VCSELs and multi-junction solar cells. Another major impediment to device performance is the lack of a straightforward process for forming a boule of GaN, which could be sliced to form native substrates, while even the most impressive device to date, the LED, still needs to make headway to unlock the door to a revolution in solid-state lighting.

Developments that could spur this revolution were a prominent feature at the tenth International Conference on Nitride Semiconductors (ICNS), which was held in Washington from 25th to 29th of August. Delegates attending this meeting learnt of: aggressive cost reduction of GaN-on-SiC LEDs; the development of high-performance GaN-on-silicon LEDs; improvements in the efficiency of green and yellow LEDs, which will aid the development of high-colour quality white light sources; the opportunity for lasers

The Gaylord Conventional Centre, situated on the bank of the Potomac river, hosted the tenth International Conference on Nitride Semiconductors. This meeting, which was held from 25th to 29th August, attracted about 900 delegates

to replace LEDs and make solid-state lighting more efficient; and advances in the efficiency of blue and green lasers.

Cutting costs on SiC

One company that is already making lighting products with its own LEDs is the US firm Cree. At ICNS, one of Cree's senior scientists, Hua-Shuang Kong, detailed improvements in the efficacy of the company's LEDs. This firm is also trimming production costs, which will help to make a more compelling case for solid-state lighting. The fall in the cost per lumen realised by this vertically integrated firm – Kong described Cree's activities as spanning "from dust to device to market" – was 45 percent in 2011, 40 percent in 2012, and should be 43 percent this year.

This increase in the bang-per-buck has been assisted by a continual improvement in the efficiency of the LED. Back in February, Cree claimed that it had broken the efficacy record for an LED driven at 350 mA with a device emitting 276 lm/W at a colour temperature of 4401K. And the performance of LEDs coming off of the production line is not that far behind, with the MK-R series that was launched in late 2012 delivering 200 lm/W.

In Kong's opinion, the high level of performance stems from an excellent chip architecture and a high-quality SiC substrate, which forms a better platform than the more widely used material, sapphire. At Cree, LEDs are grown on single crystal 4H SiC that combines a high thermal conductivity – it is 4.2 W cm^{-1} K^{-1} in the *a*-direction and 3.7 W cm^{-1} K^{-1} in the *c*-direction – with excellent transparency in the visible. Thanks to an absorption coefficient of less than 1 cm^{-1}, these substrates enable the fabrication of an LED with a very high extraction efficiency. To increase light extraction, Cree's engineers use a ray-tracing model to optimise chip geometry. By considering various aspects of chip design, including bevel cuts, internal mirrors, flip-chip geometries and surface texturing, engineers have increased the light extraction from a 1 mm^2 chip to 88 percent. According to Kang, state-of-the-art room-temperature performance of blue LEDs emitting at 447 nm is now an output of 782 mW and an efficiency of 79 percent at a 350 mA drive current.

Cree's blue LEDs are combined with yellow phosphors to make cool-white emitters, while warm-white variants use this chip to pump yellow and red phosphors. Both forms of white emitter are inserted into lighting products, where efficacy is compromised by thermal, optical and driver-related losses, according to Kong. He revealed that a chip emitting 115 lm/W at a colour temperature of 2700K delivers just 75 lm/W in a fixture, while a 6000K LED with a figure of 160 lm/W on the data sheet creates a fixture producing only 104 lm/W.

Fortunately fixture efficacies, like those of the LEDs, are improving, while purchase prices are falling. Back in 2008, Cree's LR24 Troffer retailed for $400, had a colour-rendering index (CRI) of 90, and produced 3200 lm at 65 lm/W. Fast forward to today and the same light output is possible at 100 lm/W, while the purchase price has plummeted to $159.

Increases in the efficacy in lighting fixtures will continue, driven by gains in LED efficiency. By 2015, Kong expects LEDs with colour temperatures of 6000K and 2700K to produce 210 lm/W and 151 lm/W, respectively, while fixtures based on them will deliver 174 lm/W at a CRI of 75 and 125 lm/W at a CRI of 83, respectively.

Silicon-based LEDs

One promising option for accelerating the cost reduction in LEDs, and ultimately speeding the introduction of far more affordable solid-state lighting, is to switch to growing these devices on a silicon substrate.

"To replace the fluorescent lamp, we must reduce the cost [of LEDs] more and more," proclaimed Youngjo Tak from Samsung Advanced Institute of Technology, Korea. In his talk, he argued that that although the cost-per-lumen for LEDs grown on sapphire is falling, it will plateau in 2015. So, in the long-term, alternative platforms are needed to make light-emitting chips more affordable.

Switching from 4-inch or 6-inch sapphire to 200 mm silicon is an attractive option, because it can cut costs by 31 percent and 48 percent, respectively. That's partly because the sapphire substrates are not that cheap – according to Tak, it is typically $500 for 6-inch sapphire and $1500 for an 8-inch equivalent – and also because LEDs grown on silicon can be processed in depreciated silicon fabs.

The development of GaN-on-silicon LEDs is no longer in its infancy. Initially, the efficiency of these devices fell a long way short of the incumbents, but the difference is closing fast. "[It's now] less than 10 percent," claimed Youngjo Tak.

He is not the only researcher to claim that this gap is minimal: "GaN-on-silicon LEDs have comparable efficiency to GaN-on-sapphire," revealed Martin Albrecht from the Leibniz Institute for Crystal Growth, who has been working with engineers

at Osram Opto Semiconductors and the MPIE, Germany.

Albercht unveiled details of performance of this team's latest LEDs. They require just 2.91 V to operate at 350 mA, and when combined with phosphor technology, they produce 104 lm/W of warm-white light with a colour-rendering index of 83. The efficacy increase over last year's devices is mainly due to a 6 percent fall in output voltage, which has stemmed from improvements to the epitaxial layers and the quality of the quantum wells.

Tak, in contrast, did not disclose the latest results from his group. But he did reveal that the performance of these LEDs, which are grown on 200 mm silicon, is much higher than that of the devices announced at the 2011 ICNS meeting. Back then, Samsung's researchers extracted 580 mW from a 1 mm by 1mm LED grown on 4-inch silicon. The device was driven at 350 mA under a forward voltage of 3.2 V.

Highlights of Tak's talk included insights in the difficulties of growing GaN-on-silicon LEDs, and how to overcome them. One of the biggest challenges stems from the significant lattice and thermal mismatches between the substrate and epitaxial layers. These differences can cause the wafer to bow, or even crack.

A common approach to addressing this is to turn to a buffer structure that fine-tunes the stresses and strains in the epistructure. According to Tak, with this approach Samsung's engineers can realise a bow of less than 30 μm. They have found that in order to realise a very low bow, it is critical to start with a silicon substrate with a low degree of warp. One downside of the buffer structure is that in order for it to be effective, it can have to be quite thick, and that adds substantially to the time and cost of producing an LED epiwafer. But Samsung's engineers are addressing this: Their latest LED epistructures are about 5 μm-thick, compared with 8 μm of growth for the previous generation of devices. "They have a similar processing time to sapphire," said Tak.

Enhancing colour quality

It is possible to build white light sources with a high colour quality by switching from a phosphor-based approach to the mixing of the output of red, green and blue sources. Unfortunately, this form of lighting system, which can be used to make projection sources, is currently held back by the efficacy of the green LED, which is far behind that of its blue and red counterparts.

This weakness is known as the green gap. While GaN LEDs can be very efficient in the blue, and GaAs-based devices can produce high efficiencies in the red, neither maintains their performance when the composition in the quantum wells is adjusted so that it emits in the green (or the yellow). The arsenide material system will never emit efficiently in the green, because carrier confinement is so weak in this spectral range, but it is possible that nitride LEDs could emit more efficiently at longer wavelengths.

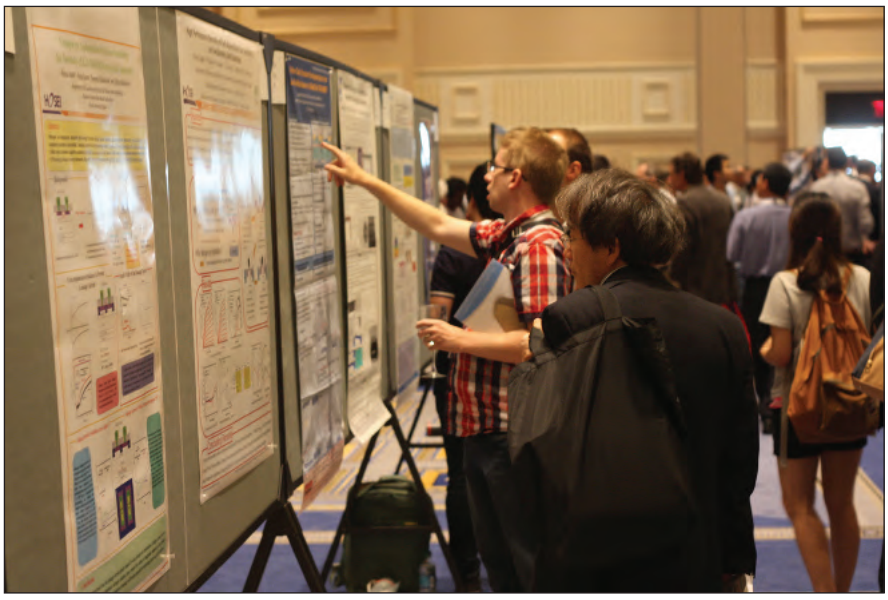
One of the weaknesses of GaN-based devices is that they are plagued by strong internal electric fields, but this can be mitigated by turning to thinner quantum wells that increase electron-hole overlap and therefore enhance carrier recombination. The performance of these LEDs is also hampered by deterioration to material quality that occurs when indium content is increased in the well so that its emission is pushed to longer wavelengths.

Encouraging news coming out of ICNS is that a novel active region can combat the green gap. Speaking on behalf of Toshiba's Corporate R&D Centre, Rei Hashimoto revealed that a modified active region – it contains 3 nm-thick InGaN quantum wells capped with a 1 nm-thick AlGaN barrier, prior to the deposition of a 10 nm-thick InGaN barrier – enables the fabrication of very efficient yellow-emitting LEDs. Driven at 20 mA, these devices produce a peak emission at 570 nm, and emit 8.4 mW at an external quantum efficiency of 19.3 percent. Indium content in the well is estimated to be about 25 percent, and less than 1 percent in the barrier.

Hashimoto argued that one of the key benefits of the new design of active region is an improved surface flatness. He and his co-workers optimised the growth conditions for the quantum wells and barriers, and by selecting the ideal growth temperature, they eliminated indium-rich clusters at the surface.

An alternative approach to forming a solid-state, green-emitting source was outlined by Thomas Lehnhardt from Osram. He revealed the results of a project using a blue LED to pump a green-emitting active region made from InGaN quantum wells. This approach culminated in the construction of a 1 mm by 1 mm device emitting at 535 nm with a wall-plug efficiency of 22 percent. Efficacy for this device is 127 lm/W, and could rise to 138 lm/W by inserting Osram's latest LEDs, which have a lower forward voltage for the same drive current.

Lehnhardt made a strong case for using this form of complex, green-emitting structure in preference to a direct-emitting green LED. He pointed out that using a blue-pump source makes



ICNS featured three posters sessions, which were all well attended

this device less susceptible to droop, the decline in the efficiency of a nitride LED at higher current densities. What's more, he explained that the blue LED has a higher electrical efficiency than a green-emitting variant, despite its higher bandgap; and that the green emitting, optically pumped structure does not suffer from an electron-hole imbalance, which is detrimental to a conventional green LED.

Trials of this novel green emitter have involved the growth of epistructure featuring a 40 period multi-quantum well. This is estimated to deliver an external quantum efficiency of 50 percent. To boost green emission and prevent significant output in the blue, three of these multi-quantum well structures were stacked on top of one another.

From LEDs to lasers

A radical alternative for solid-state lighting is to use lasers, rather than LEDs, as the primary light source. Jonathan Wierer from Sandia National Laboratories, Albuquerque, outlined this proposal, which could use a laser to pump a phosphor. He explained that he and his co-workers have tried this, and found that the colour quality is comparable to that produced by LED pumping: "Despite spiky spectra, you get good colour rendering." Wierer also reminded the audience that this approach is already being pursued by the German automaker BMW, which is developing laser-based headlights.

The attraction of lighting with lasers, rather than LEDs, is that the former class of device is not plagued with droop. This opens the door to high efficiency at high current densities, so fewer chips are needed in a fixture, and those that are employed require less thermal management. Although Weirer calculates that LEDs will get more efficient, he believes that lasers will also improve, so laser-based lighting will continue to have the potential to offer the greatest efficacies in the future.

Delegates gained insight into the efficiency of some of the latest lasers in a talk given by Osram's Adrian Avramescu, who revealed significant advances in the performance of the company's green and blue laser diodes developed in the lab. According to Avramescu, the company's green lasers, which emit around 520 nm, now deliver a kink-free output up to 250 mW and have a wall-plug efficiency of 8.7 percent at 150 mW. Meanwhile, the company's blue lasers produce an output of up to 4 W, and at 1.6 W they have a conversion efficiency of 30 percent.

Avramescu pointed out that the main applications that Osram intends to target with its green lasers are small projectors, speciality lighting, assistance with surveying and head-up displays. Small projectors, which could soon feature in mobile phones, combine red, green and blue lasers with a two-axis mirror to form a technology known as flying-spot laser projection. "You build your image up pixel by pixel," explained Avramescu.

> "The blue LED has a higher electrical efficiency than a green-emitting variant, despite its higher bandgap; and that the green emitting, optically pumped structure does not suffer from an electron-hole imbalance, which is detrimental to a conventional green LED."

Requirements for lasers used in small projectors include an output of about 80 mW, or 20 lumens. Blue lasers that the company launched in 2009 meet this, while the direct green variants that hit the market in 2012 fall short of the mark, producing 50 mW, equating to 12-13 lumens. In addition, the emission profile from these chips is not the ideal Guassian profile that is preferred for projection applications, due to interactions with the substrate.

All these weaknesses have now been remedied in the lab, thanks to various efforts at understanding the behaviour of the green laser diode. First-generation devices produced a sub-linear output above 50 mW, and investigating this decline in efficiency led the engineers at Osram to discover that the laser's differential gain varies with temperature. Self-heating and a high threshold current are partly to blame, along with imperfection injection.

Material gains

Research efforts were also directed at material issues. Dark spots were found with dimensions of 1-20 μm, alloy fluctuations were uncovered at 50 nm to 500 nm length scales, and transmission electron microscopy uncovered defects in the quantum wells, such as dislocations.

Improving the quality of the material and making proprietary modifications to laser design enabled the fabrication of higher output green lasers with improved beam quality. At 80 mW – the output power required for small projectors – efficiency is 7.5 percent at 25 °C and 7 percent at 60 °C.

Avramescu also explained that Osram's more powerful blue laser is suitable for projectors in homes and offices, which require 2000 lumen sources. In 2012, the company launched a 1.4 W blue laser in a TO56 package, and now it has raised the bar to 2.5 W at 25 °C.

Packaging is very important at these power densities, and by optimising this it is even possible to crank the output up to 4 W. However, Avramescu explained that this involves driving the chip in an "over-stressed" regime.

It will be interesting to see how laser performance improves over the next year, and whether efforts to use this source for general lighting take off. Progress occurring over this timeframe will not be reported at ICNS, because this is a biannual meeting, but the international nitride community will get together next year at the International Workshop on Nitride Semiconductors. This will be held in Poland, in the last week of August, 2014.

Building brighter and cheaper UV LEDs

It is far more challenging to make a bright, cheap ultra-violet LED than one emitting in the blue. But success is promised with a transparent contact layer, reflective electrodes, photonic structures and growth on silicon, says Hideki Hirayama from RIKEN.

THE PERFORMANCE OF THE NITRIDE-BASED LED continues to improve, opening-up new, lucrative markets. Billion dollar annual revenues began for this class of chip when it lit the keypads and backlights of mobile phones. More recently, unit shipments have surged as this solid-state source has seen widespread deployment in TVs, tablets and computer screens, and now it is starting to be deployed in lighting, in replacements for incandescent and fluorescent lamps.

One of the next big challenges for the LED is to replicate its performance in the blue – which can be converted to white by combining the chip with a yellow phosphor – in the deep ultra-violet (DUV) region of the optical spectrum, which is wavelengths of about 280 nm and below (see Figure 1). A solid-state source emitting in this spectral region could provide a replacement for mercury lamps used for sterilization, which are not ideal, because they are not monochromatic and they generate heat. A UV LED chip emitting monochromatic radiation at 270 nm, the ideal wavelength for sterilization, could address both these issues and find deployment in the home, where it would be used in refrigerators, water and air purifiers, air conditioners, foot curing systems, and vacuum cleaners. What's more, a UV LED could be used to aid the transportation of foods; help to make bank notes more difficult to forge; and be deployed in sterilization equipment in hospitals and large systems, such as water tanks and air conditioners found in office blocks.

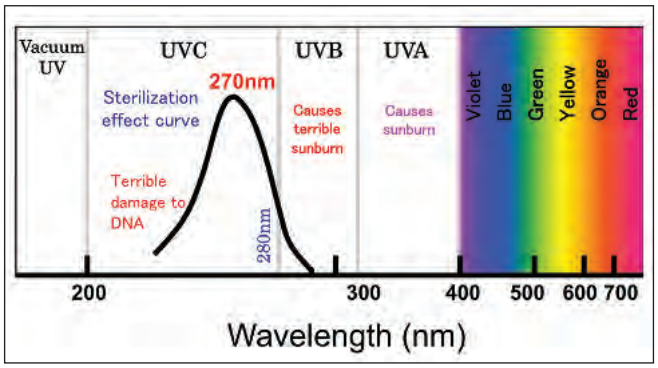


Figure 1. The ultraviolet spectrum can be sub-divided into the UVA, UVB, UVC and vacuum UV ranges. Emission at 270 nm can be used for sterilization, due to the damage that it can cause to DNA

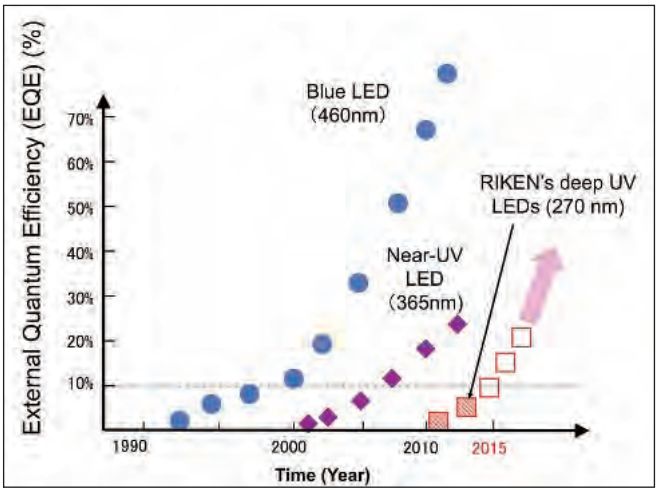


Figure 2. The efficiency of LEDs emitting in the deep UV is significantly less than that for the blue

There are also other commercial opportunities for ultraviolet, solid-state sources. They could be used for medical treatments, such as skin care; enable high-speed dissociation of pollutant materials; play a role in high colour-rendering illuminations; and form the heart of a new generation of high-density optical storage devices.

But to make significant inroads into every one of these promising markets will require a significant improvement in the efficiency of UV LEDs operating at around 280 nm and below (see Figure 2). Back in 2010, several groups announced efficiencies for these DUV LEDs of more than 1 percent, and recently values of 5-14 percent have been reported (see Figure 3). If this level of improvement is maintained, the DUV LED market could take off in 2015.

Our team at RIKEN, a research institute just outside Tokyo, Japan, is one of the leading developers of these devices. Working in partnership with Panasonic, we are developing 270 nm LEDs that will be launched on the market that combine efficiency in excess of 2 percent with a lifetime of more than 10,000 hours.

Results in our lab for this class of LED include an external quantum efficiency (EQE) of 7 percent. This compares to reports at the International Conference on Nitride Semiconductors in 2013 (ICNS-10) of an EQE of about 7 percent for Crystal IS' DUV LED that was fabricated on a single-crystal AlN substrate, and efficiencies of 14 percent and 11 percent from UV Craftory and Sensor Electric Technology Inc. So, at this stage, we are slightly behind the state-of-the-art values for external quantum efficiency. However, we have a program in place that could enable us to overtake the leaders.

Just reaching 7 percent EQE was not easy, and required improvements to many aspects of the device, including the internal quantum efficiency (IQE), electron injection efficiency and light-extraction efficiency – it is the product of these three that determines the EQE.

Now we are taking radical steps in LED design, such as the formation of the device on an array of AlN hexagonal pillars, to take device EQE to double-digit efficiencies. In addition, we have started a programme to slash the cost of DUV LEDs by growing the devices on silicon substrates.

Increasing internal efficiencies

Between 2006 and 2010, we focused our efforts on increasing the internal quantum efficiency (IQE) of our devices. When we started, this was below 1 percent, and it has been increased through improvements in material quality. The key has been the development of a low threading-dislocation density AlN buffer on sapphire, which is produced with ammonia pulse-flow multi-layer growth. With this deposition technology, we have formed AlN layers with atomically flat surfaces and threading-dislocation densities of just 3×10^8 cm^{-2}.

Diminishing this threading-dislocation density increased the IQE from the AlGaN quantum well to over 60 percent. Even higher values are possible with InAlGaN wells: We estimate that they can produced an IQE in excess of 80 percent, thanks to indium segregation effects in the quaternary alloy. Segregation causes carrier localisation, and this supresses non-radiative recombination. Further improvements to DUV LED performance have resulted from increases to the electron injection efficiency through the introduction of a multi-quantum barrier, electron-blocking layer. This electron-blocking structure is especially beneficial for DUV LEDs emitting below 250 nm.

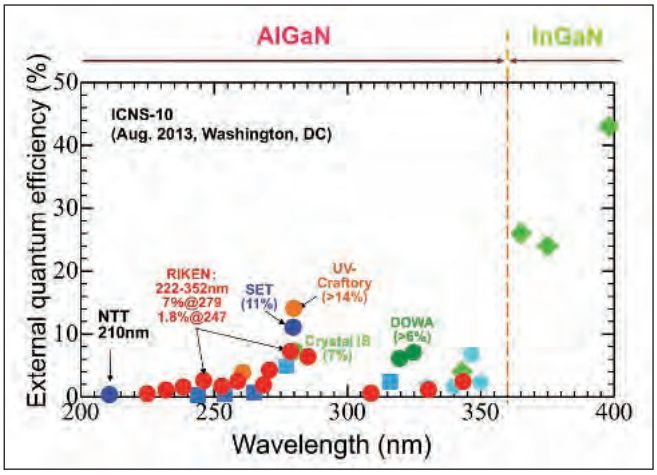


Figure 3. Some of the leading deep UV developers, including US firms Sensors Electronic Technology and Crystal IS, plus UV Craftory and RIKEN from Japan, reported EQE results at the International Workshop on Nitride Semiconductors in 2012 and ICNS 2013

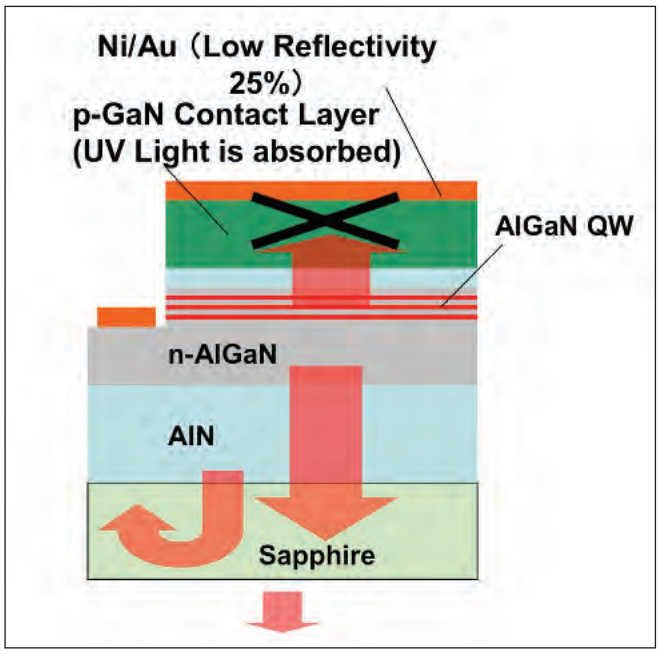


Figure 4. To enable efficient light extraction, deep-UV LEDs need to have a markedly different architecture from their blue cousins. The conventional *p*-type contact, GaN, absorbs UV light, which is partially reflected back into the device at AlN/sapphire and sapphire/air interfaces

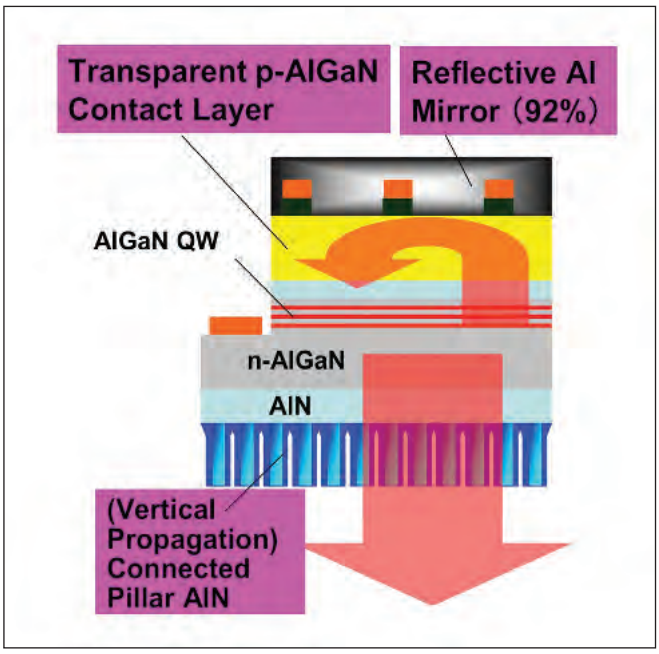


Figure 5. Light extraction in deep UV LEDs can be improved by: switching from *p*-GaN to *p*-AlGaN, a transparent contact layer; using a highly reflective mirror for this wavelength range; and forming the device on connected AlN pillars that channel light out of the chip

Despite these significant improvements, devices still produced a low output power due to poor light extraction efficiency. There are two reasons for this: All the light that exits the quantum well towards the top surface of the chip is absorbed by the *p*-GaN contact layer; and much of the light that exits towards the substrate is reflected back into the device, due to significant refractive index differences at both the sapphire/air and AlN/sapphire interfaces (see Figure 4). A result of all of this is that light extraction efficiency is restricted to just 8 percent.

To address the absorption of light by the *p*-GaN contact layer, we switched to a transparent *p*-AlGaN contact (see Figure 5). Making this adjustment in isolation can increase light extraction efficiency to more than 40 percent, but at the expense of hole injection efficiency. When high-aluminium-content *p*-AlGaN is used, the deep acceptor level of the magnesium dopant can limit the hole density to less than 10^{15} cm^{-3}. This meant that when we fabricated 265 nm DUV LEDs with a high-aluminium-content *p*-AlGaN contact layer, the EQE of the device was no better than its predecessors. However, the EQE was not significantly worse either, and as we shall see in the next paragraph, that held the key to a generation of brighter devices. To first determine what the appropriate compositional wavelength of *p*-AlGaN is, we varied this between 290 nm and 270 nm, which corresponds to aluminium compositions of approximately 48-60 percent. This short study revealed that *p*-AlGaN with aluminium composition as high as 60 percent is useful for the contact layer of a DUV LED (see Figure 6).

Validation of this choice of aluminium composition came from another set of experiments, where we fixed the compositional wavelength of *p*-type AlGaN at 270 nm, corresponding to an aluminium composition of 60 percent, and changed the emission of the quantum well from 265 nm to 282 nm. This revealed that the 270 nm *p*-AlGaN contact layer is transparent for emission at wavelengths longer than 280 nm. Our final step in this particular effort was to address the aforementioned reduction in the hole density that resulted from the switch from *p*-GaN by *p*-AlGaN. We compensated for this by adding a higher electron-blocking structure: A higher-aluminium-

> “All the light that exits the quantum well towards the top surface of the chip is absorbed by the p-GaN contact layer; and much of the light that exits towards the substrate is reflected back into the device, due to significant refractive index differences at both the sapphire/air and AlN/sapphire interfaces. A result of all of this is, light extraction efficiency is restricted to just 8 percent”

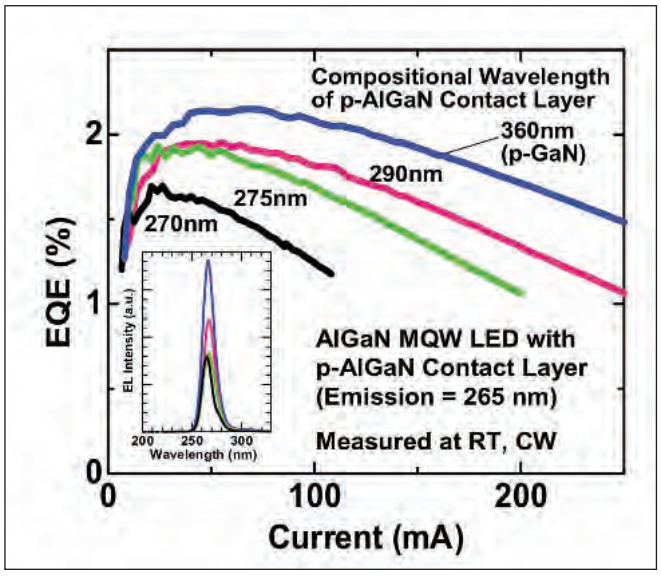


Figure 6. The aluminium composition in AlGaN can be reduced without a large impact on EQE. This indicates that an AlGaN layer, which is less absorbing than GaN, could lead to higher efficiencies in a modified device. The downside of *p*-AlGaN is a lower hole density, but this can be compensated with a better electron blocking layer. When researchers at RIKEN followed this path, their devices delivered far higher EQEs than before

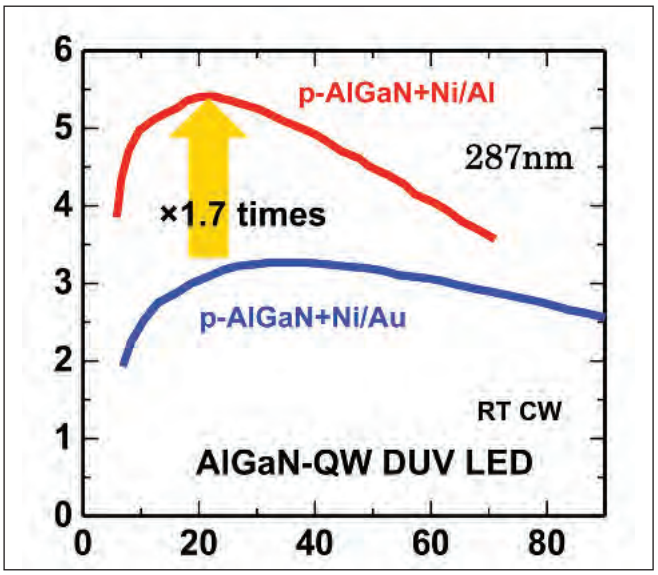


Figure 7. To take the EQE of its deep UV LEDs from about 3 percent to 5.5 percent, RIKEN's researchers used *p*-AlGaN contact layer and switched from a Ni/Au contact to Ni/Al

content AlGaN, multi-quantum barrier electron-blocking layer. The other issue that we faced – that the substrate reflects light back into the device – was addressed by introducing a new device architecture with a highly reflective *p*-electrode mirror. Why did we do this, rather than simply turning to a transparent electrode? Well, although that is a good approach for the blue LED, thanks to the availability of transparent ITO, no material can fulfil that role in the deep UV.

One candidate material for making the mirror is aluminium, which has a reflectivity of 92 percent at UVC wavelengths (280 nm to 100 nm). However, aluminium cannot form a *p*-type ohmic contact on *p*-type AlGaN, so we first insert a sub-nanometre-thick layer of nickel. Reflectivity with this combination is 64 percent, which is far superior to the conventional pairing of nickel and gold, which produces a reflectivity of just 30 percent. Note that another option for our highly reflective *p*-contact is a mesh-pattern electrode. If we decide to go down that road, we will need to insert a *p*-type, AlGaN hole-spreading layer beneath the electrode, which could be formed with a short-period superlattice. This structure could also help to combat an increase in forward voltage of about 5 V, which resulted from replacing *p*-GaN with *p*-AlGaN.

Our efforts at switching from *p*-GaN to *p*-AlGaN and adding a reflective contact were rewarded. With the new blocking layer in place, switching to the *p*-AlGaN contact layer increased EQE by about 50 percent, and a further efficiency gain of 70 percent resulted from the transparent *p*-AlGaN contact layer and highly reflective *p*-electrode (see Figure 7).

Increasing light extraction

One route to making further improvements in LED light extraction is to introduce photonic nano-structures, such as two-dimensional photonic crystals or moth-eye patterns. We are investigating this possibility and introducing a connected-pillar AlN buffer beneath our devices. An array of AlN pillars should increase device efficiency by allowing light to propagate vertically along the array, and it should also enhance material quality, because the threading dislocation in the pillars should be quite low.

Our efforts in this direction begin by taking patterned sapphire substrates and growing connected, hexagonal-shaped AlN pillars on them by controlling the V/III ratio and growth temperature (see Figure 8). To reduce the threading dislocations in these structures, an ammonia pulse-flow method is employed in the initial stage of AlN pillar growth. Once the array is formed, we reduce the V/III ratio, so that the pillars merge to form a flat surface. The threading dislocation density in the pillars is low, according to cross-sectional images provided with a transmission electron microscope.

These connected pillars have formed the foundation for 265 nm LEDs that deliver a continuous output of over 5 mW and have an EQE of a few percent. This work is still in its infancy, and we know that the external quantum efficiency of our devices will be far higher when we optimise the surface roughness of a connected pillar AlN buffer. We expect that by combining a transparent *p*-AlGaN contact layer with a connected-pillar AlN buffer, we will be able to increase the external quantum efficiency of our DUV LEDs to several tens of percent.

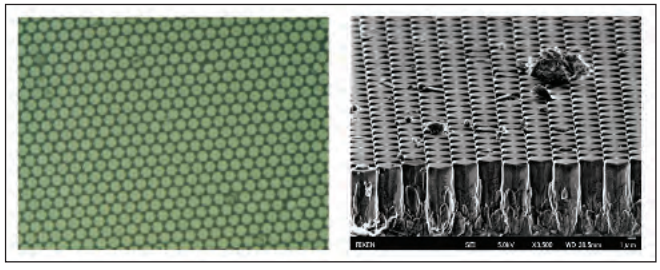


Figure 8. The array of hexagonal AlN pillars was formed by ammonia pulse-flow growth on patterned sapphire

> Silicon is a very attractive substrate for UV LEDs. It is cheap, it is available in large sizes and it is easy for it to be separated from the LED epitaxial structure with wet chemical etching. That step is essential, because silicon absorbs the device's emission, and once it has been removed, it is possible to fabricate vertical LEDs

Silicon foundations

Silicon is a very attractive substrate for UV LEDs. It is cheap, it is available in large sizes and it is easy for it to be separated from the LED epitaxial structure with wet chemical etching. That step is essential, because silicon absorbs the device's emission, and once it has been removed, it is possible to fabricate vertical LEDs. Such structures can also be made with LEDs formed on sapphire, but the substrate has to be removed with laser lift-off, and this damages the material.

We have developed a fabrication process for making DUV LEDs on silicon (see Figure 9 for the device structure). It consists of AlGaN LED growth on silicon, wafer bonding to a heat sink, silicon wafer removal, dry etching of AlN and fabrication of a mesh electrode. With this approach, the biggest challenge is to grow crack-free AlN on silicon, due to the significant difference in the thermal expansion coefficient of these two materials. One way that we have addressed this is to fabricate an AlN buffer on silicon by ammonia pulse-flow growth. Within 1 μm of buffer growth, we obtained a crack-free film with a low threading dislocation density. This provided a platform for the growth of a range of DUV LEDs on silicon that featured an InAlGaN quantum well and produced emission from 284 nm to 300 nm.

We have also explored epitaxial lateral overgrowth for the deposition of crack-free AlN on silicon. Again, we began by depositing an AlN layer on silicon using an ammonia pulse-flow method, before fabricating a stripe pattern on this binary and then growing the ELO layer. With this approach, we realised a low threading dislocation density, 3 μm-thick AlN buffer layer on silicon and demonstrated a series of DUV LEDs featuring AlGaN quantum wells emitting between 256 nm and 278 nm.
We are now planning to remove the substrate and develop vertical DUV LEDs. This should lead to devices with low operating voltages and high light extraction that will help the UV LED industry to serve many applications that would benefit from an affordable solid-state, portable source of light.

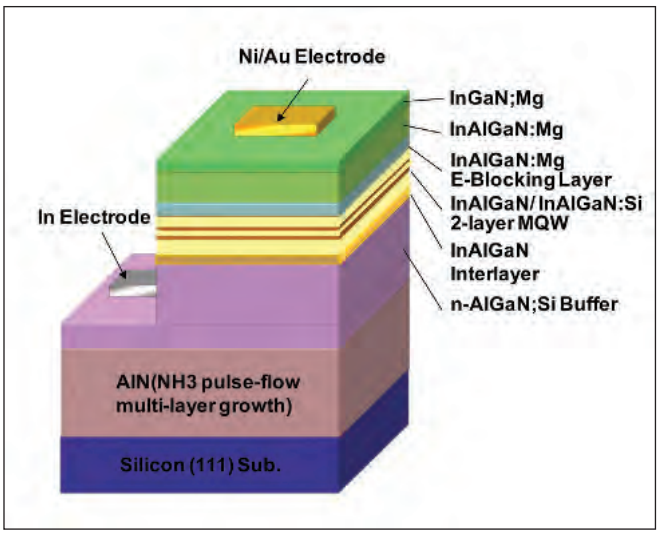


Figure 9. Moving from a sapphire substrate to one made with silicon aids the development of vertical LEDs. A damaging laser lift-off process has to be used to separate the epitaxial stack from sapphire, but with silicon a wet chemical etching approach can be employed to yield a pristine chip

Further reading

Sachie Fujikawa *et al.* Appl. Phys. Express **4** 061002 (2011)
Takuya Mino *et al.* Appl. Phys. Express **4** 09210 (2011)

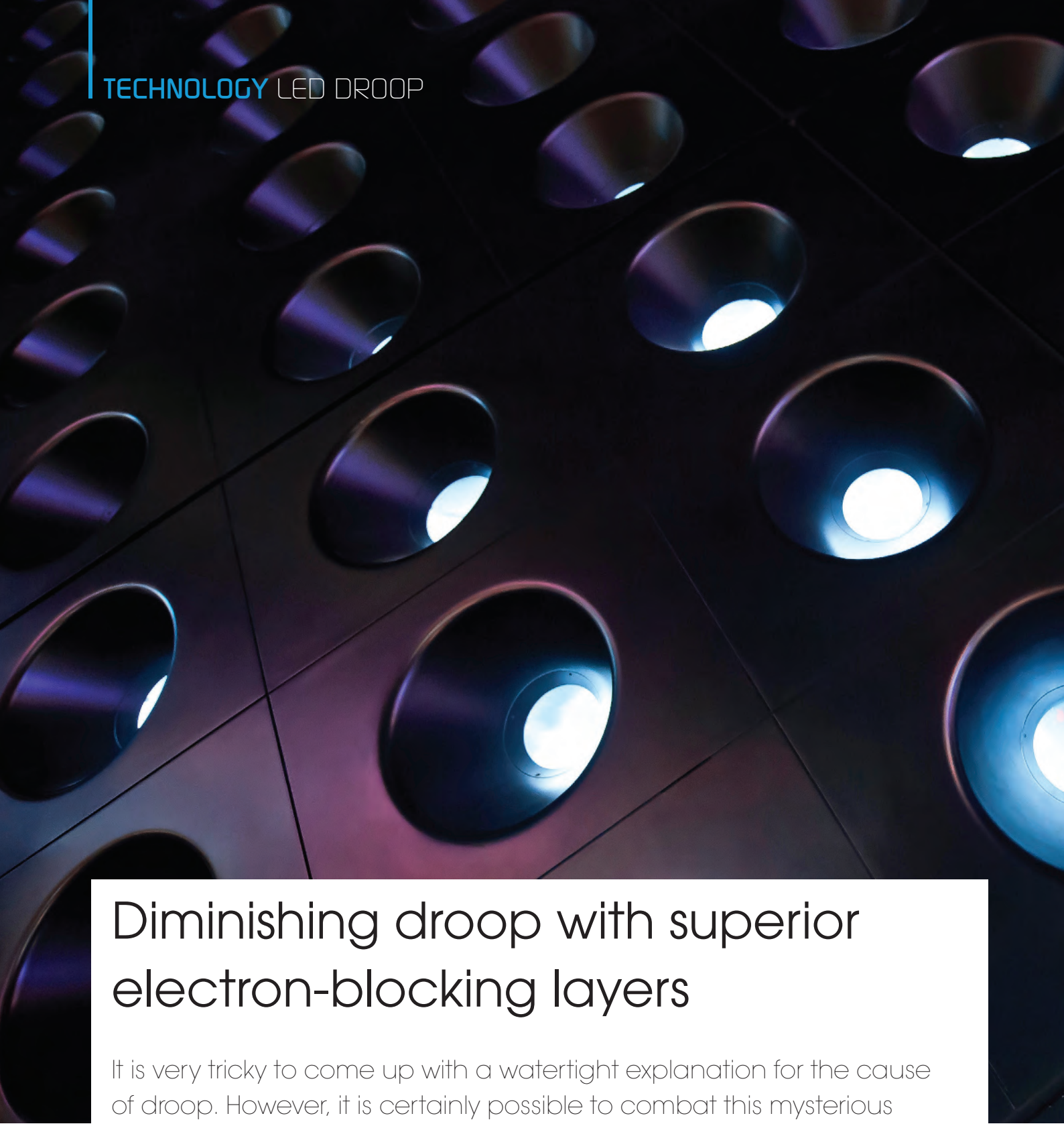
QCLs at RIKEN

In addition to RIKEN's development of DUV LEDs spanning 220 nm to 350 nm, the leading research institute has a programme devoted to the development of terahertz quantum-cascade lasers.

One notable success is the record for the highest temperature, stable operation of lasers emitting in the 2-4 THz range. Thanks to the use of a novel quantum-cascade structure, the researchers fabricated a 1.9 THz device that can operate at 160K.

The team is also developing QCLs based on the pairing of GaN and AlGaN, which have the potential to cover the 5 Thz to 12 THz range and operate at relatively high temperatures. The GaAs-based material system is not ideal for operating at these frequencies, due to phonon interactions.

RIKEN's researchers are the first group to report spontaneous emission by current injection from an AlGaN-based QCL structure. Their device has a 150 period active region based on GaN and $Al_{0.2}Ga_{0.8}N$ and emits at 1.37 THz.



Diminishing droop with superior electron-blocking layers

It is very tricky to come up with a watertight explanation for the cause of droop. However, it is certainly possible to combat this mysterious malady, which causes LED efficiency to decrease at high current densities, by: turning to better electron-blocking layers made from InAlN; and improving the injection of holes into the wells, plus their distribution throughout the active region, argues to Jae-Hyun Ryou from the University of Houston, Russell Dupuis and P. Douglas Yoder from Georgia Institute of Technology and Fernando Ponce from Arizona State University.

LED LIGHT BULBS have many attractive attributes: lifetimes of 50,000 hours, negligible warm-up times, the absence of mercury, and higher efficiencies than incumbent sources.

However, the retail prices of these lamps are too high to tempt the majority of the public to invest in solid-state lighting, partly because the gains in efficiency over compact fluorescents are not yet to be that alluring. What's needed is for the LEDs that are used in the bulbs start to delivering the eye-watering efficiencies that they do in the lab. If that happens, bulbs based on these chips will have far lower running costs and sell for much less than they do today.

When it comes to efficiency, chips in the lab have produced 276 lumens-per-Watt (lm/W), which is three-to-four times that of compact fluorescent lamps (60-80 lm/W) and vastly higher than incandescent sources (11-17 lm/W). However, according to reports coming from the US Department of Energy, the efficacies of the 'well-made' warm-white and cool-white LED lamps are only slightly higher than 100 lm/W and 130 lm/W, respectively. The culprit for this massive difference between the lab record and the efficacy of commercial LEDs in bulbs is a mysterious malady known as droop, which causes a decline in the efficiency of an LED as the current density through it reaches very high levels. What this means is that the peak quantum efficiency of the LED occurs at a lower current than the value that it is driven at in a light bulb, compromising its efficacy.

If droop could be eliminated – or even trimmed substantially – this could be a game changer for solid-state lighting, moving this industry so that it is not just serving the early adopter in the home and the lighting engineer who thinks about all the costs associated with lighting large buildings, but selling to the general public. That's because LEDs with far less droop wouldn't only be more efficient and thus cut electricity bills: They could be also driven at far higher current densities, because their greater efficiency translates into less heating, and that ultimately means that far fewer chips would be needed in a bulb, cutting its cost substantially.

A little history

Droop is clearly distinct from the thermal roll-over seen in laser diode and VCSEL plots of output power as a function of current. Until the mid 2000s, droop was understood – without much controversy – as an inevitable phenomena associated with III-nitride materials. Nearly every commercial LED is grown on a lattice- and thermal-mismatched foreign substrate, such as either sapphire, SiC, or more recently silicon, using a technique commonly referred to as strained heteroepitaxy.

This leads to a high defect density, with threading dislocations typically higher than 10^8 cm^{-2}. It is possible that these dislocations are not that

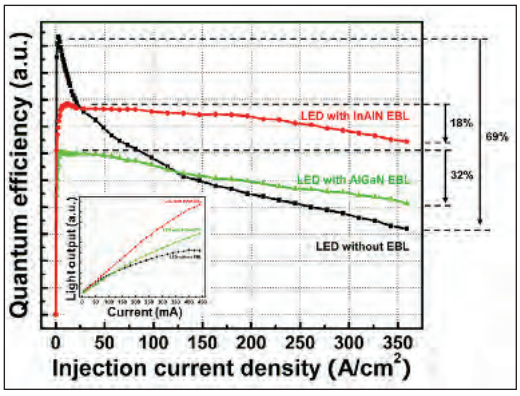


Figure 1. Quantum efficiency (QE) versus current density for blue LEDs without an electron-blocking layer (EBL), with an $Al_{0.2}Ga_{0.8}N$ EBL, and with an $In_{0.18}Al_{0.82}N$ EBL. Inset shows light output versus current (L-I) characteristics of LEDs without an EBL, with an $Al_{0.2}Ga_{0.8}N$ EBL, and with an $In_{0.18}Al_{0.82}N$ EBL. An alternative InAlN EBL significantly mitigates the efficiency droop with the lowest efficiency droop ratio of ~18 percent. (Reprinted with permission from Appl. Phys. Lett. **96** 221105 (2010). Copyright 2010 American Institute of Physics.)

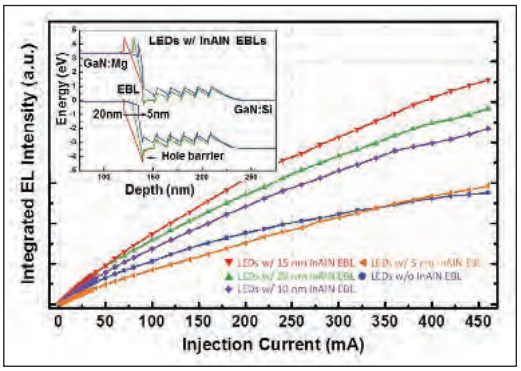


Figure. 2. Light-current characteristics of LEDs with $In_{0.18}Al_{0.82}N$ EBLs of various thicknesses. Inset shows equilibrium electronic band diagrams. These curves suggest that both hole-blocking and electron-confinement effects of the EBL should be qualitatively considered when addressing peak efficiency and efficiency droop for LED operating at high current densities. (Reprinted with permission from Appl. Phys. Lett. **101** 161110 (2012). Copyright 2012 American Institute of Physics.)

harmful for device performance – but droop is the price that you'll have to pay for this.

The reasoning behind this view is that the surprisingly high level of radiative recombination in such defect-ridden structures is a result of indium-rich, quantum-dot-like, localized states in InGaN quantum wells. At low currents, these states screen detrimental effects from crystalline defects, leading to a high quantum efficiency. But as the current through the LED is cranked up, more carriers overflow from the localized 'shelter' states to recombine non-radiatively in dislocations, causing the device's quantum efficiency to plummet.

Today, this explanation of droop has fallen out of favour. That's partly because it can't explain why LEDs with much lower dislocation densities, which are formed on free-standing GaN substrates, are plagued by droop. However, it is also because many other conjectures for droop are being offered, due to mechanisms such as: Auger recombination (including direct band-to-band and indirect defect- or phonon-assisted recombinations); electron spill-over out of the active region; inefficient hole injection and transport in the active region; and several other theories, which all have their champions.

If you look at the academic papers that detail these conjectures, you'll find that the data presented in each set of theoretical studies and experiments is fairly logical, and it supports the proposed mechanism; however, the findings and claims are not consistent with one another, and in some cases they can even be contradictory. This reveals that there is yet to be a unified, watertight explanation detailing the dominant mechanisms responsible for droop. Instead, prejudice abounds, with conclusions drawn that may heavily depend on a pre-emptive model. This state of affairs may even hamper efforts to get to the bottom of droop: It might be governed by several of the proposed mechanisms, which are inter-related and coupled to one another.

Fathoming the cause of droop is critical for advancing the understanding device physics, and it is one route towards the development of droop-free LEDs. But it is not the only way: It is also possible to come up with droop-busting designs without uncovering a universal, unquestionable explanation for this energy-sapping mechanism.

Droop and carrier dynamics

If you peruse the academic literature, you'll find that all the leading conjectures for the origin of droop are related to carrier dynamics. Droop has been blamed on electron leakage, which is related to unsatisfactory carrier confinement; it's been claimed to stem from poor hole transport into the active region, which depends on the injection of carriers and their concentration in each well; and droop has been linked to Auger recombination, which heavily depends on carrier density, so is influenced by injection efficiencies and carrier concentrations. Hence, tracking and understanding the injection, distribution and concentration of carriers will help with efforts to identify the origin of droop and possibly uncover ways to combat this malady.

It is critical that efforts to try and combat efficiency droop do not neglect the absolute value for peak quantum efficiency. Droop tends to be characterized by comparing the peak efficiency to that found at a high current density. It is possible to diminish droop by sacrificing the peak quantum efficiency, but that approach is not the right one to take, because the goal is to learn how to take LEDs that are really efficient at low current densities and replicate that performance at really high current densities.

Our US research team, a partnership between Georgia Institute of Technology, Arizona State University and the University of Houston, has focused our efforts at combatting droop on engineering carrier dynamics via alternative layer structures. Our modifications do not involve adjustments to the multi-quantum well active region, because experiments by other groups suggest that improvements in droop brought about by this come at the expense of the peak quantum efficiency of the LEDs (or even at the expense of quantum efficiencies over a wide range of current densities). Instead, we investigated how changes to the electron-blocking layers could influence electron confinement and the injection and transport of holes in the active region. As we looked at various different designs, our strategy was to: confine electrons in the active region as much as possible; inject as many holes into the active region as possible; and distribute, as uniformly as possible, both carriers among the wells within the active region.

Our first modification was to adjust the electron-blocking layer so that it is better at confining this carrier in the active region. AlGaN is the standard material for making the electron-blocking layer, which is sandwiched between a *p*-type layer and the active region and reduces the number of electrons that spill out of the quantum wells.

Moving to a material with a wider bandgap for the electron blocker promises to improve the confinement of this carrier, but recent studies show that a switch to wider-bandgap $Al_xGa_{1-x}N$ is not that effective.

A more promising replacement is $In_{0.18}Al_{0.82}N$. It combines the opportunity for lattice-matching with GaN with a wider energy bandgap than AlGaN and a larger conduction-band offset. What's more, strained – and especially in-plane compressive-strained – $In_xAl_{1-x}N$ electron-blocking layers offer unique features for visible LEDs. They change strain in the blocking layer, which can offset the interface charges induced by spontaneous polarization between InAlN and GaN in the barrier of the active region, and also mitigate the quantum-confined Stark effect in multiple quantum wells.

When we replaced the 'standard' AlGaN electron-blocking layer with $In_{0.18}Al_{0.82}N$, we found that this reduced the droop in the LED (see Figure 1). In the absence of an electron-blocking layer, there is a rapid efficiency droop: It is 69 percent, when defined as the decline between peak quantum efficiency and efficiency at a current density of 360 A cm^{-2}. In comparison, the LED with an $Al_{0.2}Ga_{0.8}N$ electron-blocking layer has a droop of 30 percent, while that with InAlN has 18 percent droop. However, although that last figure represents an improvement, droop is still significant. That might be because other mechanisms besides electron spill-over contribute to efficiency droop, or that the suppression of electron spill-over is not complete, even with a wider-bandgap $In_{0.18}Al_{0.82}N$ electron-blocking layer.

Adding an electron-blocking layer can actually be a double-edged sword. While it creates a barrier that stops electrons from leaking out of the device, it also can form a potential barrier for the injection of holes from a *p*-type layer (refer to the inset of Figure 2). Especially at low current densities, this barrier may limit hole injection, leading to lower device efficiency.

The $In_{0.18}Al_{0.82}N$ layer is perfect for studying electron confinement and hole injection simultaneously. All that is needed is to alter its thickness (see Figure 2). That's not the case for AlGaN, because changes in aluminium richness don't just change the barrier height of this blocking layer – they also influence *p*-type doping efficiency and strain.

Measurements of light output at different current densities with this series of LEDs provided an insight into device behaviour. Below current densities of 300 A cm^{-2}, an LED without an electron-blocking layer produced a higher quantum efficiency than a similar device with a 5 nm-thick electron-blocking layer. Meanwhile, the variant with a 20 nm-thick electron-blocking layer generally emitted less light than the device with a 15 nm-thick electron-blocking layer. Such results are impossible to explain when only considering the electron blocking effect of the InAlN layer.

To gain an insight into what is really happening in these devices, we extended the widely used ABC model, which features rate equations and efficiencies for various recombination paths, to include carrier spill-over and hole-injection effects. This led us to carry out the first ever theoretical and experimental study to determine the electron spill-over and the hole-blocking contributions to efficiency droop and limitations in peak quantum efficiency.

Modelling efforts revealed that, as expected, more spill-over leads to higher droop, and it also showed that it produced a small decrease in the peak quantum efficiency, which occurred at a lower current density (see Figure 3 (a), (b) and (c)). Hole blocking levels also impact droop, but not as significantly as electron spill-over (see Figure 3 (d), (e) and (f)). However, the current density that the peak efficiency occurs at is found to be more dependent on hole injection than electron over-spill.

These results show that the injection of holes into the active region, plus their transportation through it, play a major role in the efficiency droop and peak quantum efficiency. To mitigate droop, every well within an active region must be populated with a uniform distribution of electrons and holes with the same concentration. Changing

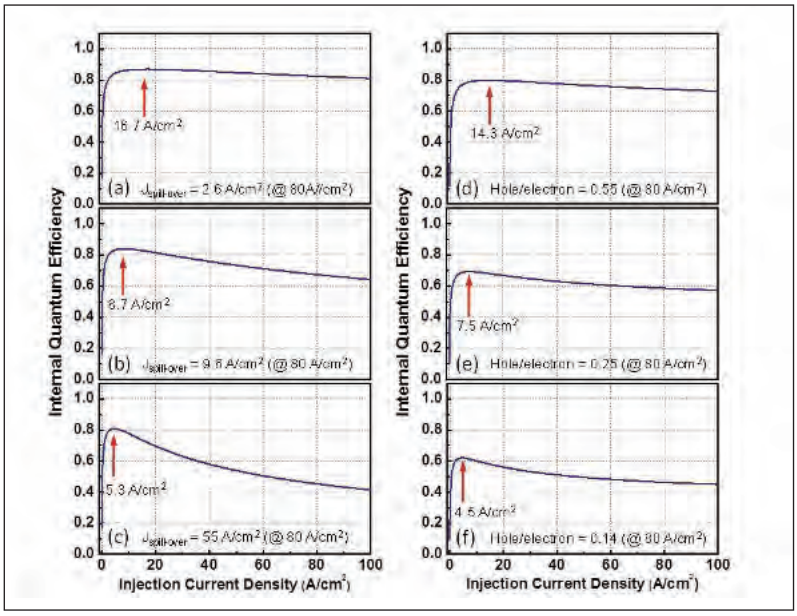


Figure 3. Calculated QE versus injection current densities of LEDs for various spill-over currents ((a), (b), and (c)) and hole/electron concentration ratios ((d), (e), and (f)). The QE curves for the LEDs with high spill-over current show more pronounced droop. For the effects of hole injection, the peak QE depending on hole concentration seems to be more pronounced than that depending on spill-over. (Reprinted with permission from Appl. Phys. Lett. **101** 161110 (2012). Copyright 2012 American Institute of Physics.)

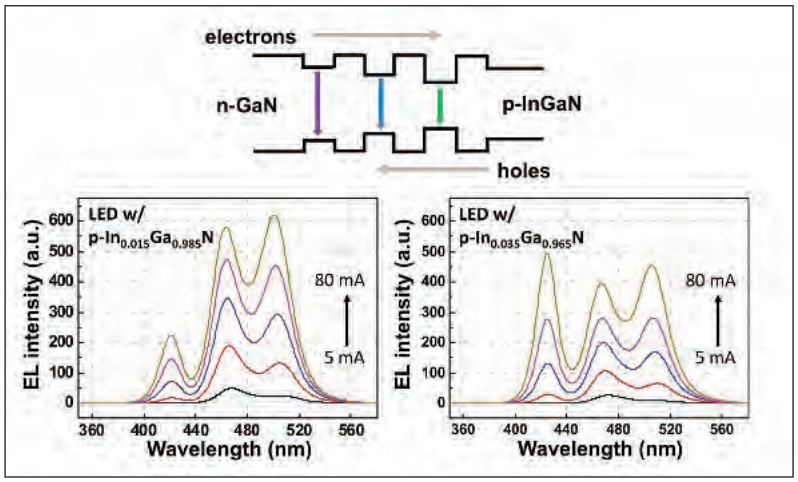


Figure 4. Electroluminescence (EL) spectra of triple-wavelength-LEDs with *p*-$In_{0.015}Ga_{0.985}N$ and *p*-$In_{0.035}Ga_{0.965}N$ layers. The lower injection efficiency for the LEDs with a higher hole barrier diminishes with increasing current. Injected holes overcoming the higher potential barrier can then be transported farther, resulting in more uniform hole distributions among the MQWs

the distribution of these carriers alters the electronic band structures and radiative and Auger recombination rates.

It is not that challenging to realise a uniform distribution of electrons among multiple quantum wells, but when it comes to holes, this is very tough. In a conventional LED, the concentration of holes differs from well to well, and it increases the closer the well is to the *p*-side. To work towards the development of an LED that combines uniform hole distribution with efficient hole injection and effective hole transport in the active region, we fabricated devices emitting at three different wavelengths, to provide an experimental evaluation of the hole distribution within the active region. Devices were also produced with different indium contents in the p-type InGaN layers, because this changes the height of the potential barrier and enables a study of the hole 'reservoir' effect.

Increasing the hole barrier by switching from *p*-$In_{0.015}Ga_{0.985}N$ to *p*-$In_{0.035}Ga_{0.965}N$ led to an increase in the uniformity of the intensities of three luminescence peaks, with the well located furthest from the *p*-type region emitting more light (see Figure 4). This stems from improved hole transport, leading to a greater uniformity of this carrier within the active region.

A valuable discussion of hole dynamics has to distinguish between hole injection efficiency and effective hole transport in the active region. Hole injection efficiency is governed by the total number of holes injected into the active region – it does not depend on which well captures them – while hole transport gives an insight into the distribution of holes among the wells with the total number of holes injected. At the interface between the *p*-type GaN and the undoped GaN barrier, there can be a reservoir for holes that fills up, prior to injection into the active region (see Figure 4). If the LEDs have a higher barrier, hole injection efficiency may be lower, but once holes overcome the potential barrier, they will gain energy. This increase in energy when entering the active region will influence the capturing efficiency of holes in each of the wells, which have different energies.

It is also possible that the potential barrier can limit hole injection efficiency, especially under low injection conditions. But this effect will diminish as the current is cranked up, and is expected to become negligible under high injection conditions. In that regime, injection efficiency is not strongly influenced by barrier height, but if the holes have overcome a higher barrier potential, they can be transported farther, leading to a more uniform hole distribution within the active region.

Our studies show that it is not essential to produce an unequivocal explanation for droop – which will hopefully come soon – to mitigate droop in LEDs and ultimately increase sales of light bulbs based on this technology. What we do show is that it is possible to combat droop by: reducing the carrier concentration in each well, so that Auger recombination does not kick-in at high injection conditions; making the carrier concentration in every well high enough to maximise the radiative recombination rate, while maintaining negligible Auger recombination; ensuring that in every well, the concentrations of electrons and holes are ideally identical; and trying to enable a uniform distribution of electrons and holes within the multiple quantum well.

Implementing those requirements is far from trivial. It may require increasing the number of wells in the LED and increasing the confinement of electrons in the active region. In addition, holes will have to be injected efficiency into the active region and transported across it very efficiently, so that this charge carrier has a fairly uniform population across the multiple-quantum-well region, even if it contains many wells.

Performing further fundamental studies and engineering of LED structures will help to uncover a route to such efficiency-droop-mitigating devices and spur the solid-state lighting revolution.

The authors wish to thank Jeomoh Kim, Suk Choi, Hee Jin Kim, Mi-Hee Ji and Md. M. Satter from Georgia Institute of Technology, Yong Suk Cho from the University of Houston, and Alec M. Fischer from Arizona State University for their contributions to this study of LED droop.

Further reading

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Isn't it time to get serious about standards?

Spec sheets can indicate identical compositions of a layer in a particular structure produced by different suppliers. But in practice there will be variations associated with in-house measurements, calibration samples, and data interpretation. Far greater consistency is possible, however, with an expanding portfolio of true reference samples that are already available, argues Kris Bertness from NIST.

DEVICES MADE FROM COMPOUND SEMICONDUCTORS have at least one key difference to those of most silicon-based devices – they vary in chemical composition from layer to layer. So, given that, you might believe that accurate measurements of composition would be a valuable endeavour and standardizing those measurements a no-brainer. Take that route and, if you work on behalf of an RF chip manufacturer with three different epitaxy suppliers, you would then get the same $Al_{0.18}Ga_{0.72}As$ layer in every single chip you buy, regardless of its vendor. Or if you send your defective chips out for SIMS (secondary ion mass spectrometry) analysis, you would get data that indicates the same alloy composition from your outside service as you do from your in-house diagnostic instruments.

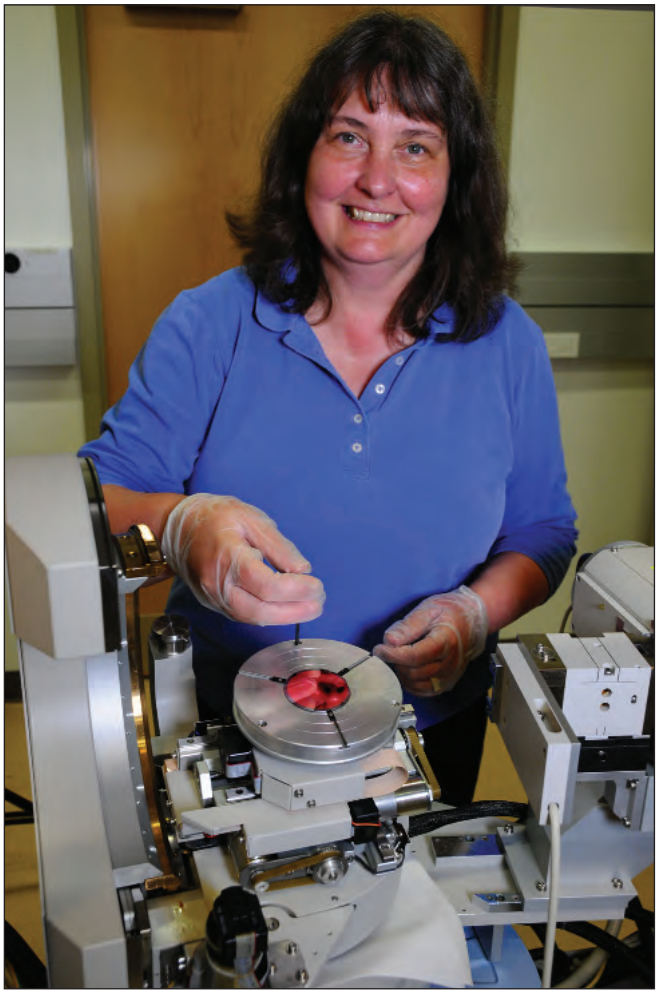
That all makes a great deal of sense, but it is a far cry from the world we currently live in. Instead, what really happens today is that most epitaxy companies and analysis companies draw on individual reference materials.

There is a huge stash of them on the shelves of these firms, because it's often not just one reference per customer, but one reference for each device process.

What this means is that efforts at determining the composition are closer to resembling the matching of paint colour cards than the making a scientific measurement. In practice, engineers tend to add a little bit of this and a little bit of that until they get a layer that matches the one they grew last month.
Several reasons can account for the persistence of this inefficient situation. Habit probably tops this list. Take a compound semiconductor alloy system with a long history of technological importance: $Al_xGa_{1-x}As$.

This alloy has the extremely useful property that its lattice parameter has almost no dependence on the aluminium mole fraction. Thanks to this very favourable attribute, hetero-junctions can easily be grown without introducing strain relaxation from defects. This has led to widespread determination of the aluminium mole fraction with an X-ray diffraction (XRD) rocking curve that can uncover the small elastic strain in AlGaAs. But this method is not flawless: It can be fooled by changes in the substrate lattice parameter or by a doping-induced expansion or contraction of the lattice.

Fortunately, this is not the only approach to determining AlGaAs composition. If the aluminium content is low, its mole fraction can be uncovered by measuring the band gap energy with photoluminescence. This is a high precision method, but it is again subject to systematic errors from sample heating, impurity and doping shifts of the apparent band edge, and excitation intensity shifts in band-edge transitions.



X-ray diffraction is widely used to determine the composition of aluminium in AlGaAs. Care is needed, however, because interpretation of the data must account for the substrate lattice parameter and doping-induced expansion or contraction of the lattice. Photo by James Burrus, NIST

If you have learnt to determine AlGaAs composition of an epilayer, what method do you follow? Chances are that it is one of the two listed above – measuring strain relative to the substrate with XRD, or determining the bandgap with photoluminescence. And it's probable that you convert this number to a composition with an equation given to you by your thesis advisor, an older graduate student, or your supervisor. If you changed institutions, you might have taken your equation with you, or maybe you accepted a new one. The local nature of these conversion factors is often an impediment to the absolute accuracy of any composition measurement.

Up until now, we've only discussed the problems associated with ternary alloys. These are magnified to an entirely new level with quaternary compounds like InGaAsP. When the National Institute of Standards and Technology (NIST) sponsored a round-robin comparison of this class of material in 2002, this institute found substantial variations in XRD and photoluminescence data on identical samples examined in nine different laboratories. Don't put down these variations to laboratory-dependent calibration factors – they persist even when these factors are removed from the data analysis.

Fortunately, it is not all doom and gloom: We have the technology to remedy this situation. Starting in 1997, NIST began a programme to standardise the measurements of compound semiconductor composition, starting with AlGaAs. Some of the impetus for the work came from the Optoelectronic Industry Development Association (OIDA), and NIST sought input through venues such as CS-MAX and SEMI committees.

Methods for determining composition analysis were examined during this programme, with several papers published that quantified the measurement uncertainty for those methods and outlined best practices. In 2006, the programme culminated with the production of Standard Reference Materials (SRMs) for an aluminium mole fraction in AlGaAs near 0.20 (SRM 2841) and near 0.30 (SRM 2842). Each standard consists of a layer of AlGaAs about 3 μm-thick on a GaAs substrate. The AlGaAs layer has been certified to have a stated aluminium mole fraction with a typical absolute uncertainty of 0.002 (2 σ).

Another highlight of this programme is that it led to a refinement for the correction factors for aluminium, gallium, and arsenic in the CITZAF method for the accurate interpretation of data collected in electron microprobe X-ray analysis.

More recently, the range of materials has increased, with NIST producing SiGe composition reference materials (RMs) in response to industry requests. (Without getting into too much detail, the RMs differ from the SRMs in that they are stated to be suitable for their intended purpose but not directly traceable to the mole.)

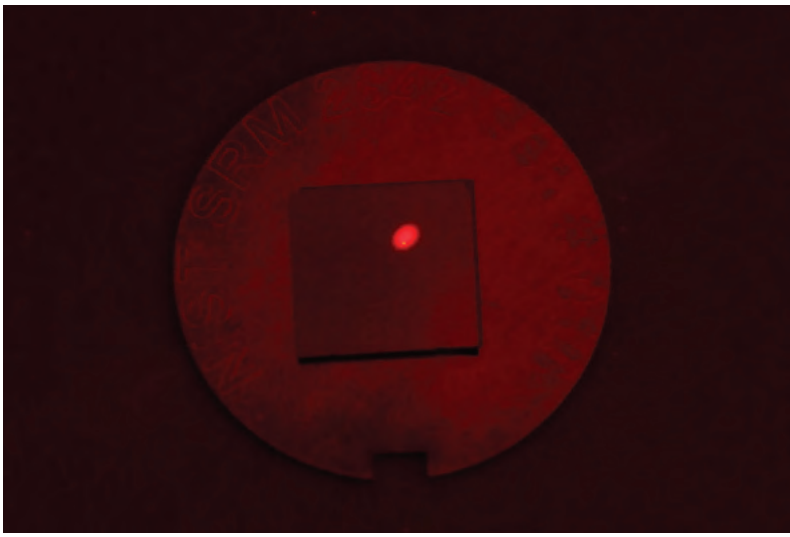
One of the benefits of having reference materials available is that they can be used to improve accuracy of other compositional analysis methods, such as Auger spectroscopy, X-ray photoemission spectroscopy, and SIMS, provided that any necessary corrections for sampling depth considerations are included. The Fundamental Parameters projects – efforts by

X-ray diffraction companies to calculate composition correction factors from fundamental parameters – is in fact one example of an attempt to provide sampling depth and matrix corrections to composition measurements dependent on X-ray emission and absorption. If reference materials are not employed, these methods tend to produce data with clear systematic errors, such as deviations far from 1.0 for the (Al+Ga):As ratio. But if a good set of standards is used, accuracy improves to where it matches or exceeds what can be achieved with XRD and photoluminescence.

So, how do we move forward? It's simple: We just have to use what we have! NIST has been reluctant to pursue further development in new alloy systems, such as the group III nitrides, because the SRMs have remained mostly on the institute's storage shelves.

However, there has been a successful implementation of their use at Evans Analytical Group, where they have been employed to calibrate SIMS measurements of a AlGaAs-based HEMT structure to aid manufacturers in identifying shifts in epitaxial supplier composition. All that it took was a little investment in an SRM artefact and some comparative studies to extend traceability.

At a recent gathering, the 2013 Lawrence Workshop on Standards, this kind of work was identified as being of high value. The workshop also highlighted communication difficulties that can create a barrier between standards suppliers and standards customers. To help to address this, NIST has on-line resources to guide interested parties in how traceability can be documented. If industry starts to use these resources and reference samples, we can move on to a time where composition determination is a precise science, rather than the crystal-growth equivalent of mixing paint.



Photoluminescence is a widely used method for determining the aluminium composition in AlGaAs. Photo by James Burrus, NIST

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Cuprous halides:

The key ingredient for cheap, ultra-efficient LEDs?

To propel widespread uptake of solid-state lighting, LEDs must be cheaper and more efficient. One way to do that is to switch the material used to make these devices from nitrides to cuprous halides, which have incredibly high exciton binding energies and can be grown on silicon substrates, argue Doyeol Ahn from the University of Seoul, Korea, and Seoung-Hwan Park from Catholic University of Daegu, Korea.

Old korean palace, anapji pond, at dawn. Gyeongju, South Korea

ALTHOUGH SALES OF LED lamps are rising fast and grabbing market share from incandescent and fluorescent bulbs, they are too pricy to dominate the market today. And that's not their only issue: Their efficiency is not that much higher than a fluorescent and can fall fast when the drive current through the LED is cranked up – a problem known as droop.

Look more closely and you'll find that the performance of LEDs, which feature a stack of InGaN quantum wells where electrons and holes recombine to generate light, are held back by inherent weaknesses. It is conventional to grow them on the crystal orientation (0001), and this spawns strain in the light-emitting active layers that creates strong built-in polarization fields that ultimately drive down device performance. These piezoelectric and spontaneous polarization fields, which can be as high as megavolts-per-centimetre, pull apart electrons and holes in the quantum well, impairing recombination efficiency.

Making matters worse, devices are typically grown via epitaxial processes on lattice-mismatched substrates, such as sapphire and SiC. This mismatch leads to the generation of many misfit dislocations, which hamper light-generation within the LED and shorten the device lifespan. To address these issues, many researchers are considering alternative devices.

One popular option – which our theoretical team at the University of Seoul, Korea, and the Catholic University of Daegu, Korea, is looking at – is to switch to a different growth plane for the nitride LED. This can either reduce or eliminate the internal electric fields. In addition, we are investigating the potential of an even more promising, novel device: An LED built from the alloy CuBr, CuCl and CuBrCl. Such a devices could combine an incredibly high degree of optical gain with lattice-matched growth on a silicon substrate.

Slashing field strengths

Various approaches can be used to reduce the impact of the electric field in the active region of a nitride LED. These include: introducing an ultrathin, indium-rich InGaN quantum-well; inserting a very thin AlGaN layer into a thick InGaN well; employing the quaternary AlInGaN; and using non-square quantum-well structures. On top of all of this, there is also the highly popular method of today – growth on a new nitride plane.

The latter approach can be traced back to the pioneering work of Tetsuya Takeuchi, Hiroshi Amano and Isamu Akasaki from Meijo University, Japan. In 1996, they reported the significant reduction in heavy hole effective masses resulting from a switch from aligning the quantum wells on the (0001) plane to $(10\bar{1}0)$ and $(10\bar{1}2)$ orientations. One key consequence of reducing heavy hole effective mass is to increase recombination efficiency.

Following on from this work, researchers throughout the world have looked to trim the piezoelectric and spontaneous polarizations by growing the epitaxial nitride stack on a semi-polar plane – a plane titled with respect to the (0001) direction. Initially, those layers that were grown on non-polar and semi-polar substrates were plagued with numerous non-radiative recombination centres, because it is difficult to achieve a high crystal quality on non-polar and semi-polar planes. However, this is far less of an issue today, and now researchers are reporting brighter devices. Other recent highlights in this area include the finding of a polarization crossover in a single InGaN/GaN quantum well grown on a semi-polar $(10\bar{1}\bar{1})$ direction and a high compositional homogeneity in an InGaN quantum well grown on a semi-polar $\{20\bar{2}1\}$ substrate and non-polar $(10\bar{1}0)$ *m*-plane. These efforts show that there is the potential for commercial devices grown on non-polar and semi-polar substrates.

Our contribution to this field is to consider the optical gain of the LED. This is a measure of the luminous efficiency of this device. We have performed calculations for a 3 nm-thick $In_{0.2}Ga_{0.8}N$ quantum well with a carrier density of 2×10^{13} cm^{-2} that is sandwiched between GaN barriers (see Figure 2, which shows the *x′* and *y′*-polarized transverse electric (TE) optical gain spectra for several crystal orientations and optical anisotropy as a function of crystal orientation).

The most striking feature of these graphs is that optical gain peaks have different strengths in different directions. As crystal angle increases, the optical gain for the *y′*- polarization shifts to

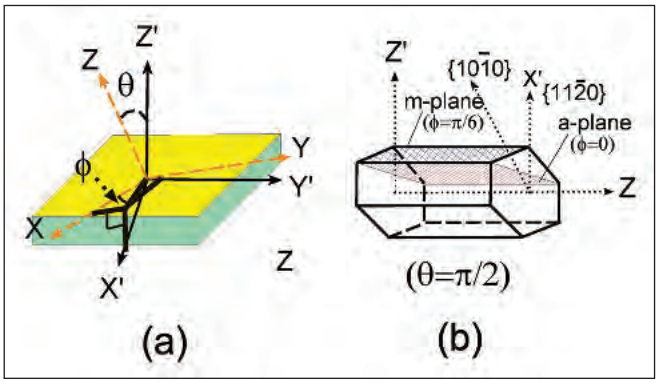


Figure 1. (a) Configuration of the coordinate systems (*x′, y′, z′*) in (*hkil*) -oriented crystals. The growth axis, or *z′*-axis, is normal to the substrate surface (*hkil*), and the coordinate system (*x, y, z*) denotes the primary crystallographic axes. The Euler angles and are the polar and azimuthal angles of the direction *z′* in terms of the coordinates. (b) Nonpolar *a*- and *m*- planes with the growth direction parallel to the *c*-axis. $\theta = \pi/2$ with $\phi = \pi/6$ corresponds to the $z' = [11\bar{2}0]$ growth direction and $\theta = \pi/2$ with $\phi = 0$ corresponds to the $z' = [10\bar{1}0]$ growth direction

a longer wavelength, while the optical gain for the *x*′-polarization shifts to a shorter wavelength. This high degree of anisotropy is not ideal for making an LED, and the optical gain is not as high as it can be in other material systems.

Cuprous halide LEDs

We believe that one material system that could take the performance of an LED to an entirely new level is that of the copper compounds CuBr and CuCl. One of the most attractive attributes of the I-VII cuprous halides is their incredibly high optical gain: It is more than an order of magnitude higher than that of AlInGaN, thanks to a combination of inherent strong excitonic effects and negligible piezoelectric internal fields. What's more, the lattice spacing in CuBr/CuCl quantum wells is close to that found in silicon substrates. That means cheap, widely available silicon substrates could be used as the foundation for producing devices that are free from misfit dislocations.

The I-VII cuprous halides, which include CuBr, CuCl and CuI, are direct bandgap semiconductors with a zincblend crystalline structure. They have piqued the interest of the research community with their very high exciton binding energies: For CuCl and CuBr, binding energies are 190 meV and 108 meV, compared with just 20 meV for GaN and 63 meV for ZnO. A high exciton binding energy is indicative of a strong attractive electron-hole Coulomb interaction, and ultimately enhanced optical transitions, even at temperatures well above room temperature.

We are not the first group to study these I-VII materials from a theoretical perspective. Efforts in this direction date back to the 1970s, led by Manual Cardona's group at the Max Plank Institute for Solid-State Research. However, this initial study and those that have followed have been restricted to bulk materials. Our breakthrough is to consider quantum well heterostructures, the region found in real LEDs.

Our calculations, which include many-body effects such as

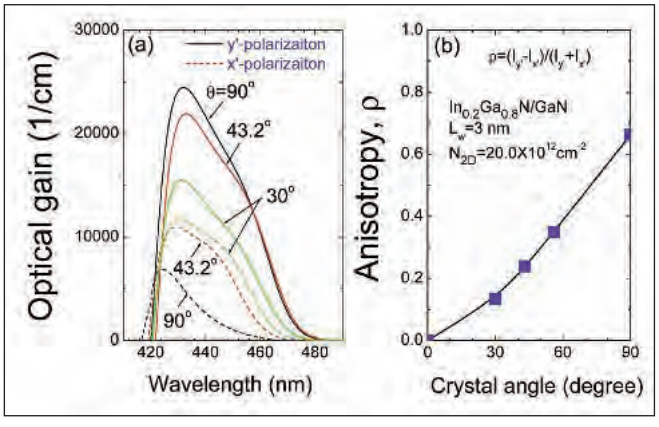


Figure 2. (a) *x*′- and *y*′-polarized optical gain spectra for several crystal orientations and (b) the in-plane optical anisotropy as a function of the crystal orientation of the wurtzite $In_{0.2}Ga_{0.8}N$ quantum well with a width of 3 nm. The decrease of the optical peak is attributed to the reduction of the optical matrix element for the *x*′-polarization. For the case of the *y*′-polarization, the optical gain peak increases significantly with the crystal angle. Note that the optical gain of the (0001)-oriented quantum well is calculated self-consistently, taking into account the piezoelectric and spontaneous polarizations

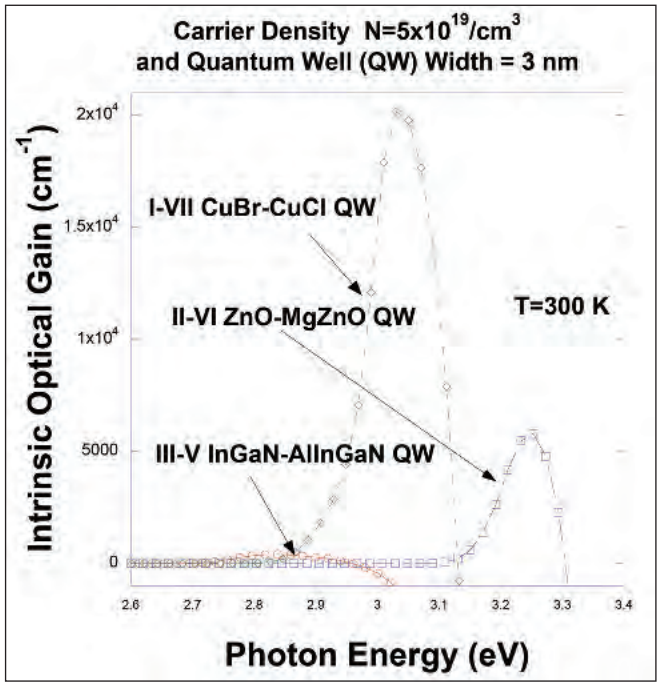


Figure 3. Optical gain spectra for CuBr/CuCl QW (green), ZnO/$Mg_{0.3}Zn_{0.7}O$ QW (blue), and $In_{0.2}Ga_{0.8}N/Al_{0.2}In_{0.005}G_{0.7995}N$ QW (red) versus photon energy for carrier density of 5 x 10^{19} cm^{-2}

bandgap renormalization, enhancement of optical gain due to excitonic effects and plasma screening, have determined the optical gain spectra for a CuBr/CuCl quantum well. Gain is 30 times that produced by an $In_{0.2}Ga_{0.8}N/Al_{0.2}In_{0.005}G_{0.7995}N$ quantum well, and significantly higher than that produced by a ZnO/$Mg_{0.3}Zn_{0.7}O$ quantum well.

Although this modelling effort shows that cuprous halide LEDs have tremendous promise, there is obviously a great deal of work still to do before they can make any commercial impact. The first step towards this is to establish a growth technology for forming high quality epitaxial films. Fortunately, some groundwork has already been carried out for this – in 2005 a partnership between scientists in Ireland reported the growth of a thin film of polycrystalline CuCl on a silicon (111) surface (this material produced strong room-temperature photoluminescence related to excitonic recombination).

In addition, the doping techniques need to be established, which could involve zinc and magnesium as *n*-type dopants and oxygen, sulphur, and selenium as *p*-type dopants. And once this has been accomplished, devices will have to be designed, shown to be robust and manufactured in high volumes. Only if all of this happens will cuprous halides be in with a chance of displacing nitrides in solid-state lighting.

Further reading
S. H. Park and D. Ahn, Proc. SPIE **8625** 862511-1, 201
D. Ahn and S. L. Chuang, Appl. Phys. Lett. **102** 121114 (2013)

Simplifying gold-free technology for nitride HEMTs

A gold-free metal stack enables HEMT processing that is compatible with silicon fabs

BY DEVELOPING a gold-free process for forming ohmic contacts, an international research team has simplified the heterogeneous integration of GaN transistors with silicon CMOS digital integrated circuits.

This work is important because the unification of GaN and silicon technologies promises to enable a new level of circuit design, but if chips are to be made in silicon fabs, they must avoid using gold in any processes. "Gold is very easy to diffuse into silicon," explains Zihong Liu from the Singapore-MIT Alliance for Research and Technology. "It generates deep acceptor and donor levels, and thereby degrades silicon device performance."

Liu, along with co-workers from MIT and Aixtron, have developed a process that involves the deposition of a Ti/Al/Ni/Pt stack of metals, which are then annealed under nitrogen.

This team is not the first to develop a gold-free process, but it claims that its approach has advantages over rival methods, mainly in terms of simplicity.

One alternative is to create a recess prior to the metallization of the ohmic contacts. Liu and his co-workers have already succeeded with this approach, forming a Ti/Al/W stack with a contact resistance of just 0.5 Ω mm.

However, having to perform recess and metallization steps increases process complexity.

Another option is to use a very thin AlGaN barrier. But Liu says that this has to be capped with SiN, which is not found in commonly used GaN HEMTs.

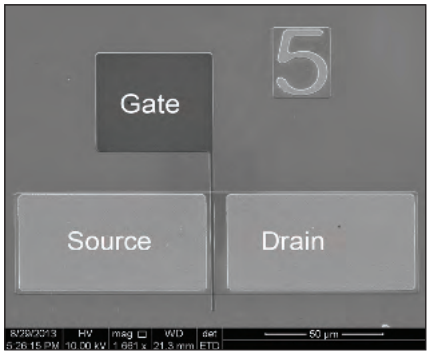
There is also a process involving implantation of ions in the AlGaN/GaN materials underneath the ohmic metals. This can realise a contact resistance of just 0.5 Ω mm, but it requires dopant activation at typically 1200 °C, and this high temperature can create defects and degrade device performance.

Finally, there are processes involving tantalum that can realise a contact resistance of just 0.5 Ω mm. However, the evaporation temperature for this metal is very high.

"For many e-beam evaporators, for example the BOC Edwards Auto 306, the power of the e-gun is not high enough to melt and evaporate tantalum," explains Liu. He adds that melting tantalum is possible with some high-power e-guns, but during evaporation the wafers tend to get very hot, and that makes subsequent lift-off processes challenging.

The latest gold-free process developed by Liu and his co-workers avoids high temperatures. It has been applied to devices formed on an epiwafer featuring a 1.5 μm-thick buffer layer, a 1 nm AlN spacer, a 20 nm undoped $Al_{0.25}Ga_{0.75}N$ barrier and a 3 nm GaN cap.

Inductively couple plasma etching formed mesa structures in this epiwafer, which was grown by MOCVD on a 150 mm high-resistivity silicon substrate. Deposition of a Ti/Al/Ni/Pt (20 nm/ 60 nm/ 40 nm/50 nm) stack, followed by rapid thermal annealing for 30 s at 975 °C in nitrogen gas, created source and drain contacts.



A partnership between researchers at MIT, Aixtron and the Singapore-MIT Alliance for Research and Technology have developed a gold-free process for forming ohmic contacts that involves an annealed Ti/Al/Ni/Pt stack

Measurements with the transition line method determined a contact resistance of 0.6 Ω mm. Liu and his co-workers believe that this ohmic contact is formed in the same way as that with Ti/Al/Ni/Au, with TiAlN penetrating into the AlGaN/AlN/GaN structures.

"But without gold, the Ti/Al/Ni/Pt needs a higher annealing temperature and a re-optimised Ti/Al ratio for TiAlN to penetrate into the AlGaN/AlN/GaN to form a good ohmic contact," says Liu.

One of the features of the Ti/Al/Ni/Pt stack is its smoothness. Atomic force microscopy images of this contact have a root-mean-square surface roughness of just 4.6 nm, compared with 13.9 nm for the conventional gold-containing stack.

According to Liu and his co-workers, this greater smoothness should aid the fabrication of high-frequency devices with very short gate spacings. What's more, they should suppress current crowding effects and avoid reliability issues in high power devices.

Comparing the HEMTs with identical devices, aside from having a gold-free contact, revealed that the change of metal stack did not make a considerable difference to DC performance. The gold-free HEMT had a maximum drain current of 700 mA and a maximum transconductance of 140 mS/mm.

"Next we will try to develop a gold-free ohmic contact method with a low annealing temperature," reveals Liu. Cutting the temperature will make this process compatible with a gate-first process and a silicon-CMOS first, GaN-on-silicon integration process.

Z. Liu *et. al.* Appl. Phys. Express **6** 096502 (2013)

Novel waveguide increases superluminescent output

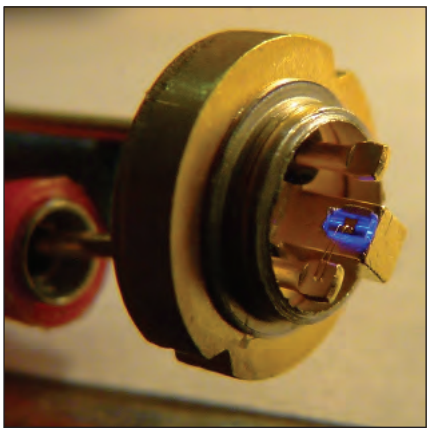
Blue superluminescent diodes deliver 200 mW of power

A PARTNERSHIP between Polish and Japanese researchers claims to have set a new benchmark for the combination of output power and smoothness of spectral output for GaN superluminescent diodes.

This team's emitter features a 'J-shaped' waveguide and could be used in fibre-optic gyroscopes and optical coherence tomography. Both applications require a light source that combines a high degree of spatial coherence with low time coherence. These conditions are met with the superluminescent diodes. They were developed in the arsenide material system in the 1970s, but the shorter wavelengths emitted by GaN-based materials are beneficial.

"In the case of fibre-optic gyroscopes, the advantage of nitride superluminescent diodes is the possibility of using plastic fibres, which may increase the robustness of the entire system," explains Anna Kafar from the Institute of High Pressure Physics in Warsaw, Poland. For optical coherence tomography, a technique that is often used to generate three-dimensional images of biological samples, the emission from the GaN-based source increases spatial resolution. "However, due to absorption, this imaging method will be better for imaging non-biological, more transparent samples," says Kafar.

The team's J-shaped device combines a straight waveguide that contains the rear facet with a curved waveguide that has the output facet."This geometry gives the benefits of a double-pass device – such as a long amplification path – while the chip length remains short, which is important from a packaging point of view," remarks Kafar.



Superluminescent diodes produce a spectral output that narrows with increasing drive current

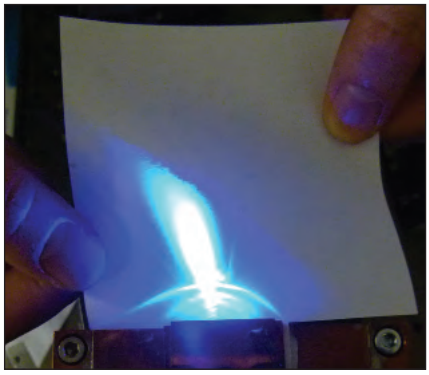
She says that the collaboration, which includes researchers from TopGaN and Kyoto University, is not the first to make a GaN-based J-shaped superluminescent diode – but they have taken its performance to a new level by optimising the architecture of these chips. This propelled the output power to 200 mW, twice that of the previous record held by researchers at Osram Opto Semiconductors, and it also enabled a smooth emission profile from this diode.

According to Kafar, the fabrication of the epitaxial structure is analogous to that of a laser. One of the biggest challenges is to optimise the bend angle, which varies with wavelength and governs the quality of the emitted spectrum.

Construction of J-shaped superluminescent diodes begins with the MOCVD growth of an epistructure on bulk GaN. This epitaxial stack comprises: an 800 nm-thick, silicon-doped $Al_{0.08}Ga_{0.92}N$ bottom cladding layer; a 140 nm-thick GaN waveguide; an active region with three $In_{0.1}Ga_{0.9}N$ quantum wells separated by $In_{0.02}Ga_{0.98}N$ barriers; an AlGaN electron-blocking layer that is 28 nm-thick; a 150 nm-thick waveguide; and a 430 nm-thick, magnesium-doped $Al_{0.05}Ga_{0.95}N$ top cladding.

Superluminescent diodes were formed with chip lengths of 700 μm, 1000 μm and 1500 μm. Angles between the waveguide axis and the axis perpendicular to the chip facet varied from 5.5° to 7.5°. Mounting these chips on a two-side copper heatsink ensured effective heat spreading of the diodes.

A 1 mm-long device with a 7.5° bend angle produced the highest optical power. Output increased exponentially with drive current up to about 300 mA, and from then on increased in a linear fashion. Measurements of emission spectra revealed that the device is not lasing, but its emission spectra is not entirely smooth. There are modulations in the emission spectra that have a 0.025 nm period, and their depth increases as the current is cranked up. This increase in modulation depth is attributed to a rise in oscillating light in the waveguide. Another consequence of increasing the drive current is a reduction in full-width half maximum from 7 nm to 2.5 nm.



Superluminescent diodes emit a spectra with a peak at about 407 nm and an output power of 200 mW

The Poland-Japan collaboration found that operating temperature strongly influences the quality and stability of the light emitted by the diode. Increasing the current in a device mounted in a standard TO56 package produced a red-shift in emission, due to an increase in the chip's temperature. However, if the diode is mounted in a two-side copper heatsink, cranking up the current leads to a blue-shift in emission, due to compensation of the built-in electric fields.

"We plan to optimise the thermal properties of our diodes, so that we can report 200 mW or more of optical power from a TO-56 can," says Kafar.

A. Kafar *et. al.*
Appl. Phys. Express **6** 092102 (2013)

Azzurro improves electroluminescence uniformity of large-diameter substrates

On-wafer testing of LEDs on 150 mm wafers reveals high uniformity in terms of electroluminescence, photoluminescence and forward voltage

GERMAN EPIWAFER VENDOR Azzurro Semiconductors claims to have raised the bar for the electroluminescence (EL) uniformity of LEDs fabricated on large-diameter substrates. GaN-on-silicon LEDs formed on 150 mm (111) silicon have a 3.9 percent EL brightness uniformity at a drive current of 350 mA.

"The high uniformity confirms the validity of the GaN-on-silicon technology on large-diameter substrates for next-generation LED manufacturing," writes the team in its paper.

GaN-on-silicon technology could help to reduce the cost-per-lumen of solid-state lighting. Today, most LED epiwafers are grown on 2-inch and 4-inch sapphire, and making a transition to a larger diameter platform is hampered by the low availability and high cost of the substrates.

According to Azzurro, depositing nitride films on large diameter sapphire is also hampered by higher growth non-uniformity and lower processing yield. The German firm argues that this makes it very challenging for GaN-on-sapphire LEDs to meet the cost roadmap for solid-state lighting.

Switching to silicon trims costs associated with both the substrate and the production of the LED, because wafers can be processed in depreciated silicon lines.

The big challenges associated with the growth of GaN-on-silicon are the 17 percent lattice mismatch between the two materials, and the 46 percent mismatch in thermal expansion coefficient. The latter difference can cause wafers to bow, and even crack, when they cool down after growth.

Azzurro addresses mismatch with a proprietary buffer technology that is claimed to also lead to a significantly reduced dislocation density in the LED's active region. With this technology, wafer bow can be below ± 20 μm across a 200 mm wafer. This level of flatness ensures that the wafers would not crack during processing and handling in silicon lines, and processing-induced non-uniformities would be at an acceptable level.

Widespread uptake of LED lighting hinges on a substantial fall in its costs. Replacing sapphire or SiC with a larger, cheaper silicon substrate will help to make LED lamps more affordable

In this latest research effort, engineers formed LED epiwafers on 150 mm and 200 mm silicon (111) using MOCVD. They deposited their proprietary, strain-engineered GaN-on-silicon buffer structure, and followed this with a 2 μm-thick, silicon-doped GaN layer, an active region, and a magnesium-doped contact.

To enable on-wafer EL testing, 400 nm-thick ITO contacts with dimensions of 1 mm by 1mm were deposited on the *p*-type GaN surface and annealed in a mixture of oxygen and nitrogen gas to increase transparency. 150 μm-diameter bond pads of platinum and aluminium were deposited on ITO to enable electrical on-wafer testing. EL measurement times were not excessive, thanks to a simple test structure. This contained light-absorbing silicon, the top surface had not been roughened to improve light extraction, and there was no mesa etching for device isolation.

On-wafer EL testing revealed excellent wavelength uniformity for both wafer sizes. By collecting emission in an integrating sphere, engineers determined standard deviations of 0.6 percent (2.8 nm) and 0.8 percent (3.7 nm) for the 150 mm and 200 mm wafers, respectively.

According to Azzurro, correlating a photoluminescence intensity map with an EL map is conventionally difficult. "This is due to poorer carrier transport through electrical injection when compared with direct photo-excitation in the active region," says the team in its paper. However, Azzurro's engineers measured the photoluminescence by pumping the device with a 375 nm laser, and found a strong correlation between these values and those for EL. Meanwhile, measurements of the uniformity of forward voltage reveal a 1.3 percent standard deviation for a 150 mm wafer.

This combination of high uniformities for photoluminescence, EL and forward voltage has led the team at Azzurro to claim that these wafers can enable reduced binning, higher manufacturing yield, and cost savings resulting from the need to test from fewer bins.

Current-voltage characteristics have also been studied, with two leakage mechanisms uncovered at different bias levels. At a bias of less than -12 V, the engineers determined an activation energy for conduction leakage of 200 meV, which is consistent with a variable range hopping model. When biasing at higher reverse voltages, Frenkel-Poole conduction takes over – this is the flow of minority carriers through the space charge region, hopping between randomly distributed traps.

Understanding of the origin of these traps is needed to improve the leakage characteristics of GaN-on-silicon LEDs.

A. Pinos *et. al.* Appl. Phys. Express **6** 095502 (2013)

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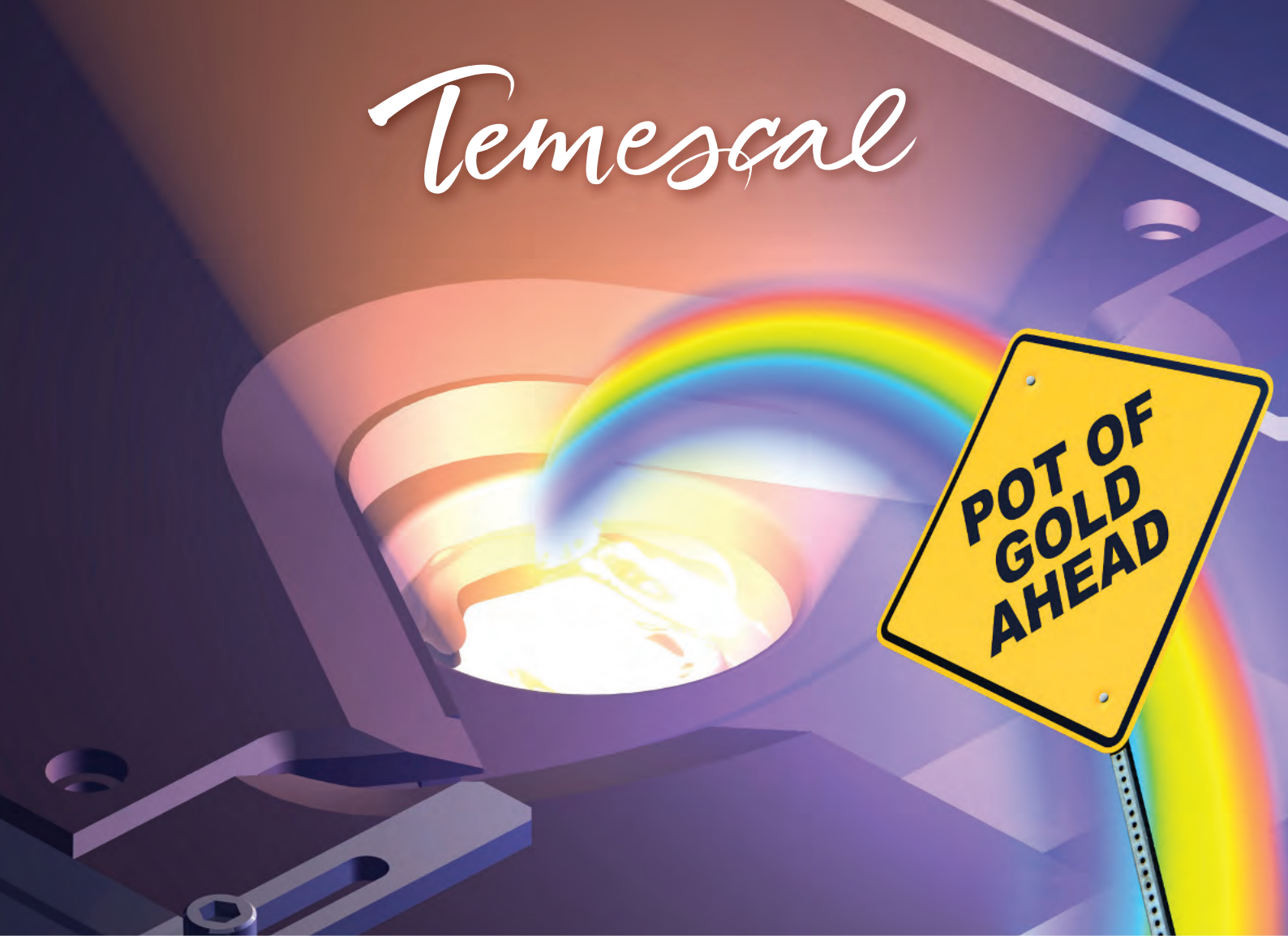

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News Digest Contents

LEDs

Osram IREDs enhance security monitoring

The firm's gallium arsenide (GaAs) based 850 nm infrared Dragon Dome LEDs will have a usable range of more than 100 metres, depending on the sensitivity and field of view of the camera

Security surveillance over large distances is now possible thanks to the infrared Dragon Dome LED from Osram Opto Semiconductors.

The focused beam of this high-power IRED achieves a range of more than 100 metres. In a 11 mm x 6 mm x 5.7 mm package, it does not require an external lens. With a wavelength of 850 nm, this LED is ideal as a light source for security surveillance tasks such as CCTV (Closed Circuit Television).

Dragon Dome SFH 4783: focusing high light output into a narrow beam angle

Osram says the Dragon Dome SFH 4783 is the first high-power infrared LED that emits its light within a narrow angle of +/- 12°. From a current of 1A it achieves a total radiated power of 430 milliwatts (mW) and a radiant intensity of 2.3 watts per steradiant (W/sr).

At this radiant intensity the beam of light will have a usable range of more than 100 metres, depending on the sensitivity and field of view of the camera. Radiant intensity is measured in watts per steradiant. It indicates the light output within a solid angle segment.

The high total radiated power of the IRED is thanks to state-of-the-art thin-film technology which enables the light to be extracted extremely efficiently from the chip.

This high radiant intensity benefits all applications that need strong focused light to provide reliable illumination over large distances. These include outdoor CCTV surveillance systems at border crossings and or at airports. With a wavelength of 850 nm the emitted light is well suited to camera sensors but is barely perceptible to the human eye. This means that surveillance can be very discreet.

The chip has the same footprint as other Dragon versions.

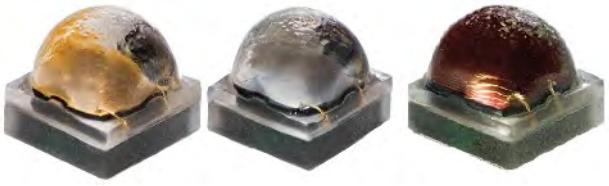
The narrow light beam is produced by the deep metallic reflector and the lens of the Dragon Dome. Jörg Heerlein, Head of Product Marketing for Industrial Infrared Components explains, "The integrated lens translates into less time and expense for our customers because they do not need an external lens to focus the light. This not only reduces installation time and system costs in the relevant application, but also enables the overall design to be made extremely compact."

The Surface Mount Technology package, which is compatible with other Dragon designs, is suitable for reflow soldering processes and helps make handling even easier and further reduces production costs.

Cree big performance XQ-E LEDs come in small packages

The firm›s latest SiC (silicon carbide) - based LEDs follow on from the XQ series launched in May and are 78 percent smaller than Cree›s XP-E2 modules

Cree is introducing the new XLamp XQ-E LED family, enabling lighting manufacturers to significantly reduce the size and total cost of their LED luminaires without sacrificing light output, efficacy or reliability.



Cree XQ-E LEDs

The new, game-changing LED packs the lighting-class performance of the XP-E2 into a package that is 78 percent smaller. The XQ-E LED family opens up new design possibilities for a wide spectrum of lighting applications, such as portable, indoor directional, architectural and vehicle lighting.

"Cree's new XQ-E LEDs are changing the way we view LEDs. No other LED manufacturer offers an LED of

this small size with such a high level of performance," says Luke Thorkildsen, director of lighting division, The Coleman Company, Inc. "We're excited about the new possibilities for smaller, lighter or brighter designs enabled by the new XQ-E LED."

The new XQ-E LEDs have a tiny 1.6 mm x 1.6 mm footprint and are available in both white and colour configurations. The XQ-E's combination of optical symmetry, consistent design across all configurations and its small size enables improved colour mixing and optical control compared to the larger XP-E2 LED.

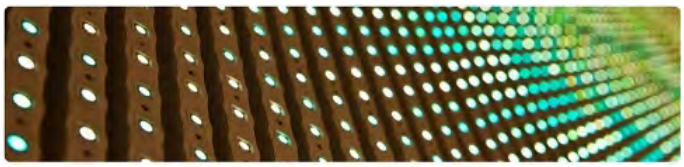
"Previously, the size of LEDs dictated the form factor of the luminaire and lighting manufacturers had to design around the light source," explains Paul Thieken, director of LED Components, Cree. "With its unparalleled performance and size, the XQ-E LED redefines what's possible with lighting designs, enabling new form factors and eliminating constraints."

Built on Cree's revolutionary SC3 Technology Platform and characterised at 85°C, the XQ-E White LED is available in 2700-K to 6200-K colour temperatures and offers minimum CRI options of 70 and 80. The XQ-E White LED delivers up to 287 lumens at 3 W, 85°C. XQ-E Colour LEDs are available in red, green and blue.

Cree XLamp XQ-E White LED samples are available now, and colour LED samples will be available in late October. Production quantities are available with standard lead times.

Nitride Solutions ships first AT-50 AlN templates

The aluminium nitride templates, produced using HVPE, have been sold to a major Asian LED manufacturer



Nitride Solutions has achieved the first commercial sales of its new AT-50 AlN template.

Nitride is manufacturing the product in volume at its manufacturing facility in Wichita, Kansas, using its proprietary advanced HVPE process.

Troy Baker, Nitride's research and development director, presented data at the 2013 International Conference on Nitride Semiconductors that showed commercial template properties far superior to any presented before. This data accelerated requests for sampling by major manufacturers of LEDs and power-switching devices.

"Our templates are by far the best in the market, and our manufacturing processes are designed for volume production and tight statistical process control. We offer customers the best commercially available XRD specs (average (002): 135 arc sec and (102): 513 arc sec), low defect densities, and wafer uniformity," says Jeremy Jones, Nitride Solutions CEO.

He continues, "We believe that our recent sales and growing sample requests validate the quality and value of our products and technology. We realise that customer's make decisions on substrates based on performance, quality, consistency, value delivered and supply assurance. Our combination of a superior product in the AT-50 plus a growing global distribution and technical support channel will provide the best solution for these customers. The planned introduction of four-inch aluminium nitride templates and the expansion of our template product line to GaN will bring additional value to device markets."

James H. Edgar, department head of chemical engineering and university distinguished professor at Kansas State University comments, "The AlN on sapphire templates offered by Nitride Solutions are a much lower-cost alternative of high-quality material compared to bulk AlN substrates. That these substrates are available in two-inch diameter size greatly facilitates their use by standard device fabrication tools. The availability of these AlN templates creates exciting new opportunities for improved short-wavelength optoelectronic and high-power electronic devices."

Nitride Solutions develops and manufactures bulk and template nitride materials for the LED, laser diode and the power electronics markets. Founded in 2009, the firm's leadership has over 35 years of experience in supplying advanced materials to global manufacturers of semiconductor, display and memory devices, combined with a total of more than 35 years in nitride process development. The company maintains strong ties to Kansas State University in Manhattan, with key employees and advisors hailing from the university, as well as UC Santa Barbara.

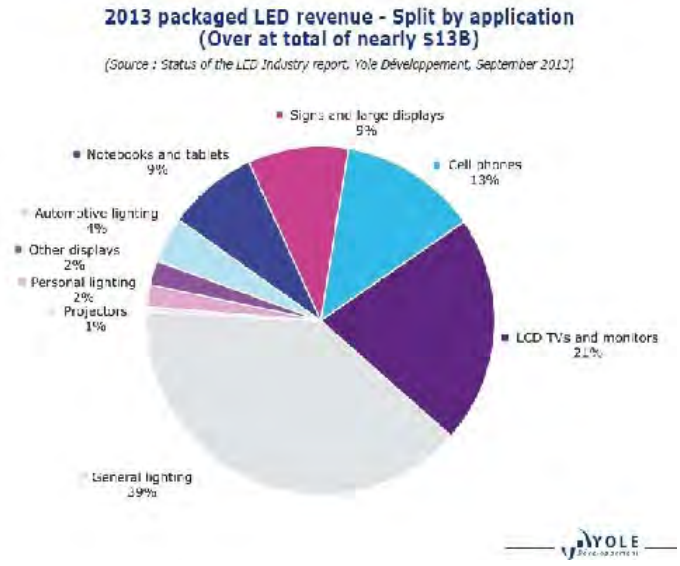
Yole: Inexpensive LED solutions pushing adoption in general lighting

The packaged LED market will balloon from $13.9 billion in 2013 to $16 billion by 2018, driven mainly by general lighting and completed by display applications

Growth of the LED industry has come initially from the small display application and has been driven forward by the LCD display application. In 2012, General lighting surpassed all other applications, representing nearly 39 percent of total revenue of packaged LEDs.

This is according to Yole Developpement›s third edition of its best seller, «Status of the LED Industry».

Indeed, the LED TV crisis of 2011 (following an overestimation of the market) had the benefit of decreasing LED prices and intensifying the competitive environment. As a matter of fact, LED-based lighting product prices have decreased more rapidly than expected, increasing the penetration rate of the technology.



Yole estimates packaged LED will reach a market size of $13.9 billion in 2013 and will peak at $16 billion by 2018. Growth will be driven mainly by general lighting applications (45 percent to 65 percent of total revenue during this period), completed by display applications.

Other applications are still in motion

Regarding display and other applications, most products currently on the market integrate LED technology. Saturation mixed with strong price pressure and competition from OLED will make most of these markets decline starting from 2013 / 2014. Contrary to general lighting, overcapacity (inducing price pressure) has prompted a decrease in market size more rapidly than predicted.

This report presents all applications of LED and associated market metrics within the period 2008 - 2020.

To keep the momentum, LED-based lighting product costs still need to be reduced

“ Cost represents the main barrier LEDs must overcome to fully compete with incumbent technologies,” explains Pars Mukish, Market and technology analyst, LED at Yole Developpement. “Since 2010, the price of packaged LEDs have sharply decreased, which has had the consequence of decreasing the price of LED-based lighting products,” he adds.

However, to maintain the growth trajectory, more efforts are needed in terms of price. LED still has some potential for cost reduction, but widespread adoption will also require manufacturers to play on all components of the system such as drivers, heat sink, PCB...

Merger of LED industry with lighting industry has started

Over the past 3 years (2010 to 2012), the number of mergers and acquisitions has continuously grown, reflecting the increased consolidation of the LED industry. During this period, Yole has listed approximately 60 significant M&A deals. And 17 additional deals have already been identified during the first half of 2013.

Main objectives of these deals are:

Vertical integration

A consistent trend in the LED space, reinforced by the promising boom of general lighting applications. Such deals are motivated by the need for companies to access to new technologies, to close knowledge gaps in the LED supply chain, secure supply....

Strategic acquisition

The LED lighting market remains highly fragmented in all regions of the world (i.e., local features of fixtures... In this environment, strategic acquisitions are mainly motivated by economies of scale, desire for improved market share, access to a wider customer portfolio, and increase the sales force (¡K).

Geographical acquisition

Mergers and acquisitions, rather than organic growth, have proved to be the main market-entry strategy by overseas acquirers. Such deals have been driven

primarily by companies seeking access to new markets and local distribution networks.

The number of mergers and acquisitions deals is likely to continue to grow as LED technology has created a Solid State Lighting (SSL) chasm, modifying all traditional aspects of the lighting industry (light source, system design, test...) and forcing supply chain players to acquire new competencies.

Emerging substrates could change the rules in an industry dominated by sapphire

Sapphire (and SIC) remain the most widely used substrates for GaN epitaxy but many research teams are working on finding better alternatives in terms of performance and total cost of ownership. In that context, silicon and GaN are the main new substrates developed in the LED industry:

Benefits of GaN-on-silicon LEDs rely on decreasing manufacturing cost by using cheaper silicon substrates but mainly by switching to an 8"¨ substrate and using fully depreciated and highly automated CMOS fabs.

Benefits of GaN-on-GaN LEDs stem from the lower defect density in the epitaxial layers, allowing the device to be driven at higher current levels and to use a lower number of LED devices per system.

However, several barriers need to be overcome:

- GaN-on-silicon LEDs are closer to GaN-on-sapphire LED performance but increased manufacturing yields and full compatibility with CMOS fab still need to be achieved.

- GaN-on-GaN LEDs suffer from GaN substrate availability and its cost.

While GaN (GaN-on-GaN LEDs) holds some potential on specific high-end niches, Yole considers silicon (GaN-on-silicon LEDs) as the more serious contender as a potential alternative to the widespread use of sapphire. But the success of GaN-on-silicon LEDs will depend on the development of associated LEDs performance and development of manufacturing techniques.

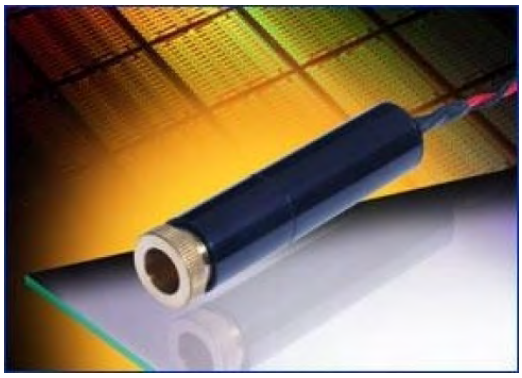
Optoelectronics Company reveals compact III-V laser diode modules

The miniature devices are composed of Oclaro's Opbext aluminium indium gallium phosphide (AlInGaP) and aluminium gallium arsenide (AlGaAs) laser diodes with externally adjustable optics. They also incorporate a Panasonic aspherical glass lens in rugged modular anodised aluminium housing

The Optoelectronics Company, a manufacturer of innovative optoelectronic components and distributor of Oclaro (Opnext) laser diodes and Panasonic glass lenses, has launched another innovative and cost-effective range of laser diode modules.

The devices are optimised for compact integration into OEM applications where size is critical.

With a diameter of only 11 mm, the modules are ergonomically designed with a small form factor for integration into a wide range of applications. These include industrial and medical alignment, low level laser therapy, inspection and sensing where a tiny package is essential to fit into very compact spaces.



Tiny laser diode modules

This new range of laser diode modules combines a high performance Oclaro (Opnext) laser diode with externally adjustable optics, a Panasonic aspherical glass lens, sophisticated electronics and rugged modular anodised aluminium housing . It provides a reliable, energy-efficient and precise laser source for OEMs, end-users and systems integrators. A key feature is the brass lens holder which enables smoother, more accurate focussing by using a finer pitched thread.

"As applications get more sophisticated and devices get smaller, these laser modules are a perfect solution for OEMs to design in where space is at a premium", comments Tony Pope, Managing Director, the Optoelectronics Company. "Combining high performance with energy efficiency, they require less power, generate less heat, have longer lifetimes and fit into smaller spaces than other laser sources" he adds.

The CW lasers produce a high-quality elliptical beam at 5 visible and infrared lasing wavelengths, (635 nm, 639 nm, 660 nm, 830 nm and 852 nm), and offer a combination of low noise and output stability with powers of up to 75 mW. For easy identification they can be supplied with coloured end caps or customer specified

engraving on the rear sleeve. Mechanical dimensions are 11 mm diameter x 49 mm length.

The 635, 639 and 660 nm lasers are AlInGaP based while the 830 and 852 nm modules are based on AlGaAs.

With an operating voltage of 3 - 6V DC and a broad ambient temperature operating range from -10 degrees C to +500C, the modules are also static, surge and reverse-polarity protected and RoHS compliant. Electrical connections are made via 300 mm external flying leads.

Custom lasing wavelengths, from 405 nm to 852 nm, and power options are available on request. Both standard and custom configurations provide OEMs, end-users and systems integrators with complete cost-effective laser solutions.

The Optoelectronics Company, founded in 2009 by Tony Pope and Damon Cookman, is a manufacturer of high performance custom-designed and standard laser diode modules and also an authorised distributor of innovative optoelectronic components, including Oclaro (Opnext) Laser Diodes and Panasonic Lenses, to industrial, medical, telecommunications and defence markets in the UK, Europe and USA.

Philips Lumileds pumps up LED efficacy and flux

In the high-power LUXEON Q III-nitride device, high flux and high efficacy are achieved in a standard 3535 surface-mount package

The new LUXEON Q from Philips Lumileds delivers superior performance in a high-power emitter that serves as a direct drop-in replacement for products that use the standard 3535 surface mount package.

LUXEON Q

LUXEON Q is the first high-power LED based on LUXEON Flip Chip die, Philips Lumileds high performance Chip Scale Package (CSP) device architecture. Efficacy for the LUXEON Q emitter is 135 lm/W at 5700K 70 CRI and 115 lm/W at 3000K 80 CRI (@85˚C and 350 mA).

Kathleen Hartnett, Product Line Director for LUXEON Emitters notes, “Our LED is especially competitive when it’s driven harder. For instance, at 1 Ampere, a flux of more than 300 lm at an efficacy of 102 lm/W at 85˚C is achieved in neutral white at 4000K. The high efficacy at high drive current of the LUXEON Q emitter is achieved as a result of the industry leading wall plug and conversion efficiency of Philips Lumileds next-generation CSP architecture.”

The LUXEON Q takes advantage of a fully developed ecosystem for 3535 components, including a wide range of optics, to speed the time-to-market for omnidirectional indoor and outdoor luminaires.

Applications include high bay and low bay luminaires, downlights, outdoor wall packs, replacement lamps and specialty luminaires. “Customers are starting with a familiar LED package and can quickly build their products from there using readily available optics and other compatible components,” says Hartnett.

The LUXEON Q emitter line is available in CCTs of 2700K, 3000K, and 3500K at 80 CRI and CCTs of 4000K and 5700K at 70 CRI.

Epitaxial cascading of nitride LEDs overcomes efficiency droop

As the number of the cascaded LEDs increases, efficiency droop is greatly reduced

Researchers at the Ohio State University have experimentally demonstrated epitaxial cascading of multiple *p-n* junction diodes with low series resistance.

They have shown that cascading multiple LEDs circumvents nitride LED efficiency droop and reduces overall joule heating.

Efficiency droop in GaN LEDs is one of the major roadblocks to widespread adoption of solid state lighting. In the last decade there has been extensive work on identifying and overcoming the nitride LED efficiency droop. But the underlying reason is still under debate and no designs have been completely successful in solving the problem. It is possible that material limitations of III-nitride material system may preclude complete elimination in traditional single active region LED structures.

Cascading multiple LEDs pushes the input power of the peak efficiency to higher values by exploiting each

injected electron for multiple emissions rather than a single emission process as in conventional LEDs.

Therefore, higher radiative output power can be obtained at lower current levels and efficiency loss due to droop can be minimised. The design can be applied to all existing nitride emitters regardless of energy of the emission.

To show the feasibility of cascading GaN emitters, the authors demonstrate devices using multiple (1, 2 and 4) epitaxially cascaded *p-n* junctions with gadolinium nitride (GdN) visible wavelength transparent tunnel junctions by plasma assisted MBE.

All of the devices have *n*-type GaN on top and bottom layers device since tunnel junctions eliminates the need for a *p*-type contact, as shown in Figure 1.

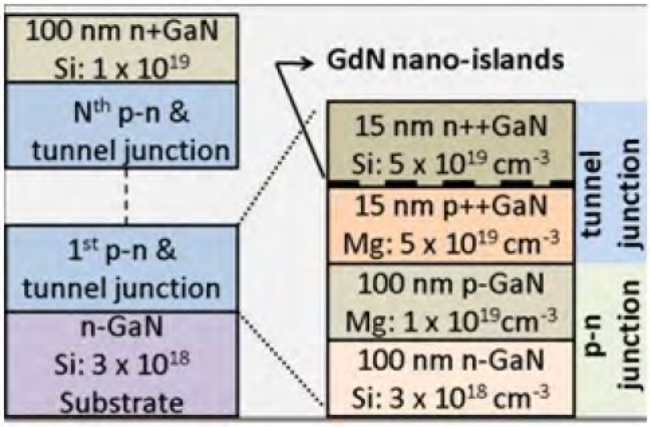


Figure 1: Epitaxial design of the cascaded p-n junctions

As the *p-n* junctions forward biased, tunnel junctions get reverse biased. Electrons from valance band of the *p*-type layer tunnel into conduction band of *n*-type layer, leaving a hole behind, in *p*-type layer. The carriers generated in this process get injected into *p-n* junction diode regions, thus tunnel junctions work as carrier regeneration centres, supplying majority carriers to device active regions.

The cascaded diode structures showed rectifying behaviour. Diode turn-on voltage increased with N-repeats of the device sections, as expected. Analysis of series resistances of the 100μm2 devices leads to a very low resistance ~ 5x10-4 Ω-cm2 per tunnel junction.

Using the performance parameters of these tunnel junctions, the authors calculated the characteristics of LEDs designed with multiple cascaded junctions, with each junction simulating the characteristics of a commercial LED.

The calculation shows that as the number of the cascaded LEDs increases, efficiency droop is greatly reduced, and the wall plug efficiency of a conventional LED can be boosted at elevated powers, as depicted in Figure 2 below.

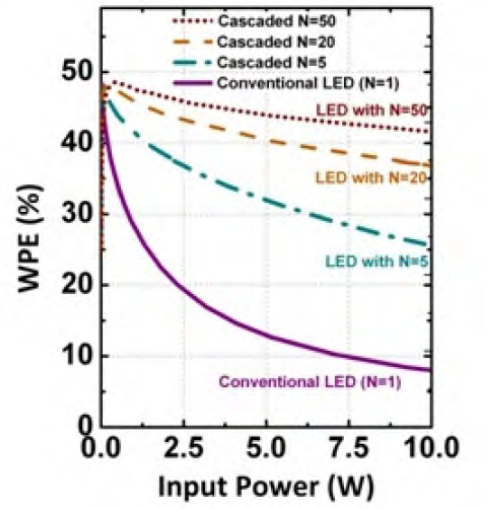


Figure 2: The change in wall plug efficiency of the modeled commercial LED (N=1) and cascaded LEDs with N=5, N=20, and N=50

The enhancement is not only due to superior external quantum efficiency, but also suppression of joule heating. Since the LED is operated at higher voltage and lower current, resistive losses are lower.

This work is described in detail in the paper, "Tunneling-based carrier regeneration in cascaded GaN light emitting diodes to overcome efficiency droop," by Fatih Akyol in *Applied Physics Letters*, 103, 081107 (2013). http://dx.doi.org/10.1063/1.4819737

Intematix awarded GAL phosphor patents for LEDs

When combined with red nitride or other red phosphors, arrangements also covered by these patents, CRIs up to 98 (out of 100) have been demonstrated. The firm's latest technology is also instrumental to meeting new standards such as California's Quality LED Lamp Specification

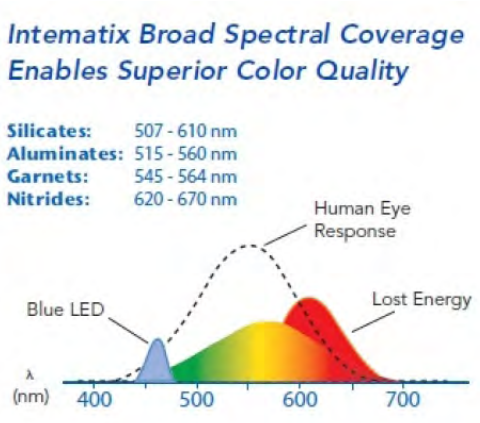
Intematix Corporation has had patents covering its green and yellow GAL phosphor products and certain LuAG phosphors granted by the United States Patent and Trademark Office.

Patent numbers 8,529,791 and 8,475,683 regarding green and yellow emitting, garnet-based phosphors used in lighting and display applications were issued on September 10th, 2013 and July 2nd, 2013, respectively.

Intematix GAL phosphors enable exceptional performance for LED lighting compared to other options

in these colour ranges.

GAL phosphors' light emission characteristics result in higher Colour Rendering Index (CRI) in LED lighting applications. When combined with red nitride or other red phosphors, arrangements also covered by these patents, CRIs up to 98 (out of 100) have been demonstrated.



"By using our GAL phosphors, LED solutions may be designed for efficient performance at CRIs greater than 90," says Yi-Qun Li, Chief Technology Officer at Intematix. "This technology is instrumental to meeting new standards like California's Quality LED Lamp Specification."

GAL phosphors also provide up to 95 percent lumen maintenance at 200°C phosphor temperature, enabling LEDs of all types, including mid-power LEDs, to operate at higher output and efficacy. The products are also versatile design tools for LEDs used in displays like TVs and tablets.

Even more intelligent headlights from Osram

The new variant of the III-nitride based LED Osram Ostar Headlamp Pro enables the simple implementation of Advanced Forward Lighting Systems

Advanced Forward Lighting Systems (AFS), meaning headlight systems that for example adapt their illumination direction to the direction of the bend when driving through curves, can now be even more simply realized by automotive producers,

Osram Opto Semiconductors from Regensburg, Germany says it has developed the new Osram Ostar Headlamp Pro which is the first specific LED component for this particular implementation. The five chips of the new multi-chip LED can be individually controlled and thus flexibly switched on and off according to the driving situations and positions of other road users.

The new variant of the Osram Ostar Headlamp Pro LED is the first multi-chip LED specifically developed for Advanced Forward Lighting Systems (Picture: Osram)

Thanks to LED technology, AFS can be implemented more simply than before because no mechanical assemblies are required to move parts of the headlight or the complete headlight.

With LEDs such as the new Osram Ostar Headlamp Pro, the individual chips are specifically switched on and off via intelligent control. The control utilises sensors and electronic components for high beam light without glare by flexibly concealing areas within the light cone of the headlight according to the specific driving situation and with dynamic adaptation to the positions of other road users.

It is also thanks to LED that adaptable cornering light and spot light can be easily implemented for illuminating possible obstacles at the edge of the carriageway.

The new Osram Ostar Headlamp Pro is claimed to be the first LED specifically for AFS Multi-chip LEDs with higher performance classes are needed for use in headlights, and the Osram Ostar Headlamp LED range features high performance-capable technology, homogeneous luminance and temperature stability. It is therefore especially suitable for high power applications.

This is the reason why LEDs of this family have been used since 2008 for various automotive lighting functions. "Osram Ostar Headlamp Pro is now the first LED specifically developed for use in AFS. Its five chips each with one square millimeter can be controlled individually, forming the basis for intelligent light solutions," explains Peter Knittl, responsible for LED Automotive Marketing at Osram Opto Semiconductors.

Optimal vision for vehicle drivers

"Intelligent headlight systems with our light emitting diodes give car drivers optimal vision even on the edges of roads or with approaching vehicles, offering better

protection from possible accidents. Thanks to the five individually controllable chips, more than one road user can be concealed from view and the intermediate area is still completely illuminated," says Knittl.

Possible thanks to Osram LEDs: Intelligent headlight systems for even more safety (Picture: Osram)

A distinct bright-dark contrast of 1:65 between illuminated and non-illuminated chips is required so that the AFS is as effective as possible and the light beam on the road is optimally transmitted. This means that concealed chips must be genuinely dark and must not be illuminated by their adjacent chips. An integrated shutter also enables a clearly defined light beam from the headlight.

Technical data:

Package dimensions	20 mm x 21 mm
Transmission angle	120 °
Typical light intensity (at 500mA/25℃)	Minimum 710 lm
Chip technology	ThinGaN (UX:3)
Color	Cx = 0.32, Cy = 0.33 in accordance with CIE 1931 (ultra-white)
ESD stability	8 kV
Further characteristics	- improved corrosion stability - with plug connection

GE infuses energy-efficient LED modules with versatility

The latest III-nitride modules are suited to retail lighting and have an interchangeable, Zhaga-compliant mounting socket

Lighting plays a vital role in today's retail environments, maximising shopping experiences and making merchandise appear its best.

GE's Infusion LED Module product line offers an adaptable LED lighting solution that provides highly flexible LED lighting options critical for retailers who want to highlight certain products or create emphasis through a display.

GE's family of Infusion LED Modules features a range of optic designs with a twist-lock interface for easy, tool-free attachment that delivers precise, smooth beam control for optimal performance

"As LED technology continues to advance, the Infusion LED Module accommodates future generations through its interchangeable, Zhaga-compliant mounting socket-making installation, servicing and upgrades nearly hassle-free," says John Koster, product manager of LED Modules, GE Lighting.

Koster adds, "Engineered with a simple twist-fit installation process, users have the ultimate flexibility to alternate beam angles or light packages to suit changing requirements. They are easily upgradeable to allow direct replacement as efficiencies improve, without the need to change lighting fixtures."

Infusion Gen3 Spot Light Modules

Infusion Gen3 LED modules feature a twist-lock interface for easy, tool-free attachment that delivers precise, smooth beam control for optimal performance. GE offers a range of lumen packages, from 850 to 4500 lumens, as well as colour options of 2700K, 3000K and 4000K to meet a variety of retail LED lighting needs.

Infusion Down Light Module (DLM)

The Infusion DLM features outstanding efficacy and colour rendering across the entire DLM 1000 - DLM 4000 Series, providing the ideal ambient lighting solution for high-end retail applications. With down light LED lumen levels up to 4000 lumens, Infusion DLM is also ideal for high-ceiling applications, such as lobbies, auditoriums, convention centres and shopping malls.

Infusion Narrow Punch Module (NPM)

The Infusion NPM is the latest advance in LED-based accent lighting, delivering a high-intensity, narrow spot beam that brings drama and impact to retail lighting applications. The NPM provides small, high-intensity LED source and proprietary optics for maximum performance.

Oslon Black Flat LED now split into two

The compact Osram III-nitride based LED is suited for automotive headlights now comes with two chips for greater brightness

The Oslon Black Flat is now also available on the market as a 2-chip variant.

The Oslon Black Flat LED is now available with two chips (KW H2L531)

As with other LEDs from the Oslon Black family, the new version also features a high level of brightness and is suitable for all headlight functions.

The major advantage of the new LED: As an SMT component it can be attached directly to the PCB and can then be processed further with other components as part of a standard soldering process. The simplicity of this implementation translates into large cost and time savings during further processing.

Thanks to UX:3 chip technology, the new Oslon Black Flat features a very high light output even with high currents, achieving over 500 lumens at 1 ampere. The high brightness level of the new LED is emitted from a very compact package with dimensions of merely 3.1 mm x 3.75 mm and a height of 0.5 mm.

“With the new Oslon Black Flat we’re bringing a significantly more slender LED than the previous version into our portfolio to enable even more compact headlight systems,” explains Florian Rommen, LED Automotive Marketing at Osram Opto Semiconductors. The 2-chip LED is suitable for all headlight functions, primarily for daylight running light with light guides, as well as generally for low beam and high beam light.

Oslon Black Flat in car headlights. Cyclic stability, homogeneous light distribution, small package dimensions and more: the new 2-chip LED from Osram Opto Semiconductors lines up with a wealth of advantages

Cost savings with Surface Mount Technology (SMT)

As a surface mountable component, the new Oslon Black Flat can be, akin to other electronic components, attached simply to a circuit board and processed further as part of standard soldering.

“This soldering capability enables processing the LED in a simple, standardised process and reduces the complexity of the processing steps, which saves a good deal of time and costs,” continues Rommen.

Oslon Black Flat - good stability and homogeneous light distribution Further benefits of the Oslon Black Flat are their homogeneous distribution of light, very good contrast ratio and cyclic stability.

The black QFN (Quad Flat No Leads) housing expands in a similar manner to the circuit board during high temperature cycle loads. As a result, soldered joints are considerably stronger and exposed to much less strain.

A special sealing technology together with the sophisticated package and ceramic converter enable the highly uniform distribution of light as well as good contrast conditions on roads:

Chip encapsulation is directly in the package to achieve a defined bright/dark border in the light beam, and the high contrast of the luminous surface of both chips in relation to the package also contributes to this.

Samples of the Oslon Black Flat are available now, and volume start-up is planned for the turn of the year.

Oslon Black Flat (KW H2L531) technical data:

Footprint	3.1 mm x 3.75 mm x 0.5 mm
Brightness	> 500 lm at 1A
Typical electrical thermal resistance	1.2 K/W
Chip technology	UX:3, Rth improved
Chip-to-chip distance	100 µm (0.1 mm)
Further information	QFN multichip LED

Luminus Devices and Lightera Corporation complete merger

The integrated company will accelerate III-nitride LED technology development and market expansion

Luminus Devices, Inc a manufacturer of Big Chip LEDs, and Lightera, a US - based developer of LED components, have completed all merger activities previously announced on June 11th, 2013.

Luminus is now a subsidiary of Lightera, and will continue to operate under the name Luminus Devices.

The merged entity will utilise combined resources to accelerate the commercialisation of new solutions and expand market opportunities in core markets including display, entertainment and medical lighting.

Expected synergies and corporate R&D expertise will increase emphasis on advanced LED technology development for both general lighting and specialty lighting markets.

“We are pleased to announce that the merger has been completed, and we are now one entity,” says Decai Sun, Chairman and CEO of the combined company. “With solid financial backing, increased R&D resources, and access to the technology innovation in Silicon Valley, we are in a position to more aggressively commercialise our existing portfolio while inventing new LED technologies in order to remain the leader in our core markets and enter new markets with a compelling value proposition.”

Luminus Devices will continue to operate out of its Billerica, Massachusetts headquarters and will gain access to Lightera’s advanced R&D operation in Sunnyvale, California.

Yole: LED phosphor IP is shaping the industry

The market for phosphors and some of the critical IP are currently dominated by Mitsubishi and Denka, which have acquired nitrides and oxynitrides licenses from NIMS. But other players include Intematix, Beijing Yuji and Dow Electronics

Phosphor related intellectual property has been and remains a major driving force with strong impact on the shape of the LED industry.

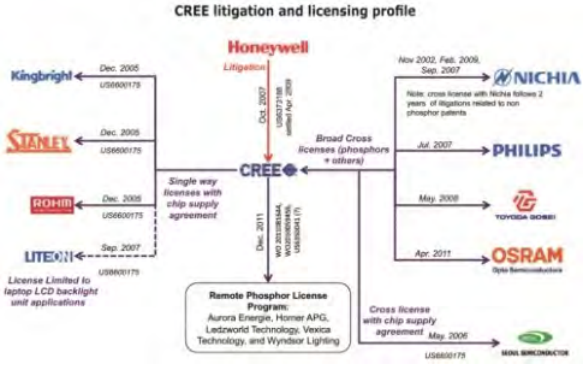
The first commercial GaN-based blue LEDs were produced in Japan in the mid 90’s after researchers Shuji Nakamura at Nichia and Professor Akasaki at Nagoya University (IP assigned to Toyoda Gosei) succeeded in removing some of the major remaining roadblocks associated with this technology (p-doping, epitaxy quality…).

Quickly leveraging on this success, some fundamental patents describing the use of a blue LED combined with a phosphor to produce white LEDs were filed by Nichia, Osram, ATMI and others.

Those fundamental patents were rapidly followed by a fast growing number of applications through 2005 as an increasing number of companies started to compete in the LED market and new applications in cell phone, laptop and LCD TV display, and general lighting were being addressed.

Phosphor IP is a major force in the LED industry. With more than 40 litigation cases, it is also used as leverage by companies which have negotiated close to 70 licensing and supply agreements to date.

It can also be argued that in the first half of the 2000 decade, the strict enforcement and lack of license grants for some fundamental IP related to the design and manufacturing of white LEDs might also have slowed down the progress of the industry by preventing more efficient competition that would allow prices to decrease.



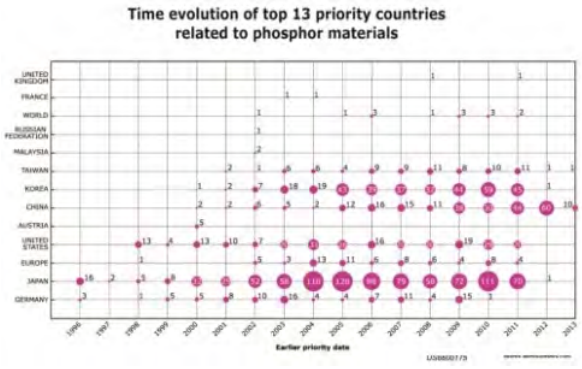
Key players

Hundreds of companies are involved in LED phosphor

IP. Most of the major LED players are present in the list of the top patent assignees. But independent phosphor manufacturers like Intematix or Mitsubishi that are offering their phosphors on the open market are also emerging as major forces in the IP landscape.

Leading Taiwan based packagers are notably absent from Yole's ranking. This weak position explains the large number of litigations and one way, royalty or supply based license agreements involving those companies.

Based on this portfolio analysis as well as on their litigation and licensing history, Yole identified 15 major players that are profiled in this report.



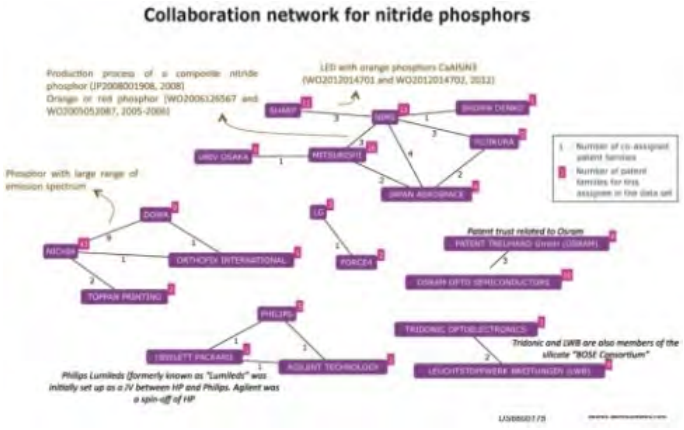
Composition focus shifting from yellow to red and green phosphors

With high performing silicates now widely available as a YAG substitutes for yellow emission, the focus on new composition development and patent protection has shifted toward red and green converters.

The market for those new phosphors and some of the most critical IP are currently dominated by Mitsubishi and Denka, which have acquired nitrides and oxynitrides licenses from NIMS.

However, many other players are also developing nitride and oxynitride compositions, including Intematix, Beijing Yuji and Lightscape (now dow electronic materials). New material families are also considered as promising phosphors including Tungstate and Molybdates as well as Fluorides championed by GE.

Following recent progress in thermal stability and manufacturability, quantum dot are also finally emerging as a credible option. Because of their narrow emission bands, LCD display is the most promising application for the technology. In lighting, the use of red QD in combination with standard phosphor could emerge in remote phosphor applications.

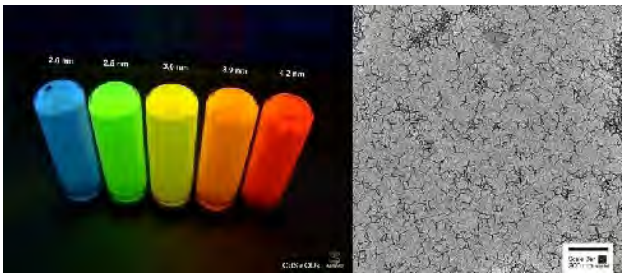


QMC sends CdSe samples to Asian LCD display manufacturer

The cadmium selenide samples will be used to enhance the performance and energy efficiency of high-resolution computer, TV and smartphone displays

Quantum Materials says it has shipped CdSe Tetrapod Quantum Dots in sample quantities to a leading Asian-based electronics manufacturer.

Quantum Materials Corporation (QMC) recently developed tetrapod quantum dots to meet the client's performance specifications.



QMC's CdSe Tetrapod Quantum Dots. Left: Luminescent Vials show colour varies with QD size. Right: Tetrapod Quantum Dots by Electron Microscope

Tetrapod Quantum Dots are an advanced nanoscale material that improves the performance and energy efficiency of very high-resolution computer, TV and smartphone displays.

Quantum Materials' patent-pending continuous-flow technology produces uniform, narrow bandwidth tetrapod quantum dots with bright emission, less aggregation, purer colours (including high-luminous red) and precise colour rendition.

Manufacturers are seeking to “print” tetrapod quantum dots onto backplane films in liquid crystal displays (LCD) for brighter images, larger screens and a wider gamut of colours to deliver a new visual experience in image technology.

Thinner, lighter, brighter and less expensive QD-LED displays, including portable and flexible devices, will offer almost infinite contrast levels, deep black levels and high light output with no motion blur or field-of-view issues.

Stephen B. Squires, Quantum Materials Corp’s Founder and CEO says, “Tetrapod Quantum Dots ultimately allow for lower display manufacturing costs due to their superior luminescence and much lower incidence of aggregation. Far fewer quantum dots are required to achieve the same level of performance. We believe this performance advantage coupled with our continuous-flow manufacturing technology will ensure the lowest quantum dot cost.”

David C. Doderer, vice president of research and development for Quantum Materials wrote the feature article in the July/August 2013 issue of iSP Magazine entitled “Quantum Dots: The Future of Displays”. The article details Quantum Materials’ ability to reduce the cost of quantum dot creation while ensuring uniformity in quantities sufficient to meet high volume display-manufacturing needs.

Nanomarkets’ August article “Key Quantum Dots Markets” highlighted “U.S.-based Quantum Materials Corporation” and the need for “cost-effective large-scale manufacturing techniques, which will be the key to the commercialisation of cost-effective and high-performance QDs”.

Susan Eustis of Wintergreen Research stated in their 2013 report, “Quantum Dot and Quantum Dot Display (QLED) - Markets Reach $6.4 billion by 2019” that “Once manufacturers learn to integrate higher efficiency luminescent quantum dots into their products, each vendor will need to follow or dramatically lose market share. This level of change brought by quantum dot and quantum dot displays (QLED) represents a new paradigm that will create new industries, products and jobs in science and industry.”

Seoul Semi launches LEDs reaching 140 lumens/Watt

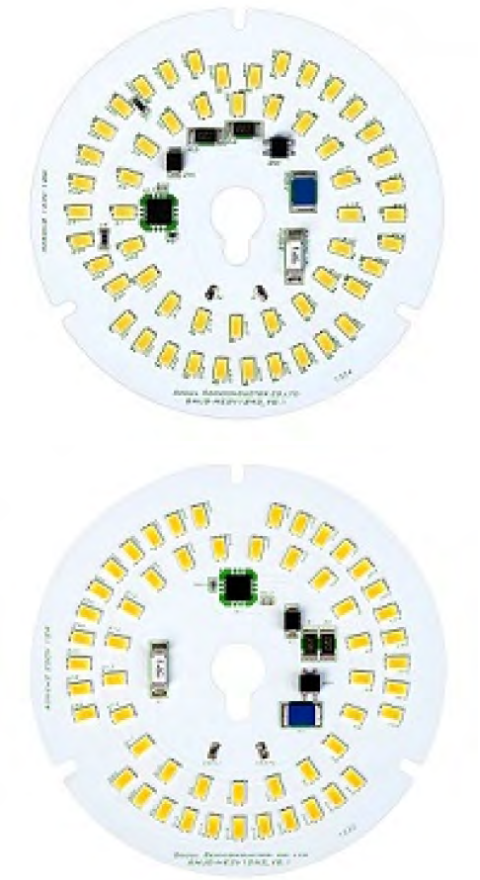
The firm’s III-nitride based AC-driven Acrich2 LED modules reach the equivalent luminance efficiency of DC LEDs

Seoul Semiconductor has announced that Acrich2 LED modules powered by AC are now achieving luminous efficacies of 140lm/W, nearly a 20 percent upgrade from previous versions.

The technology has been incorporated into lighting fixtures already being sold in major North American lighting retailers and has become the world’s best luminance efficacy AC LED module in the global solid state lighting market.

The latest product being released is 10W and can achieve 1,400 lumen in cool white and 1,250 lumen in warm white. Accordingly, it achieves the same level of luminance efficacy that DC LED module with 180lm/W LEDs would offer.

This increased efficacy saves an additional 20 percent of power compared to the older versions. In addition, new arrangements of the LEDs on the board optimise the light pattern for specialised solutions such as flush-mount ceiling lights for living rooms, kitchens and porches.



Acrich2 Module with 140 Lm/W (Left:120V, Right: 220V)

Seoul Semi says its Acrich2 is the world’s first module with an on-board IC and multi-junction technology (MJT) LED that can be directly plugged into the wall without a ballast, driver, or converter.

Newer variations of the Acrich2 family include smart functions such as dimming inputs and surge suppression circuits which create exceptional added value for lighting designers.

Marten Willemsen, Vice President of Marketing for Seoul Semiconductor, says, “Efficiency and design flexibility have been dramatically improved with the latest Acrich2 modules giving 140lm/W.”

He adds, “Acrich2 modules have already been adopted by well-known lighting manufacturers and are selling in major retail stores. We believe the success of the Acrich2 LED modules will increase our market share in both the indoor and outdoor LED lighting markets.”

Fraunhofer GaN transistors hit 98 percent efficiency

Gallium nitride devices for efficient power electronics can handle currents of up to 100 A and breakdown voltages beyond 600 V

To increase the efficiency of voltage converters and minimise heat losses, researchers at the Fraunhofer Institute for Applied Solid State Physics IAF have developed a transistors based on GaN.

The devices have a low on-resistance and high switching speed.

Gallium-nitride-based voltage converters are intended to minimise power losses of electric cars in the future. (credit Robert Bosch GmbH)

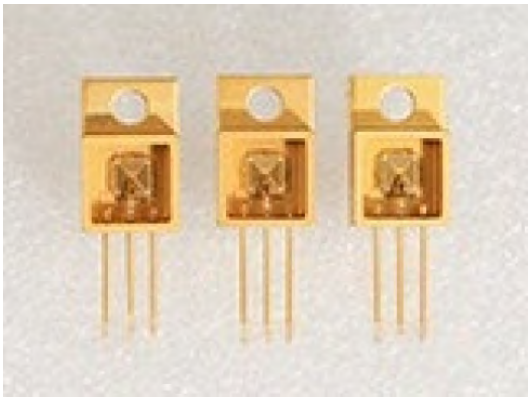
Voltage converters have recently achieved an efficiency level of 98 percent. And this saves energy in electromobility and photovoltaics.

In order to foster the development of electromobility it is critical to reduce the energy consumption caused by electric cars. Efficient voltage converters can minimise losses and thus save energy during operation and the charging of batteries.

Researchers of the Fraunhofer Institute for Applied Solid State Physics IAF and the Ferdinand-Braun-Institut in Berlin have now managed to develop GaN devices for applications in electromobility and photovoltaics.

“We have increased the efficiency level of the transistors in our voltage converters to 98 percent. Practical tests have shown a performance of up to 1 kW. Thereby we have closed the gap to the international state-of-the-art,” explains Michael Schlechtweg, head of department at Fraunhofer IAF.

In contrast to conventional devices based on silicon, GaN transistors allow the reduction of losses in voltage converters by more than half.



GaN transistors for efficient power electronics: currents of up to 100 A and breakdown voltages beyond 600 V are possible (© Fraunhofer IAF)

The new devices are the result of the research project “PowerGaNPlus”, which was supported by the German Federal Ministry of Education and Research (BMBF) for a period of over three years providing three million Euros of funding.

The funding was part of different research and development projects on the topic of “Power Electronics for Increased Energy Efficiency« in the program called »IKT 2020 – Research for Innovation”.

The goal is to establish Germany as the leading provider for technologies of electromobility and to contribute to a future-oriented mobility. Therefore, the BMBF supports particularly innovative partnerships between science and industry.

Practical tests show robust gallium nitride devices

Concerning the development of gallium nitride

technology, Fraunhofer IAF cooperates, among others, with Robert Bosch GmbH in order to test the real-life behaviour of the devices. Stress tests conducted so far have not only shown the devices' good performance, but gave also a first indication of high short-circuit strength.

"Validation of the devices developed within the project with a breakdown voltage of more than 600 V showed encouraging performance. Already in this early development stage, low conduction and switching losses comparable to considerably more mature and commercially available silicon carbide transistors were demonstrated during operation of the GaN devices in circuits ready for application. The stress tests conducted so far have also hinted at high short-circuit strength and thermal stability," confirms Walter Daves, who supervised the project at Robert Bosch GmbH. The devices reached maximum currents of up to 100 A during on-resistance operation.

The transistors have already been tested for applications in battery chargers for electric cars, and, together with KACO new energy GmbH, also in photovoltaic inverters. The following partners also cooperate with Fraunhofer IAF in this research project, IXYS Semiconductor GmbH, United Monolithic Semiconductors GmbH, Universität Erlangen-Nürnberg, RWTH Aachen.

New opportunities for GaN technology

Whereas silicon-based devices are slowly reaching their physical limits, gallium nitride technology offers new opportunities for power electronics. Gallium nitride devices can be operated under higher voltages and temperatures than conventional power devices based on silicon.

This allows a reduction of the cooling efforts; compact, light-weight and cost-effective voltage converters become possible. In comparison with silicon transistors, gallium nitride allows to increase the switching frequency by at least a factor of three.

Due to the higher breakdown strength and power density of the material, the devices are considerably more efficient than their silicon equivalent. This will reduce the energy consumed in order to charge the battery of an electric car or to feed in energy from solar parks into the grid.

"Besides using GaN transistors in electromobility and photovoltaics, they will also be able to increase efficiency and save energy in household applications, production technology or in generators for plasma and laser systems. Our continuous goal will be to increase reliability, thermal stability and switching frequency in order to use the full potential offered by gallium nitride technology," explains Patrick Waltereit, project leader at Fraunhofer IAF.

Gadolinium doped UV LEDs could enable portable low cost devices

The doped wires enable LED tuning at precise frequencies for commercial applications

Commercial uses for ultraviolet (UV) light are growing, and now a new kind of LED under development at Ohio State University could lead to more portable and low-cost uses of the technology.

The patent-pending LED creates a more precise wavelength of UV light than today's commercially available UV LEDs, and runs at much lower voltages and is more compact than other experimental methods for creating precise wavelength UV light.

The LED could lend itself to applications for chemical detection, disinfection, and UV curing. With significant further development, it might someday be able to provide a source for UV lasers for eye surgery and computer chip manufacture.

In the journal *Applied Physics Letters*, Ohio State engineers describe how they created LEDs out of semiconductor nanowires which were doped with the rare earth element gadolinium.

The unique design enabled the engineers to excite the rare earth metal by passing electricity through the nanowires, says study co-author Roberto Myers, associate professor of materials science and engineering at Ohio State.

But his team didn't set out to make a UV LED.

"As far as we know, nobody had ever driven electrons through gadolinium inside an LED before," Myers says. "We just wanted to see what would happen."

When doctoral students Thomas Kent and Santino Carnevale started creating gadolinium-containing LEDs in the lab, they utilised another patent-pending technology they had helped develop - one for creating nanowire LEDs. On a silicon wafer, they tailor the wires' composition to tune the polarisation of the wires and the wavelength, or colour, of the light emitted by the LED.

Gadolinium was chosen not to make a good UV LED, but to carry out a simple experiment probing the basic properties of a new material they were studying, called gadolinium nitride. During the course of that original

experiment, Kent noticed that sharp emission lines characteristic of the element gadolinium could be controlled with electric current.

Different elements fluoresce at different wavelengths when they are excited, and gadolinium fluoresces most strongly at a very precise wavelength in the UV, outside of the range of human vision. The engineers found that the gadolinium-doped wires glowed brightly at several specific UV frequencies.

Exciting different materials to generate light is nothing new, but materials that glow in UV are harder to excite. The only other reported device which can electrically control gadolinium light emission requires more than 250 volts to operate.

The Ohio State team showed that in a nanowire LED structure, the same effect can occur, but at far lower operating voltages: around 10 volts. High voltage devices are difficult to miniaturise, making the nanowire LEDs attractive for portable applications.

"The other device needs high voltage because it pushes electrons through a vacuum and accelerates them, just like a cathode ray tube in an old-style TV. The high-energy electrons then slam into gadolinium atoms, which absorb the energy and re-emit it as light in the UV," Myers explains.

"We believe our device works at significantly less voltage precisely because of the LED structure, where the gadolinium is placed in the centre of the LED, exactly where electrons are losing their energy. The gadolinium atoms get excited and emit the same UV light, but the device only requires around 10 volts."

Because the LED emits light at specific wavelengths, it could be useful for research spectroscopy applications that require a reference wavelength, and because it requires only 10 volts, it might be useful in portable devices.

The same technology could conceivably be used to make UV laser diodes. Currently high-powered gas lasers are used to produce a laser at UV wavelengths with applications from advanced electronics manufacturing to eye surgery. The so-called excimer lasers contain toxic gases and run on high voltages, so solid-state lasers are being explored as a lower power and non-toxic alternative.

As to cost, Kent pointed out that the team grows its LEDs on a standard silicon wafer, which is inexpensive and easily scaled up to use in industry. "Using a cheap substrate is good; it balances the cost of manufacturing the nanowires," he says.

The team is now working to maximise the efficiency of the UV LED, and the university's Technology Commercialisation and Knowledge Transfer Office will license the design as well as the method for making specially doped nanowires to industry.

This research is described in detail in the paper, "

This research was sponsored by the National Science Foundation (NSF) and Ohio State's Centre for Emergent Materials, one of a network of Materials Research Science and Engineering Centres funded by NSF.

NASA headquarters brightened up by Cree LED lights

Cree's CR series of III-nitride based troffers deliver improved light quality with an estimated 52 percent savings in energy costs

The National Aeronautics and Space Administration (NASA) headquarters, a leased facility in Washington, D.C., has been outfitted with energy-saving CR Series LED Troffers by Cree.

The high-performance LED installation is part of a renovation to maximise energy savings of the 600,000 square-foot building.

More than 1,300 Cree CR22 architectural LED troffers have been installed, and Piedmont Office Realty Trust, owners of the NASA headquarters building, expects the new fixtures to deliver energy savings of 52 percent over the previously installed T8 fluorescent fixtures. An additional 5,200 Cree CR22 troffers are planned to complete the lighting upgrade.

Cree CR22 troffer

"We originally considered replacing the existing T8 fluorescent tubes with T5 fluorescents, but after testing Cree's CR22 LED troffer, we knew it was the best solution for this installation," says Tony Roberts, senior chief engineer supporting Piedmont Office Realty

Trust. “No other manufacturer offered the combination of performance, pricing and efficacy we desired. We continue to be impressed by the improved lighting quality and significant savings the CR22 troffers provide.”

Featuring Cree TrueWhite Technology, Cree linear luminaires enabled Piedmont Office Realty Trust to reduce the fixture count by 10 percent, adding to the overall savings. Designed to last for more than 50,000 hours, twice the lifetime of comparable linear fluorescents, the new fixtures are designed to reduce maintenance and operational costs for the headquarters.

The CR22 troffers feature integrated Lutron EcoSystem dimming technology. The system is controlled by a Lutron Quantum lighting control system, which provides the flexibility needed to reconfigure and improve the occupant experience in any space and can extend LED lifetime.

The ability to fine-tune light levels individually in each fixture, and ultimately to achieve the perfect lighting environment, is the result of an ideal marriage between the Cree luminaires and Lutron digital control technology.

“The CR Series is a no-compromise alternative to fluorescent lighting and demonstrates our commitment to driving the broad adoption of LED lighting,” says Mike Bauer, vice president of lighting sales, Cree.

“The successful integration of CR troffers with digital controls and dimming allows Cree to further the obsolescence of antiquated fluorescent lighting. Optimal lighting is essential to workplace environments like NASA’s headquarters. Cree linear luminaires deliver unrivalled performance, making the decision to choose LED lighting over fluorescent options an obvious choice.”

Cree raises the bar for standard LED bulbs

The firm’s III-nitride based LED bulbs are suitable for use in 60W replacement bulbs

Cree’s TW (TrueWhite) series LED bulb emits natural LED light - setting a new standard with a Colour Rendering Index (CRI) of 93.

Cree says it is the first company to meet the California Energy Commission (CEC) LED bulb specification.

The new TW Series bulb looks like a light bulb, lights like a light bulb and gives consumers another reason to switch to LED. The new Cree bulb is available for $19.97 for the 60-watt replacement.

New Cree TW Series LED Bulb

California is yet again leading the nation with a higher standard for energy efficiency - this time it’s across the lighting industry. The introduction of Compact Fluorescent Lighting (CFL) led to a backlash of consumer dissatisfaction for many reasons, the greatest being its failure to provide Californians a quality lighting alternative to inefficient incandescent technology.

New technology, like the new Cree TW Series LED Bulb, offers CA consumers a no-compromise alternative to CFL and incandescents.

The Sacramento Municipal Utility District (SMUD) has long been a proponent for energy-efficient lighting technologies for its customers. SMUD will provide a rebate for the new Cree TW Series LED Bulb. “SMUD sees huge value in reducing the lighting portion of electric bills and is a staunch supporter of the new CA LED Quality lighting standard,” says Elisabeth Brinton, SMUD Chief Customer Officer. “We are thrilled to see the first bulbs reach the market. This technical accomplishment makes a huge contribution to energy efficiency, while benefiting consumers with quality lighting,” says Brinton.

The CA specification focuses on six quality attributes for LED lamps, including colour temperature, colour consistency, colour rendering, dimmability, lifetime and light distribution. The new CA standard requires all retrofit lamps to achieve a CRI of 90 or better – the higher the CRI of a bulb, the more accurate the actual colour of the objects it illuminates.

“The Voluntary California Quality LED Lamp Specification was created to move consumers away from inefficient

lighting of the past century and toward more efficient LED lighting technology," said Michael Siminovitch, director, California Lighting Technology Centre. "The new Cree TW Series is the first bulb to meet the CA Specification and is exactly what consumers need to see in order to finally transform this marketplace."

The new Cree TW Series LED Bulb delivers an unprecedented 93 CRI. The high-performance bulb uses 78 percent less energy and lasts 25 times longer than typical incandescent light bulbs. The bulbs turn on instantly, are dimmable with most standard incandescent dimmers and are backed by Cree's industry-leading 10-year limited warranty. With a retail price of $17.97 for the soft white 40-watt replacement (450 lumens) and $19.97 for the soft white 60-watt replacement (800 lumens), the Cree bulb quickly pays for itself then pays consumers year after year.*

"The new TW Series is a great complement to our market-leading Cree LED Bulb that was launched in March and gives consumers more reasons to switch to LED lighting," finishes Chuck Swoboda, Cree chairman and CEO. "The Cree TW Series LED Bulb is another example of Cree's commitment to innovation and driving 100 percent adoption of LED lighting."

*Based on Cree TW Series LED Bulb 60-watt replacements at 13.5 watts, $0.11 per kilowatt-hour, 25,000 hour lifetime and average use of six hours per day.

Cree LED lights brighten up Raley's Petroleum and Convenience Store

The firm's LED lighting delivers savings and rapid payback at a New South Lake Tahoe location

Raley's Family of Fine Stores has selected LED lighting by Cree to illuminate its new petroleum station, car wash and convenience store in South Lake Tahoe, California.

Featuring advanced LED technology paired with an integrated dimming system, Cree lighting delivers improved light quality combined with reduced energy consumption and maintenance costs for the store, with payback in less than one year.

This is based on typical commercial usage of 12 hours per day for exterior products and 24 hours per day for interior products, and the state of California average of $0.14 per kWh electric costs, lighting-related HVAC impact and relamp maintenance reductions.

Sixty Cree LED luminaires illuminate the South Lake Tahoe store, generating significant energy savings compared to the fluorescent, metal halide and halogen fixtures used at Raley's existing Fair Oaks, California location. Cree's interior and exterior fixtures deliver exceptional colour rendering, light quality and distribution and allow the use of fewer fixtures than required with traditional lighting.

The new Cree lighting system includes Cree 304 Series recessed soffit luminaires and Cree CR24 troffers in the convenience store along with Cree 304 Series recessed canopy luminaires installed over the fuel canopy deck and Cree 227 Series recessed soffit luminaires in the car wash bay.

Cree Edge wall-mount security luminaires, as well as post-top and arm-mounted luminaires provide further exterior lighting in the parking lot.

"Implementing energy-efficient LED lighting supports our goal of reducing overall energy consumption at new stores and in upgrades to our 128 locations," says Randy Walthers, energy and utility manager, Raley's. "We found a valued partner in Hi-Def Lighting & Electrical, Inc. who met our needs with high-quality Cree LED lighting equipped with a sophisticated control system for remarkable savings and light quality."

Featuring an optional integrated sensor, Cree luminaires help Raley's conserve energy and meet California's daylight control requirement at the South Lake Tahoe store. Cree luminaires in the car wash, for example, operate at 20 percent power until the occupancy sensor brings them to full power and then dims them when not in use.

An additional benefit of the Cree lighting installation is the universal drivers that provide continuous illumination during periodic brownouts that are common to the area.

"In South Lake Tahoe, the voltage will drop as much as 30 percent during hot afternoons creating multiple problems with electrical systems," comments Walthers. "Cree luminaires are unaffected by these erratic voltage drops and continue performing at peak efficiency due to dependable drivers that include AC input protection."

"Raley's is fast becoming a model of energy efficiency in the petroleum and convenience store industry," adds Mike Bauer, vice president sales, lighting at Cree. "Cree offers a full suite of energy-efficient lighting for 24/7 operations, helping Raley's continue its mission toward environmental stewardship, while supporting their bottom line."

Bruker reveals electroluminescence tool for HB-LED wafer analysis

The firm's new technology for optical and electrical characterisation delivers fast and repeatable measurements for epi process quality control

A the 15th China International Optoelectronic Exposition (CIOE 2013), Bruker introduced the new LumiMap Electroluminescence System for HB-LED epi wafer process metrology.

LumiMap Instrument

LumiMap joins a suite of other Bruker HB-LED epi metrology tools, and it incorporates many of the advanced features of Bruker's flagship metrology products. Proprietary, patent-pending features of the new system include the durable conducting probe, a unique wafer edge contact solution, and advanced I-V curve modelling for accurate and repeatable forward voltage value measurement.

These features enable LumiMap to deliver accurate and repeatable forward and reverse IV characteristics, spectral intensity, wavelength and spectral width measurements on 2- to 6-inch epi wafers, with a wide range of current settings.

"LumiMap provides more accurate and reliable electrical and optical epi wafer measurements than the traditional indium dot method," says. Ryan Lee, Executive VP and CTO of Foshan Nationstar Optoelectronics Co. Ltd. "A reliable electro-luminescence quality check immediately after MOCVD will help us further improve epi wafer yield and reduce costs."

"Bruker is pleased to bring a new technology solution to HB-LED manufacturing, rounding out our other HB-LED metrology technologies in 3D optical microscopy, atomic force microscopy and XRD/XRF for PSS wafers and epi wafer multi-quantum layer characterisation," adds Xiaomei Li, Vice President of Segment Marketing of the Bruker Nano Surfaces division. "LumiMap ideally serves stringent HB-LED manufacturing cost reduction goals at a time when the industry is poised for unprecedented growth."

"LumiMap electroluminescence technology fills the current lack of fast, non-destructive, reliable and repeatable optical and electrical measurement solutions to improve epi wafer yield and LED device quality at the epi wafer stage," concludes Robert M. Loiterman, Executive Vice President and General Manager of Bruker's Stylus and Optical Metrology Business. "With LumiMap, the HB-LED industry can now get accurate electrical and optical feedback in minutes rather than days, reducing scrap events and operating costs."

LumiMap is a value-oriented alternative to conventional, multistep, operator-dependent indium dot methods of epi (made by epitaxial growth) wafer characterisation. The system features rapid, non-destructive, no post measurement chemical cleaning, software-controlled measurement locations, and repeatable optical and electrical measurement capabilities through forming a temporary LED device on an epi wafer.

The results obtained by LumiMap are well correlated with those on the final HB-LED device, providing an early warning of process shifts, which in turn reduces the risk of expensive scrap events and improves yields.

Simple wafer exchange and intuitive software provides the industry's easiest to use interface for production quality control, as well as epi process development. The long measurement lifetime of the proprietary conducting probe meets the strictest industry cost of ownership requirements. A the 15th China International Optoelectronic Exposition (CIOE 2013), Bruker introduced the new LumiMap Electroluminescence System for uncompromised HB-LED epi wafer process metrology.

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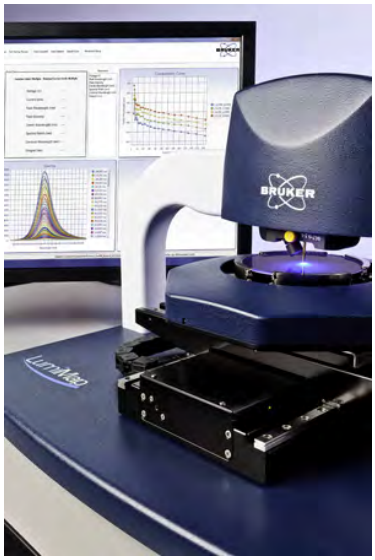

LumiMap Electroluminescence System lights up wafer with non-destructive proprietary probe

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Rudolph expands macro defect inspection series

The new NSX 220 tool is designed for semiconductor, MEMS and LED packaging and test facilities to achieve productivity at a low price

Rudolph Technologies has launched its new NSX 220 automated macro defect inspection system.

The company says its system, pictured below, provides fast, easy defect inspection for traditional back-end processes including the LED market at a reduced price.

NSX220 system

The NSX 220 tool joins the NSX 320 system in the NSX family of automated macro defect inspection and metrology systems for final manufacturing facilities.

The first NSX 220 system was installed in July at a major outsourced assembly and test (OSAT) facility in Asia.

Mike Jost, vice president and general manager of Rudolph's Inspection Business Unit says, "The NSX 220 system is a streamlined version of our NSX 320 system. The NSX 220 system is designed for traditional macro defect inspection of wafers up to 300mm at conventional semiconductor, MEMS and LED final manufacturing

facilities, while the NSX 320 System serves next-generation advanced packaging processes with defect inspection and three-dimensional metrology for wafers up to 450mm."

He continues, "The NSX 220 system benefits from many of the hardware and software innovations that made the NSX 320 system the market leader in advanced packaging, but is targeted for back-end facilities that do not need the full suite of capabilities offered by the NSX 320 System. Adding the NSX 220 system to the NSX family gives our customers a choice of best-in-class capabilities."

The NSX 220 is an automated macro defect inspection system that uses grey-scale image analysis (with colour image capture) to provide fast, accurate inspection and metrology in final manufacturing applications for wafers up to 300mm. It can detect traditional advanced macro defects such as scratches, mechanical damage, foreign materials, voids and probe damage, while also performing two-dimensional measurements on bumps, probe marks and edge trim processes.

The tool operates over a range of resolutions (10µm - 0.5µm) with both brightfield and optional darkfield illumination. The software platform, leveraged from the NSX 320 system's success, uses host-based image processing and delivers significant improvements in usability and productivity over older-generation NSX series equipment. Using centrally-managed recipe creation and editing, multiple NSX 220 tools can share a single recipe and be matched across the fab.

An optional suite of yield management software optimises the productivity of both the NSX 220 and 320 systems and minimises the need for operator assistance. Discover Software is designed for use with Rudolph inspection systems to allow real-time analysis for faster solutions and intelligent defect sampling for reduced offline review.

Imec and Veeco unite on GaN-on-Si development

The gallium nitride on silicon R&D will concentrate on LED and power electronics applications

Nanoelectronics research centre imec of Belgium and Veeco Instruments are collaborating on a project aimed at lowering the cost of producing gallium nitride-on-silicon based power devices and LEDs.

Barun Dutta, imec's Chief Scientist, comments, "The productivity, repeatability, uniformity and crystal quality of Veeco's MOCVD equipment has been instrumental in helping us meet our development milestones on GaN-on-Si for power and LED applications.

The device performance enabled by the epi has helped us realise state-of-the-art D-mode (depletion mode) and E-mode (enhancement mode) power devices. Our goal is to establish an entire manufacturing infrastructure that allows GaN-on-Si to be a competitive technology."

Imec's multi-partner GaN-on-Si research and development program gathers the industry to jointly develop world-class GaN LED and power devices on 200 mm silicon substrates compatible with a 200 mm CMOS-compatible infrastructure. By joining forces at imec, companies share costs, talent and intellectual property to develop advanced technologies and bring them to the market faster.

Jim Jenson, Senior Vice President, General Manager, Veeco MOCVD, says, "We have been working with imec on this program since 2011 and are encouraged by our progress. Our work is mutually rewarding, as we are both focused on being able to realize lower costs while maintaining world-class performance on GaN-on-Si devices. This technology can be used to create lower cost LEDs that enable solid state lighting, more efficient power devices for applications such as power supplies and adapters, PV inverters for solar panels, and power conversion for electric vehicles."

Veeco's MOCVD equipment incorporates the firm's Uniform FlowFlange technology for superior uniformity and excellent run-to-run repeatability. Low maintenance TurboDisc technology enables highest system availability, excellent particle performance and high throughput.

Everlight extends JU series of COB LEDs

The firm's expanding portfolio of single light sources for directional lighting applications offer a cost/performance ratio of over 400lm/$

Everlight has expanded its JU series of chip-on-board (COB) LEDs to include 7, 10 and 15 W types in addition to the existing 4W version.

COB LEDs are especially suited for directional applications that require a powerful single light source for effective illumination such as GU, MR and PAR retrofits, downlights and candelabras.

The JU series now consists of four JU1215 (15 x 12 x

1.6mm) and one JU2024 (20 x 24 x 1.6mm) type/s with powers ranging from 4 watts to 15 watts.

JU 1215 LEDs

JU 2024 LED

All types provide an efficacy of 110lm/W or more at 3000K CCT, a CRI of over 80Ra and 25°C substrate temperature, and are available in versions ranging from ANSI bin 2,700 K to 6,500 K. The JU series also offers 3 step (McAdam) options for advanced utilisation.

JU COB LEDs are multi-chip solutions that are directly applied to the board without housing, for efficient thermal dissipation. Their ceramic substrate base allows for thermal resistances of below 2°C/W, with the largest wattage COB measuring around 0.8C°/W. Low thermal resistance and good heat dissipation ensure high reliability and increase the LEDs' service life.

Each COB has its unique features with carefully calculated chip configurations for optimal lumens per dollar of over 400lm/$ and optically compact light emission surfaces (LES) for effective pairing with secondary optics.

Additional JU COB options such as "Color Choice", high voltages from 45 to 250V for different regions and applications, and high CRI (>90Ra) are available to meet customers' specific needs. All JU COBs have completed LM80 lumen maintenance testing and are offered with a complete line of accessories such as standardized holders, appropriate reflectors and more.

The future product roadmap of the JU family provides for additional higher power members as 25W / 35W / 50W for track light, down light or low bay applications by Q4/2013. Meanwhile, 4W / 8W / 13W / 17W / 26W MCPCB 120lm/W COB are coming out for wider options.

Samples are available upon request and mass production has already started.

Telecoms

MACOM launches first surface mount L-Band 90W GaN power module

A novel modular, SMT-optimised approach unlocks the full promise of gallium nitride in plastic for radar applications

M/A-COM Technology Solutions Inc. (MACOM) has announced the newest entry in its portfolio of GaN in Plastic packaged power products.

Optimised for L-Band commercial air traffic control, military radar, and long range perimeter monitoring applications at 1.2 to 1.4 GHz, MACOM's new 2-stage, fully matched GaN in Plastic power module scales to peak pulse power levels of 100W in a 14 x 24 mm package size - delivering twice the power of comparably sized competing products

MACOM says its new high gain GaN in Plastic power modules are the first and only GaN-based modules to support surface mount technology (SMT) assembly, providing significant cost and process advantages compared to ceramic-packaged flange-mount components.

Delivering clear benefits in size, weight and power (SWaP) while enabling high volume manufacturing

efficiency, MACOM's new GaN power modules extend the performance attributes of its discrete GaN in Plastic power transistors and establish new standards for GaN module integration.

Under pulsed conditions, these modules deliver output power greater than 90W, with 30 dB typical associated power gain and 58 percent typical power added efficiency. Supporting 50V operation and up to 3 ms pulse width/duration for improved time on target, MACOM's GaN in Plastic power modules reduce overall power consumption and cooling requirements compared to existing options.

The module features a Land Grid Array pattern for enhanced thermal flow and 'True SMT' assembly. All inputs and outputs are formed on the back of the module and include edge castellations for ease of assembly inspection.

The module's flexible design allows for gate and/or drain pulsing, and includes a gate voltage sense port for use in temperature compensation or pulse droop compensation. Leveraging sophisticated thermal management techniques to ensure high reliability, the calculated mean-time-to-failure at 200□C is approximately 600 years.

"Building on a long history of providing similarly sized, very high power LGA module solutions in GaAs, MACOM's GaN in Plastic power modules represent a pivotal evolution in GaN semiconductor technology, providing high overall power performance in a light, ultra-compact 14 x 24 mm package while enabling the greatest possible ease of assembly," says Damian McCann, Engineering Director, MACOM. "This modular, SMT-optimised approach unlocks the full promise of GaN in Plastic for radar applications and introduces unprecedented efficiencies from design to manufacturing."

The table below outlines typical performance:

Test condition for the below table: 1ms pulses, 10% duty cycle P_{IN}= 20dBm

Parameter	MAMG-001214-090PSM
Frequency	1.2-1.4 GHz
Output Power	50 dBm
Power Added Efficiency	58 %
Pulse Droop	0.3 dB
Power Gain	30 dB
2nd Harmonic	-40 dBc
3rd Harmonic	-52 dBc
Load Mismatch Stability	5:1
Load Mismatch Tolerance	6:1
Package Size	14 x 24 mm

MACOM's new GaN in Plastic L-Band 90W power modules are sampling to customers today.

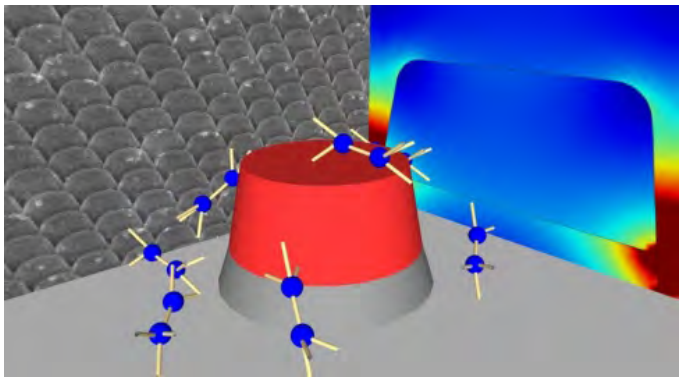
Tiny InAs antennas give long light waves IR vision

The indium arsenide antenna arrays enable the detection of small volumes of materials with a standard infrared spectrometer

University of Illinois at Urbana-Champaign researchers have developed arrays of tiny nano-antennas that can enable sensing of molecules that resonate in the infrared (IR) spectrum.

The antennas are composed of III-V compound semiconductor InAs.

"The identification of molecules by sensing their unique absorption resonances is very important for environmental monitoring, industrial process control and military applications," says team leader Daniel Wasserman, a professor of electrical and computer engineering. Wasserman is also a part of the Micro and Nano Technology Laboratory at Illinois.



Nanoantennas made of semiconductor InAs can help scientists detect molecules with infrared light (Credit: Daniel Wasserman)

The food and pharmaceutical industries use light to detect contaminants and to ensure quality. The light interacts with the bonds in the molecules, which resonate at particular frequencies, giving each molecule a "spectral fingerprint." Many molecules and materials more strongly resonate in the IR end of the spectrum, which has very long wavelengths of light - often larger than the molecules themselves.

"The absorption signatures of some of the molecules of interest for these applications can be quite weak, and as we move to nano-scale materials, it can be very difficult to see absorption from volumes smaller than the wavelength of light," Wasserman says. "It is here that our

antenna array surfaces could have a significant impact."

Other nano-scale antenna systems cannot be tuned to a longer light wavelength because of the limitations of traditional nanoantenna materials. The Illinois team used highly doped semiconductors grown by MBE.

"We have shown that nanostructures fabricated from highly doped semiconductors act as antennas in the infrared," notes Stephanie Law, a postdoctoral researcher at Illinois and the lead author of the work published in the journal *Nano Letters*. "The antennas concentrate this very long wavelength light into ultra-subwavelength volumes, and can be used to sense molecules with very weak absorption resonances."

The semiconductor antenna arrays allow long-wavelength light to strongly interact with nano-scale samples, so the arrays could enhance the detection of small volumes of materials with a standard IR spectrometer - already a commonplace piece of equipment in many industrial and research labs.

The researchers further demonstrated their ability to control the position and strength of the antenna resonance by adjusting the nanoantenna dimensions and the semiconductor material properties.

The group will continue to explore new shapes and structures to further enhance light-matter interaction at very small scales and to potentially integrate these materials with other sensing systems.

"We are looking to integrate these antenna structures with optoelectronic devices to make more efficient, smaller, optoelectronic components for sensing and security applications," Wasserman concludes.

This work is described in detail the paper, "All-Semiconductor Plasmonic Nanoantennas for Infrared Sensing," by Stephanie Law *et al* in *Nano Letters*, 2013, 13 (9), pp 4569-4574. DOI: 10.1021/nl402766t

Infinera InP PICs extend mid-atlantic broadband network

MBD has increased the reach of its indium phosphide DTNX platform to new high-bandwidth sites in DC and Virginia

Mid-Atlantic Broadband Communities Corporation (MBC), a wholesale open-access network transport provider, has expanded its network in the mid-Atlantic region with connections in Washington, DC and Richmond, Virginia.

MBC has expanded the reach of its advanced open-access transport network with new Points of Presence (POP) locations at the CoreSite data centre at 1275 K Street in Washington, DC and the QTS data centre at 6000 Technology Boulevard, Richmond, Virginia.

These expanded POP locations will enable MBC to provide wholesale transport services to its carrier customers as well as enable additional connectivity options.

MBC has extended itsrobust Infinera DTN network into these new interconnection facilities. MBC's Infinera network enables rapid provisioning for high bandwidth transport services, and provides low latency transport connections to southern Virginia and MBC interconnection facilities in the Carolina's and Georgia.

"We are pleased to work with MBC to expand their network into Washington, DC," says Mark Showalter, Sr. Director of Communications at Infinera. "Infinera's Intelligent Transport Network enables MBC to rapidly deploy 10G and 100G connectivity to both small and large service providers in the region."

"Our goal of providing a robust open-access wholesale transport network for carriers continues to pay dividends for our region," comments Tad Deriso, President and CEO of MBC. "Creating more on-net connections between carrier neutral data centers in major markets and our Southern Virginia region supports our mission of enhancing our regional competitive advantage with communications infrastructure."

MBC now has 32 on-net locations for interconnection and will continue to expand its reach to enhance its robust regional network.

NeoPhotonics adds smaller NLW laser and ICR To 100G product portfolio

The compact indium phosphide (InP) PIC narrow linewidth μITLA and compact ICR enable higher port density on 100G and above coherent line cards and transponders

NeoPhotonics Corporation will be exhibiting its suite of small form factor Photonic Integrated Circuit (PIC) based optical components for 100G Coherent Transport at the European Conference on Optical Communications (ECOC).

NeoPhotonics is a designer and manufacturer of InP based photonic integrated circuit, or PIC, based

optoelectronic modules and subsystems for bandwidth intensive high speed communications networks.

These small form factor products are designed to meet the requirements of high port density 100G coherent systems and to scale to 200G and 400G applications using higher order modulation schemes.

NeoPhotonics supplies Narrow Linewidth Tuneable Lasers (NLW-TL) and Intradyne Coherent Receivers (ICR), which are key components in the 100G Coherent Transport systems currently being deployed in growing numbers around the world.

NeoPhotonics has now added new small form factor versions to its current optical components for coherent systems. The first new product is a narrow-linewidth, micro-Integrable Tuneable Laser Assembly (micro-ITLA), which is designed to reduce the footprint by more than a factor of three and to reduce power consumption compared to current generation ITLAs.

What's more, NeoPhotonics' micro-ITLA is designed to support the high optical output power and the narrow linewidth required for next generation coherent network architectures. The second product is a Small Form Factor Intradyne Coherent Receiver (SFF-ICR), which is less than half of the size of currently shipping ICRs.

The SFF-ICR has the option of an integrated VOA on the signal path and a monitor photodiode (MPD) to simplify board level integration. This versatile device is well-suited for both single incoming channel and multiple incoming channel applications.

"Photonic Integration has played a major role in enabling the current generation of coherent systems which are now transforming the optical communications landscape, and we are proud of the contribution NeoPhotonics has made to this sea change," says Tim Jenks, Chairman and CEO of NeoPhotonics.

"As exemplified by these new products, we are utilizing our Photonic Integration technology to bring our customers the benefits of reduced size, reduced power consumption and higher levels of integration and performance," continues Jenks.

Inphi appoints Nicholas Brathwaite to its Board

The indium phosphide (InP) provider of high-speed, mixed signal semiconductor solutions for the communications and computing markets has a new person on board

Inphi Corporation has announced that Nicholas Brathwaite has joined its Board of Directors.

"We are extremely pleased to welcome Nicholas to Inphi's Board of Directors," says Ford Tamer, Inphi's president and CEO. "We are excited about his in-depth knowledge and wealth of expertise in driving innovation for high-tech, global companies."

Brathwaite is a founding Partner of Riverwood Capital, a growth equity, middle market technology investment firm with investments in Asia, Latin America and the United States. He has also been involved with semiconductor companies, hardware development and electronic services (including manufacturing) since 1986.

Brathwaite served as the CEO of Aptina Imaging Corporation for approximately two years and is currently its Chairman of the Board.

Prior to Aptina, he joined Flextronics International Ltd. in 1995 as its Vice President of Technology and then from 2000 to 2007 served as its Chief Technology Officer. Flextronics acquired nChip, where he then held the position of Vice President and General Manager of operations from 1992 to 1996. Brathwaite also spent six years with Intel Corporation in various engineering management positions in technology development and manufacturing.

Brathwaite has served as a director of Power Integrations since January 2000 and as a member of the board of Lighting Science Group since April 2011. Nicholas Brathwaite also served as a member of the board of directors of Tessera Technologies, Inc., from February 2008 until May 2011 and Photon Dynamics, Inc. prior to its acquisition in 2008.

Brathwaite received a B.S. in Applied Chemistry from McMaster University, and an M.S. in Polymer Science & Engineering from University of Waterloo. He has also completed the Wharton Executive Education Training Program on Corporate Governance.

Infinera InP devices expand TeliaSonera International Carrier

The firm has accomplished this with its indium phosphide (InP) based Super-Channel SD-FEC

Infinera says it has the ability to double capacity on a key link in TeliaSonera International Carrier's (TSIC) North America terrestrial network using the world's first super-

channel implementation of Soft Decision Forward Error Correction (SD-FEC).

This is featured on the Infinera InP based DTN-X platform and the company has successfully completed this verification test on a production route in TSIC's North America network.

The company also announced that the SD-FEC capability is now generally available on the DTN-X platform.

The test was performed on TSIC's Houston to Phoenix fibre link and verifies the ability of Infinera's SD-FEC technology to double the available transmission capacity on this network link. SD-FEC is an advanced error detection and correction technology that enables transport networks to deliver error-free digital information at extremely high data rates and over very long distances, offering networks greater capacity and reach without the need to regenerate the signal en route.

Infinera says its DTN-X platform delivers the industry's only long haul FlexCoherent 500 Gigabit per second (Gb/s) super-channels based 500 Gb/s Photonic Integrated Circuits (PICs) and the FlexCoherent Processor.

The company has deployed DTN-X networks in 30 countries with hundreds of super-channels activated into production. The DTN-X now offers SD-FEC, which is integrated into Infinera's third generation FlexCoherent Processor chip and combined with a world-record Polarisation Mode Dispersion (PMD) compensation capability that is specifically engineered to optimise capacity and reach.

"As network operators face increasing capacity requirements, they continue to seek solutions at the optical layer that add features and services to increase reach and capacity for 100G and beyond," says Ron Kline, principal analyst, network infrastructure at Ovum.

"Service providers are continuously looking to make better use of their network assets so an SD-FEC enabled 500G supper-channel that nearly doubles the reach of the current system will really resonate with large network operators," he continues.

Mattias Fridström, Head of Technology at TSIC and keynote speaker at the coming DWM America conference notes, "We operate one of the world's most extensive fibre backbones across North America and Europe including Russia. We operate networks in a variety of environments and conditions; Infinera has proved with us that SD-FEC can double the capacity of key routes on our network."

Infinera Co-founder and President David Welch adds, "Earlier this year, we demonstrated our third generation FlexCoherent Processor, integrated with SD-FEC along with 500 Gb/s PICs, in a trial that doubled capacity on a submarine cable link from Hawaii to California. Today, we are pleased to announce that these benefits can also be delivered in a terrestrial environment and that the industry's first super-channel SD-FEC solution is now generally available."

The Intelligent Transport Network, featuring the DTN-X, enables carriers to use time as a weapon to increase revenues with highly reliable, differentiated services while reducing operating costs through scale, multi-layer convergence and automation.

TeliaSonera International Carrier is part of TeliaSonera Group, owner and operator of one of the world's most extensive fibre backbones, the first to be 100G enabled across Europe and North America. TSIC has deployed an Infinera Intelligent Transport Network in North America and in northern Europe.

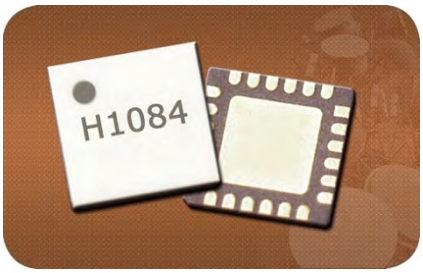
Hittite GaAs MMIC switch covers 23 to 30 GHz

The firm's gallium arsenide based device is Ideal for microwave radio, SATCOM & sensor applications

Hittite Microwave Corporation, a supplier of complete MMIC based solutions for communication & military markets, has introduced a new reflective, Single Pole Four Throw (SP4T) switch.

The GaAs based switch is suited to demanding applications requiring broadband performance, low insertion loss, fast switching speed and high power handling capability.

The HMC1084LC4 is a broadband reflective GaAs MESFET SP4T switch that provides frequency coverage from 23 to 30 GHz, and is controlled with 0/-3V logic.



The HMC1084LC4 SP4T switch exhibits fast switching speed of 15 ns (rise and fall times) and consumes much less DC current than PIN diode based solutions. With

an input signal of 30 GHz, the HMC1084LC4 exhibits 11 dB return loss, 26 dB isolation and only 2.8 dB insertion loss.

What's more, the HMC1084LC4 SP4T switch is capable of handling high power levels in excess of +27 dBm, that make it ideal for a wide range of applications including telecom infrastructure, sensors, microwave radio, SATCOM, antenna arrays and test instrumentation.

Housed in a compact leadless 4x4 mm ceramic SMT package and compatible with surface mount manufacturing techniques, the HMC1084LC4 SP4T switch complements Hittite's extensive line of single, double and multi-throw MMIC switches with frequency coverage from DC to 86 GHz.

Samples are available from stock and can be ordered via the company's e-commerce site or via direct purchase order.

BinOptics' InP laser technology gives more than Moore

The new technology helps overcome cost, yield and performance barriers associated with sources for silicon photonics

BinOptics Corporation, a manufacturer and supplier of semiconductor lasers has successfully incorporated its patented Etched Facet Technology (EFT) into a variety of silicon photonic applications.

Creating InP based lasers and other photonic components using EFT, opposed to the conventional cleaving process, improves performance, reproducibility, reliability and quality while maintaining affordable manufacturing costs.

Silicon photonics has emerged as a key technology to keep Moore's Law intact for computing in the march towards exaflop (a quintillion or 1018 mathematical operations per second) computing.

Similarly, advances in Datacom infrastructure in recent years have further necessitated cost-effective, highly reliable lasers capable of supporting next-gen high-speed information transfer.

An efficient, reliable, and non-hermetic photonic source is required to provide infrared radiation to silicon photonics circuits.

BinOptics has fabricated semiconductor lasers and other photonic elements on InP that meet these specific requirements.

EFT was first conceived and co-invented by the CEO of BinOptics, Alex Behfar, while pursuing a PhD at Cornell's School of Electrical and Computer Engineering. Since Behfar co-founded BinOptics in 2000, EFT has been utilised in the manufacturing of more than 40 million lasers shipped.

"Our customers have experienced the benefits of our EFT produced lasers for a long time and across a wide variety of applications, but only recently have they been aggressively exploring the unique benefits of our EFT offerings in silicon photonics applications," says Behfar. "EFT is solving a new set of unique challenges as organisations look for solutions to enable the next generation of computing. Many industry experts expect chip-to-chip and on-chip photonics to be the most significant technology impacting the future of computing."

Challenges with reproduction, flexibility, integration, and performance using conventional cleaving processes drive up cost and threaten the sustainability of continuous improvement. The BinOptics EFT design philosophy eliminates those barriers, helping support the rapid advancement of silicon photonics.

Attributes of the technology are listed below.

Reproducibility and Flexibility: EFT allows facets to be defined through high precision photolithography rather than imprecise cleaving. The result is unprecedented uniformity and yield, as well as the capability to build structures that are impossible to realise with conventional techniques. With no dependency on the crystallographic plane of the wafer, unique anti-reflection geometries can be used in place of expensive coatings.

High Yield: Facet cleaving and bar testing is often one of the most costly operations in other factories. BinOptics' lasers are fully fabricated with EFT and automatically tested on the wafer before separation into individual chips. As a result, BinOptics is able to fully evaluate all the lasers on the wafer in an automated, high-throughput test operation, in addition to dramatically reducing the cost of chip handling.

Surface Emission: The BinOptics' technology platform enables etching of angled facets that allow the light from a laser to emerge perpendicular, or at an angle off from perpendicular, to the surface of the InP chip. This is particularly helpful with coupling to grating couplers on silicon photonic chips.

Performance and Reliability: Facet cleaving operation and subsequent coating operations can cause failures and performance issues due to the disruptive nature

of the process. EFT eliminates both these sources of failure. Devices made using EFT with proprietary passivation technology are exceptionally robust with respect to temperature and humidity, eliminating the need for costly hermetic packages.

Precision Facet Location: Device facets are formed with extreme precision, enabling low-cost passive alignment with silicon photonics.

“Active alignment of a light source to the silicon photonics chip is a costly process, requiring extremely expensive equipment,” comments Jonathan Klamkin, Director of the Integrated Photonics Laboratory at Boston University. “With EFT, BinOptics found a way to reap the cost and efficiency benefits of passive alignment without sacrificing the accuracy associated with real-time active alignment. This should be a critical factor for companies seeking economical, large-scale rollout of silicon photonics applications.”

“We needed an experienced but innovative InP partner who could provide a reliable, easy-to-integrate, non-hermetic light source for our silicon photonics platform,” concludes Mehdi Asghari, CTO, of Kotura. “BinOptics provided us with the fastest path to market for our new 100 Gbps optical engine, exceeding our expectations in every way.”

Harvesting energy from light in a new way

A new discovery could enhance optoelectronic devices and solar cell performance

Researchers from the University of Pennsylvania have demonstrated a new mechanism for extracting energy from light.

This could improve technologies for generating electricity from solar energy and lead to more efficient optoelectronic devices used in communications.

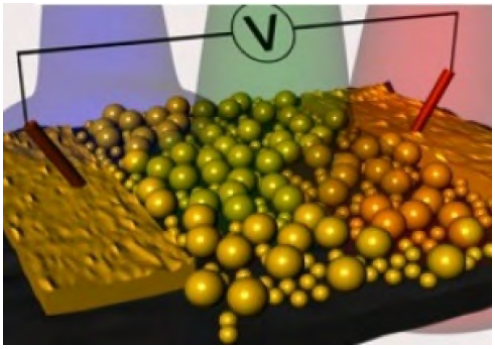
Dawn Bonnell, Penn’s vice provost for research and Trustee Professor of Materials Science and Engineering in the School of Engineering and Applied Science, led the work, along with David Conklin, a doctoral student.

“We’re excited to have found a process that is much more efficient than conventional photoconduction,” Bonnell comments. “Using such an approach could make solar energy harvesting and optoelectronic devices much better.”

The new work centres on plasmonic nanostructures, specifically, materials fabricated from gold particles and light-sensitive molecules of porphyin, of precise sizes and arranged in specific patterns.

Plasmons, or a collective oscillation of electrons, can be excited in these systems by optical radiation and induce an electrical current that can move in a pattern determined by the size and layout of the gold particles, as well as the electrical properties of the surrounding environment.

Because these materials can enhance the scattering of light, they have the potential to be used to advantage in a range of technological applications, such as increasing absorption in solar cells.



Researchers fabricated nanostructures with various photoconduction properties

In 2010, Bonnell and colleagues published a paper in *ACS Nano* reporting the fabrication of a plasmonic nanostructure, which induced and projected an electrical current across molecules.

In some cases they designed the material, an array of gold nanoparticles, using a technique Bonnell’s group invented, known as ferroelectric nanolithography.

The discovery was potentially powerful, but the scientists couldn’t prove that the improved transduction of optical radiation to an electrical current was due to the “hot electrons” produced by the excited plasmons. Other possibilities included that the porphyin molecule itself was excited or that the electric field could focus the incoming light.

“We hypothesised that, when plasmons are excited to a high energy state, we should be able to harvest the electrons out of the material,” Bonnell explains. “If we could do that, we could use them for molecular electronics device applications, such as circuit components or solar energy extraction.”

To examine the mechanism of the plasmon-induced current, the researchers systematically varied the different components of the plasmonic nanostructure, changing the size of the gold nanoparticles, the size

of the porphyin molecules and the spacing of those components. They designed specific structures that ruled out the other possibilities so that the only contribution to enhanced photocurrent could be from the hot electrons harvested from the plasmons.

"In our measurements, compared to conventional photoexcitation, we saw increases of three to 10 times in the efficiency of our process," Bonnell comments. "And we didn't even optimise the system. In principle you can envision huge increases in efficiency."

Devices incorporating this process of harvesting plasmon-induced hot electrons could be customized for different applications by changing the size and spacing of nanoparticles, which would alter the wavelength of light to which the plasmon responds.

"You could imagine having a paint on your laptop that acted like a solar cell to power it using only sunlight," Bonnell says. "These materials could also improve communications devices, becoming part of efficient molecular circuits."

This work is described further in the paper, «Plasmon-Induced Electrical Conduction in Molecular Devices,» by Parag Banerjee *et al* in *ACS Nano*, 2010, 4 (2), pp 1019 - 1025. DOI: 10.1021/nn901148m

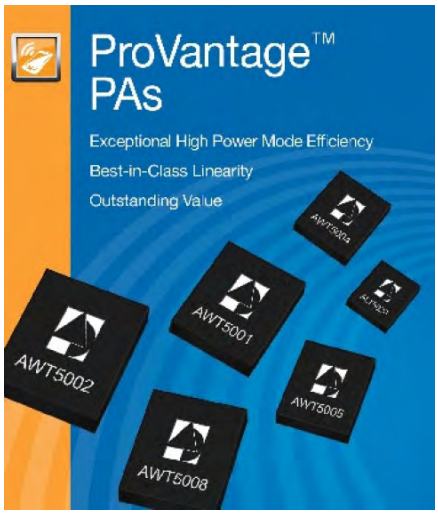
The research was supported by the U.S. Department of Energy and the National Science Foundation.

Anadigics unveils InGaP power amplifier series

The company's ProVantage indium gallium phosphide PAs are suited to 3G & 4G high power mode efficiency

Anadigics has introduced the new ProVantage power amplifier (PA) product family.

The company's ProVantage solutions deliver excellent efficiency and linearity to extend battery life and ensure high data throughput in LTE, WCDMA/HSPA, CDMA/EVDO, and TD-SCDMA mobile devices.



"We recognise the tremendous diversity in mobile device requirements, ranging from voice-centric feature phones to power-hungry smartphones and tablets," says Navi Miglani, product marketing director of Cellular Products at Anadigics.

"Our new ProVantage power amplifiers are optimised to deliver outstanding value by providing a best-in-class combination of high power mode efficiency, linearity, and reduced system costs. This, addition to our world-class cellular products portfolio, complements our industry-leading ProEficient and ProEficient-Plus solutions and enables Anadigics to target the needs of a wider range of market segments," Miglani continues.

Anadigics ProVantage power amplifiers leverage the company's InGaP-Plus technology to achieve outstanding performance and integration. These power amplifiers help extend battery life by offering three selectable bias modes that optimise efficiency for low, medium and high output power levels, as well as a shutdown mode with low leakage current.

ProVantage solutions are also designed for use with an external switch mode power supply (SMPS), such as average power tracking (APT), to further increase efficiency and reduce current consumption at low and medium operating powers.

Anadigics' ProVantage power amplifiers provide world-class linearity to ensure stable cellular connectivity and high data throughput. The complete family of ProVantage solutions are offered in compact 3 mm x 3 mm x 0.9 mm packages and feature internal voltage regulation to save valuable PCB space.

Details of the packages are shown in the table below.

ANADIGICS ProVantage PA Family Key Specifications:

Product	Frequency Band	Efficiency
AWT5001	Band 1 (1920 to 1980 MHz)	48% @ +28.2 dBm (WCDMA)
AWT5002	Band 2 (1850 to 1915 MHz)	48% @ +28.6 dBm (WCDMA)
AWT5004	Band 4 (1710 to 1755 MHz)	48% @ +28.5 dBm (WCDMA)
AWT5005	Band 5 (824 to 849 MHz)	48% @ +28.6 dBm (WCDMA)
AWT5008	Band 8 (880 to 915 MHz)	47% @ +28.5 dBm (WCDMA)
ALT5020	Band 20 (832 to 862 MHz)	42% @ +27.7 dBm (LTE)

Finisar achieves record quarterly revenues

The manufacturer of III-V subsystems and components for fibre optic communications is celebrating its latest results

Finisar Corporation has announced financial results for its first fiscal quarter ended July 28th, 2013.

"I am pleased to report first quarter revenues were $266.1 million, an all-time record for Finisar. This was an increase of $22.7 million, or 9.3 percent, over the prior quarter and an increase of $45.5 million, or 20.7 percent over the first quarter of the prior year. Revenues exceeded the guidance of $245 million to $260 million that we provided early in the first quarter and grew for the fourth consecutive quarter," said Jerry Rawls, Finisar's executive Chairman of the Board.

He added, "The growth in revenues in the first quarter came primarily from increased sales of 10G, 40G and 100G Ethernet transceivers for datacom applications. As a result of these higher than expected revenues, a favourable product mix and operating leverage, we also were able to achieve gross margin and earnings per diluted share that exceeded our original guidance range,"

"During the quarter, we continued to invest significantly in technology and product development. Our new products for 100 gigabit parallel and serial applications for either single mode and multi mode fiber applications continue to have strong customer demand. We also expect our new platform of high density dual and single WSS will extend our leadership in the WSS market in both the component and ROADM linecard form," said Eitan Gertel, Finisar's Chief Executive Officer.

Business Outlook

The company indicated that it currently expects revenues for the second quarter of fiscal 2014 to be in the range of $277 to $292 million and GAAP operating margin to be in the range of approximately 9.7 percent to 10.7 percent.

An audio replay of a conference call discussing the results can be accessed on the company's website until the next regularly scheduled earnings conference call.

Advanced Wireless chooses Mentor Graphics GaAs IC analysis tool

Mentor's platform for the verification of gallium arsenide ICs will be used to analyse mobile and other wireless applications

Advanced Wireless Semiconductor Company (AWSC) has selected Mentor Graphics' Calibre nmDRC and nmLVS products.

As part of its foundry offering, AWSC will provide the Calibre design rule decks to its customers to help them ensure their designs are error-free and meet all foundry requirements before submitting them to AWSC manufacturing.

"We moved to Calibre for our new offerings to take advantage of its highly efficient commands and unique capabilities not available in other products, such as equation-based DRC, which makes it easier to implement complex design rules for RF applications," says Louis Lu, manager of product development engineering at AWSC.

He adds, "Calibre is widely used by our fastest growing customers, and it works seamlessly in any of the design flows our customers use, including the Agilent ADS custom RF design platform. Also very important in our decision is the high level of product support and application knowledge we receive from Mentor."

"We're pleased to see the adoption of Calibre for state-of-the-art RF ICs such as those fabricated by AWSC," says Shu-Wen Chang, director of Calibre Foundry Programs at Mentor Graphics. "AWSC's adoption of Calibre for advanced GaAs ICs for RF applications is part of a growing worldwide trend to use the most advanced Calibre technologies for larger feature size applications. Our mutual customers are pushing much more complex designs through processes initially developed for simpler geometric data, particularly in mobile applications (e.g. smart phones, tablets, etc.) where AMS/RF processes are increasingly important."

One example of advanced features being used by AWS is the Calibre nmDRC product's equation-based DRC (eqDRC) facility, which fills the void between traditional DRC and DFM process simulators. Some design rules are simply too complex to capture with traditional DRC

measurements and rule tables.

Equation-based DRC allows these rules to be expressed as complex multi-variable equations, enabling precise and accurate characterisation of complex 2D and 3D interactions that have a direct impact on manufacturability.

Equation-based DRC brings user extensibility and fast runtimes to a whole host of new design and process interactions. It also provides precise numerical feedback allowing users to make reliable design tradeoffs, and to quickly determine the best fix.

AWSC is a pure foundry service company located in Hsin-shi, Taiwan, which specialises in fabbing Monolithic Microwave Integrated Circuits (MMIC) fabricated with GaAs HBT, pHEMT/IPD and GaAs/Ge CPV processes for smart phone and WiFi applications.

RF Electronics

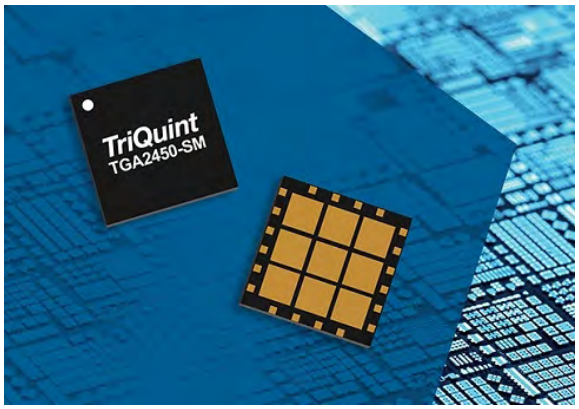
TriQuint uses InGaP / GaAs HBT technology to halve PA board space

With this board space reduction, network infrastructure OEMs can reduce the size of radio systems and their bills of materials

TriQuint Semiconductor has revealed its first integrated power amplifier solution for 'small cell' and active antenna base stations that dramatically reduces board space while delivering high efficiency.

Small cell solutions are key components in 3G/4G mobile networks including LTE.

TriQuint's integrated small cell PA, the TGA2450-SM, is the first in a family serving all key mobile infrastructure frequency bands. It incorporates a Doherty final stage delivering high power added efficiency of 35 percent for the entire module at 2.5 W average power. The TGA2450-SM supports multi-mode and multicarrier signals. The module incorporates InGaP/GaAs HBT device technology to provide a combination of high efficiency and Data Processing Design friendliness.



As the name implies, 'small cell' radio systems have deliberately-defined coverage areas that can improve connectivity where it is most needed. The radio transceivers in these systems are smaller by design to support indoor or outdoor deployment as required. By significantly reducing board space, network infrastructure OEMs can reduce the size of radio systems and their bills of materials.

"The market trend is towards more densely-packed, smaller radio links - small cells. TriQuint's highly-integrated solution offers the flexibility to support our customers' emerging designs. Our product family uses only half the space of traditional discrete parts," says Infrastructure and Defense Products Vice President and General Manager, James L. Klein.

Noted infrastructure researcher Earl J. Lum reports that small cell and active antenna solutions will be a growing part of infrastructure and future heterogeneous networks supporting faster 3G/4G data rates.

"Highly integrated power amplifier solutions such as the TGA2450-SM and filtering technology offered by TriQuint support additional network capacity, higher efficiency systems and reduced system BOMs. The overall LTE outdoor microcell market is expected to begin high volume shipments in 2014 and reach USD $1.8 billion by 2017," adds Earl J. Lum, President of EJL Wireless Research.

New Base Station TGA2450-SMPower Amplifier Module Details:

Frequency Range (GHz)	Average Output Power (W)	PAR / P3dB (dBm) / (W)	Gain (dB)	Vcc / PAE	Linearity (dBc)	Package Style
2.11-2.17	2.5	7.5-8 / 18	35	18 & 5 / 35%	-55 ACLR	SMP

Samples and evaluation fixtures of the new power amplifier are available.

Lasers

Oclaro develops minute ultra-bright AlInGaP laser diode for displays

The 3.8mm diameter super-bright device delivers more power but uses less energy. This is thanks to new processes, including an optimised waveguide structure and fine-tuning of the laser device structural parameters

Oclaro has developed the HL63153AT, a tiny red laser diode that delivers 150mW single-transverse-mode optical output power at 638nm.

The AlInGaP based laser offers 25 percent more power than its predecessors. Distributor, the Optoelectronics Company says this is currently the highest single-transverse-mode optical output power at a red wavelength available on the market.

Oclaro HL63153AT

Technology breakthrough enables higher power

The massive increase in output power is due to a technology breakthrough which Oclaro accomplished by developing new processes, including an optimised waveguide structure, and fine-tuning the laser device structural parameters.

The consequent leap forward in performance enables a brighter, more vibrant high-lumen image display for compact mobile devices such as pico projectors, smartphones and mobile gaming devices while greatly decreasing power consumption.

“System designers are working on the development of ever more compact RGB modules for the rapidly expanding mobile display market”, says Tony Pope, M.D., the Optoelectronics Company. “The Oclaro HL63153AT addresses their need for a light source that combines high brightness and high operating temperature range with a small-form-factor package which is fundamental to further miniaturisation”.

Quest for low energy and long battery life

Size reduction of mobile, handheld devices which employ RGB laser technology is often limited by the power requirements of the display which must have vibrant colour and sharp images while still offering low energy consumption and a long battery life. The Oclaro HL63153AT will benefit manufacturers with its low power consumption of only 0.6W in a tiny 3.8mm-diameter TO industry-standard package.

Takayuki Kanno, President, Oclaro Japan, comments, “This newest red laser diode has been designed as a direct result of customer requests for a shorter wavelength diode that delivers higher power in a thin package”.

The introduction of the HL63153AT is well-timed as a global company announces what it says is the highest resolution smartphone screen to date which is also the slimmest available on the market with the bonus of reduced power consumption and extended battery life.

Oclaro HL63153AT specifications

The HL63153AT delivers 150mW single transverse mode optical output power from a tiny 3.8mm package at a typical wavelength of 638nm. It has a low operating current of 230mA and threshold current of 75mA. Operating voltage is only 2.7V and LD reverse voltage is 2V. Operating temperature is from -10 to +600C.

As well as laser displays, the Oclaro HL63153AT is ideal as a light source for optical equipment and small laser modules.

Oclaro’s high performance laser diodes are proven to consume a low operating current which extends battery life while maintaining the integrity of the laser diode power in a variety of applications such as range finding, line levelling construction systems and biomedical applications.

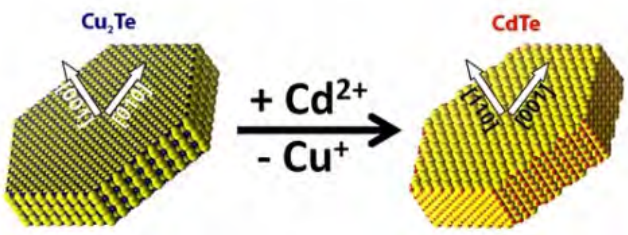
The HL63153AT will be in full production from February

2014. Oclaro high performance laser diode samples may be requested through the Optoelectronics Company.

Enhancing lasing properties of CdTe quantum disks

Suitable for use in lasers, a novel preparation method of cadmium telluride quantum disks can leads to more stable nanocrystals compared to conventional preparation methods. Tuning the shape of the disks can strongly improve conditions for lasing or single-photon emission

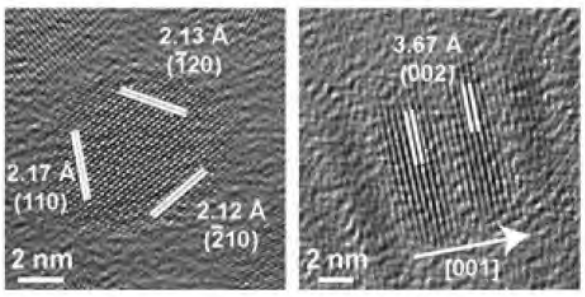
Researchers have used a novel synthesis method to produce hexagonal CdTe nanocrystals from disk-shaped Cu2Te nanocrystals.



Schematic showing disk-shaped hexagonal Cu2Te nanocrystals and subsequent cation exchange of Cu to Cd at high temperature (180 °C) resulting in highly fluorescent CdTe nanocrystals

The Cu2Te nanocrystals have a well-defined stoichiometric composition and tuneable diameter and thickness. The resultantCdTe has less than 1 mol % of residual Cu remaining in the lattice.

The synthesis preserves the overall disk shape, but is accompanied by a substantial reconstruction of the anion sublattice. This results in a reorientation of the *c*-axis from the surface normal in Cu2Te into the disk plane in CdTe nanodisks.



TEM micrographs showing Cu2Te (left) and CdTe (right)

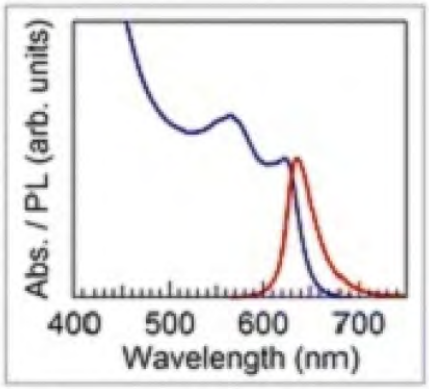
The scientists from the Istituto Italiano di Tecnologia, Genova and IMEM-CNR, Parma in Italy, used the FLS920 photoluminescence spectrometer made by Edinburgh Instruments to measure the photoluminescence (PL) spectral properties, quantum efficiencies and lifetimes of the CdTe disks.

Fluorescent nanocrystals are currently being applied in lasers or displays, and offer exciting prospects for future photonics such as quantum emitters. The nanocrystal shape plays an important role in these applications. The flat CdTe quantum disks with high fluorescence efficiency therefore provide an interesting possibility to explore the shape- and crystal structure-dependent fluorescence properties of semiconductor nanocrystals.

The measurements conditions could be carefully controlled using the FLS920: the PL quantum efficiency of the CdTe quantum disks was measured with an integrating sphere, by exciting the samples at 500 nm.

Band-edge PL lifetime measurements were made with the FLS920 using time-correlated single-photon counting, exciting the samples at 400 nm with a 50 ps laser diode. The repetition rate of the diode was adjusted to 1 MHz to ensure complete decay of the emission between subsequent excitation pulses.

The disks show a PL peak that can be tuned continuously from 600 to 640 nm according to their thickness. The researchers also reached a faster PL decay time compared to spherical CdTe quantum dots, which confirms that simply tuning the shape can strongly improve conditions for lasing or single-photon emission. What's more, the current synthesis also leads to more stable nanocrystals compared to conventional preparation methods, opening up the way for practical application of the quantum dots.



The CdTe nanodisks show a continuously tuneable PL peak position, scaling with the thickness of the disks

The results were recently published in the paper, "Synthesis of Uniform Disk-Shaped Copper Telluride Nanocrystals and Cation Exchange to Cadmium Telluride Quantum Disks with Stable Red Emission," by Hongbo Li *et al* in *Journal of the American Chemical Society* . http://dx.doi.org/10.1021/ja404694k

Bomb detecting lasers could improve security checkpoints

Michigan State University research has put the possibility of bomb-detecting lasers at security checkpoints within reach

In the current issue of *Applied Physics Letters*, Marcos Dantus, MSU chemistry professor and founder of BioPhotonic Solutions, has developed a laser that can detect micro traces of explosive chemicals on clothing and luggage.

"Since this method uses a single beam and requires no bulky spectrometers, it is quite practical and could scan many people and their belongings quickly," Dantus comments. "Not only does it detect the explosive material, but it also provides an image of the chemical's exact location, even if it's merely a minute trace on a zipper."

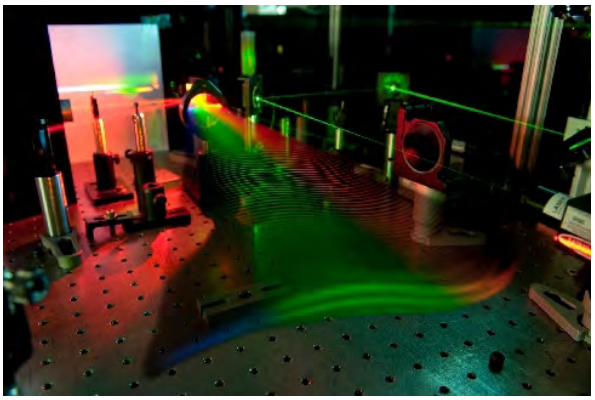
This doesn't mean that security forces will be armed with handheld laser in airports, however. This laser would more likely be in a conveyor belt, like the X-ray scanners already used for airport security. The low-energy laser is safe to use on luggage as well as passengers, he adds.

For decades, scientists have been working to develop lasers that are powerful enough for detection, but safe enough to use on people. Dantus' initial spark for this breakthrough came from collaboration with Harvard University that developed a laser that could be used to detect cancer, but has the beam output of a simple presentation pointer.

"While working on biomedical imaging, I began exploring additional applications," Dantus says. "We soon learned how effective it was for detecting traces of hazardous substances from distances up to 10 metres away."

Dantus' bomb-detecting laser works as a single beam, but uses two pulses. The first resonates with certain chemical frequencies found in explosives. The second, a shadow pulse, serves as a reference. A discrepancy between the two pulses indicates the presence of explosive materials.

"The laser is not affected by the colour or surface of clothes or luggage," Dantus says. "The resonant pulse and the shadow pulse are always in balance unless something is detected. Our method has Raman chemical specificity, excellent sensitivity and robust performance on virtually all surfaces."



Not only does the laser detect explosive material, but it also provides an image of the chemical's exact location, even if it's merely a minute trace on a zipper. (Courtesy of MSU)

An aerospace company has already expressed interest in furthering this technology. With additional funding, a standalone prototype could be created in about one year, he adds.

This work is described in detail in the paper, "Standoff explosives trace detection and imaging by selective stimulated Raman scattering," published online in *Applied Physics Letters*, 103, 061119 (2013). The full paper can be accessed via the website http://dx.doi.org/10.1063/1.4817248

Funding for this research was provided by the Department of Homeland Security, Science and Technology Directorate. BioPhotonic Solutions is a high-tech company Dantus launched in 2003 to commercialise technology invented by his research group at MSU.

Nanoplus orders Oxford Instruments tool for laser etching

The Ionfab300 Plus will be used for laser bar facet coating with anti-reflective and high-reflection multilayers, and the PlasmaPro System100 RIE system will be used for GaAs and InP compound etching

Oxford Instruments Plasma Technology (OIPT) has just received an order from Nanoplus in Germany for an ion beam deposition and a plasma etch system for use on novel types of semiconductor laser production.

Nanoplus produces semiconductor lasers over several wavelength ranges (some exclusively) for many different customers with a wide range of applications.

The Ionfab300 Plus ion beam deposition is a multi-

batch cassette loading tool allowing many devices to be produced for several applications and various customers in one load. The Ionfab300 Plus will be used for laser bar facet coating with anti-reflective and high-reflection multilayers, and the PlasmaPro System100 RIE system will be used for GaAs and InP compound etching.

David Pearson, OIPT's Senior Ion Beam Technologist, comments, "Our Ionfab optical coating tools are becoming the tools of choice for many types of precision optical coatings worldwide, in particular in laser applications."

"Nanoplus is an internationally leading supplier of single mode DFB lasers for sensing, metrology, spectroscopy and telecom applications. We even have one of our sensors on NASA's Mars Curiosity Rover', say sAlfred Forchel, founder of Nanoplus, "We chose Oxford Instruments systems for their versatility, superior process capabilities and excellent customer support."

Frazer Anderson, Business Group Director at Oxford Instruments concludes, "Our tools offer the ideal platform for production as well as research & development in many new application areas, and Laser Bar facet coating is just one of these. Our excellent process applications team and global service support ensure that our customers are supported in every respect and can count on their Oxford Instruments systems for maximum uptime and reliability."

Solar

CIGS technology distributed generation goes mainstream

Jie Chen is currently is the director of the solar energy centre in the National Institute of Clean and-low-carbon Energy (NICE), Beijing.

He successfully established a nano electronic devices laboratory in 2005 at the Helmholtz-Zentrum Berlin fur Materialien und Energie (formerly HMI), Germany and was the director of the laboratory from then on.

Under Chen's leadership, his team made the first vertical nanowire field effect transistor in flexible polymer foils and the invention has been use in new generation flexible OLED displays. A lot of innovation techniques invented by his team have been used in the industrial process of fabricating CIGS solar cells.

Chen's academic and engineering activities cover photovoltaic solar energy, material, and nano technology. He participated in accomplishing the EU's strategic research for photovoltaic technology in 2007.

So which way forward for China's PV industry?

A number of favourable policies for solar industry development have been implemented. These include the Guidelines from the State Council on Encouraging Healthy Solar Industry Developments and Guidelines from the State Council on Financial Services Supporting Distributed Solar Generation. Thanks to this, the trend of distributed solar power generation has become the mainstream development direction.

Thin-film solar batteries are arguably the most ideal solar battery technology applied in distributed generation. In virtue of its distinct advantages of being thin-film and flexible, thin-film technology will inevitably become the mainstream solar technology in the future and is expected to witness large-scale application in the Chinese market.

CIGS Thin-Film Solar Technology Features Distinct Advantages

PV solar industry mainly comprises two major solar battery technology routes: one is crystalline silicon technology, including monocrystalline silicon and polycrystalline silicon solar battery. The other is another is thin film technology, the most potential of which is Copper Indium Gallium Selenide (CIGS) thin film solar technology.

Thin film solar batteries have five prominent advantages compared to crystalline silicon batteries as described below.

Low industry chain energy consumption

A wider choices of materials for making thin film and diversified manufacturing technology

Thin film batteries have a higher generating capacity

Thin film batteries are lighter and flexible which could be more widely used and suitable to fit onto the rooftops and building integrated photovoltaics

CIGS batteries in thin-film solar technology currently has the highest conversion efficiency, reaching nearly 20 percent in the lab

According to the conversion efficiency data of the products of the world's renowned solar power companies in May 2013, the best product of MiaSolé, A CIGS thin film battery manufacturer, has reached conversion efficiency of 15.7 percent, the highest in the market.

Most important of all, generating capacity of CIGS battery is approximately 20%-30% higher than that of silicon solar battery in actual operation. For this reason, the LCOE of CIGS battery could be lower than that of silicon solar battery. With the advance of CIGS thin film solar technology at a tremendous pace, conversion efficiency could be further improved rapidly. Especially after the GW-grade mass production, the cost advantages of CIGS technology could be given full play to with lower LCOE.

In fact, quite a few experts believe that CIGS technology will be the important solar technology which could most boost the feed-in tariff of the solar power generation

Proven CIGS Technology Route Promotes Industrialisation Development

Currently, CIGS technology routes fall into three categories, namely physical method, chemical method and printing method. There are mainly two methods which could be put into commercial mass production, namely sputtering method and co-evaporation method which pertain to physical method. Having the whole world in view, CIGS industrialization has entered into mature period.

MiaSolé and Global Solar of US, Solibro and BOSCH of Germany as well as Solar Frontier of Japan are paradigm enterprises which are enable to successfully apply CIGS technology in large-scale industrialisation.

China's CIGS industrialisation is entitled to extraordinary huge development potential, while the blue-ocean market of distributed generation energetically pushed forward by China will present unprecedented opportunities for thin film PV products.

Concerning China's market, currently most solar power plants are large-scale ground-mounted power plants and small-sized distributed power plants only account for 20 percent, while distributed generation accounts for over 80% in world's many developed countries such as Japan, US and Europe.

As large-scale ground-mounted power plants require land of vast area, such power plants will have comparative advantages in western China with scarce population. While in eastern or central developed regions, distributed generation will inevitably become the future mainstream development direction. As such, in the foreseeable future, distributed generation will occupy a larger and larger proportion in China.

With regard to practical application, thin film solar battery is more suitable to fit onto rooftop and distributed PV constructions such as BIPV. As distributed generation mainly depends on rooftop power plants, thin film battery especially flexible light battery has higher generating capacity in cloudy and hot days as compared to silicon solar cell. Also being light, thin film battery could cling to buildings. In addition, small-sized distributed power plants are mainly built upon rooftops which could substantially reduce land costs.

Localisation of leading CIGS thin-film technology

Different from other solar technologies, CIGS thin-film technology requires three major elements: equipment, technology and staff, not a single one of which can be omitted.

Localisation of equipment is not simply copying production technology, whilst the key for the success lies in how to realise localisation of materials for manufacturing batteries and localization of technology.

During the process, China needs to give more attention and support to innovative enterprises in respect of core technology R&D. The substantial support offered to industry leaders and leading enterprises with independent innovative and R&D capabilities is a significant guarantee for improving China's core competitiveness.

Emcore awarded for III-V multi-junction solar cells

The AURP has honoured Emcore for its III-v solar cell technology development

Emcore Corporation, a provider of compound semiconductor-based components and subsystems for the fibre optics and solar power markets, has received the Association of University Research Parks' (AURP) Innovation Award.

The firm was honoured for its pioneering work in the development and commercialisation of high-efficiency III-V multi-junction solar cells for space and terrestrial solar power applications.

The award was presented to Emcore's President and Chief Executive Officer, Hong Q. Hou on September 26th, 2013 at the AURP's International Conference Awards Luncheon. Annually, the AURP presents Awards of Excellence in several categories including the Innovation Award presented to Emcore and the Outstanding Research/Science Park Award presented to Sandia Science & Technology Park in 2008.

Emcore started its efforts to design and manufacture radiation-hardened, high-efficiency multi-junction solar

cells for satellite and space power applications at the Sandia Science & Technology Park (SS&TP) in early 1998.

The research and development team led by Hong Hou, who had come to Emcore from Sandia National Laboratories, licensed background intellectual properties related to multi-junction solar cells from Sandia, the Air Force Research Laboratory, and the National Renewable Energy Laboratory.

From there Emcore formed its PV division in Albuquerque, New Mexico and built its 160,000 square foot state-of-the-art semiconductor wafer fabrication facility. Today that facility is one of the largest multi-junction solar cell manufacturing plants in the world.

Emcore's high-efficiency multi-junction solar cells have led the way in the transformation of the space solar power industry over the past 15 years. Emcore's entry into the industry has advanced solar cell efficiency from 17 percent, the standard for silicon-based technology prior to 1998, to 37 percent conversion efficiency for its latest generation Inverted Metamorphic Multi-Junction (IMM) solar cells that are currently being introduced to volume production.

With the success of the commercialisation of high-efficiency multi-junction solar cells for space power applications, Emcore relocated its corporate headquarters from New Jersey to the SS&TP in Albuquerque in 2006.

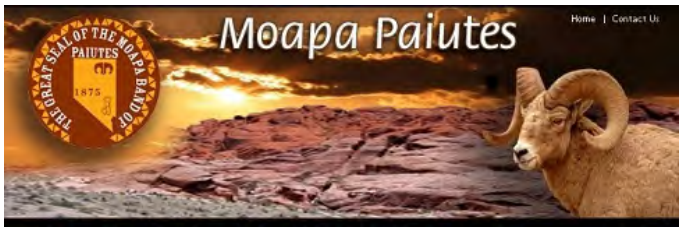
"We are very pleased and honoured to receive the AURP's Innovation Award for our work in multi-junction solar cell technology development and commercialization," says Hong Hou.

"I would also like to thank the Sandia National Laboratories and the SS&TP for their superb resources and support of our efforts from the very beginning. And, I would especially like to thank our employees in the PV division for their dedication and innovative work all these years, paving the way for Emcore's success in the industry," adds Hong Hou.

"Emcore is more than deserving of the AURP's Innovation Award," comments Jackie Kerby Moore, Executive Director of the SS&TP. "They are creating products used in the global marketplace, and they are doing most of that right here in the Sandia Science &Technology Par

First Solar acquires 250MW Moapa tribal project in Nevada

The CdTe (cadmium telluride) solar cell manufacturer will design and build the project in the 2,000-acre segment of the Moapa Band of Paiutes tribal land



First Solar has acquired the 250 megawatt (MW)AC photovoltaic Moapa Solar Project in Nevada from K Road Power Holdings.

The Moapa Solar Project, located on the Moapa River Indian Reservation in Clark County, northeast of Las Vegas, Nevada, is the first large-scale solar project approved to be built on tribal land in North America. The project is in an advanced stage of development, and has in place a 25-year Power Purchase Agreement (PPA) with the Los Angeles Department of Water and Power (LADWP).

Construction of the project, situated within a 2,000-acre segment of the Moapa Band of Paiutes tribal land, could start as soon as the fourth quarter of 2013, and be completed by the end of 2015.

The project is expected to create up to 400 jobs during peak of construction, and approximately 10 permanent jobs when the power plant is in operation. First Solar will design and build the project, using its CdTe thin film solar modules.

"First Solar is proud to participate in this landmark project on lands where it can benefit the economic development of the Moapa Paiute tribe and serve clean energy to the City of Los Angeles," says Jim Hughes, First Solar's Chief Executive Officer. "We're excited to build on the foundation and hard work of K Road and so many key stakeholders to make this project a reality, establishing a significant source of clean, renewable energy for the region."

"K Road is pleased to announce the launch of this pioneering project, and grateful for the stalwart support of our key partners and stakeholders, the Moapa Tribe, the federal and state agencies, and the IBEW. These folks have played an invaluable role in helping bring this novel project to the eve of construction," comments William Kriegel, K Road's Chief Executive Officer. "First Solar's deep experience and proven capabilities will ensure that the project is expeditiously completed to the highest

standard, while carefully considering the interests of all stakeholders."

In its first year of operation, the Moapa Solar Project will generate enough clean energy to power approximately 100,000 average homes. The project will displace more than 178,000 metric tons of CO2, the equivalent of taking more than 34,000 cars off the road, and will displace more than 142,000 metric tons of water consumption annually.

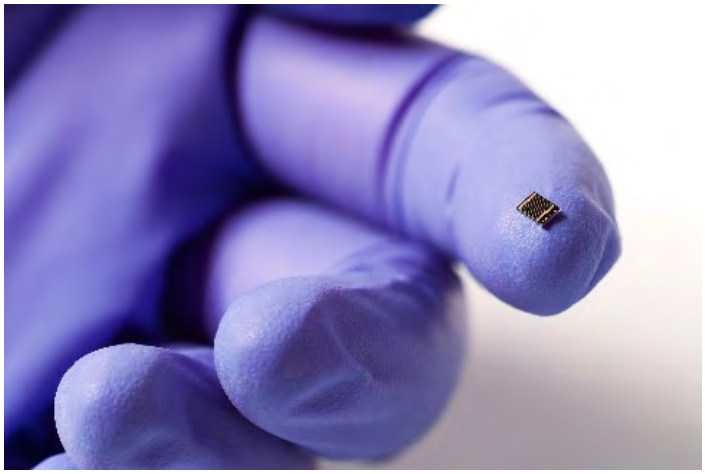
The project will advance tribal economic competitiveness and job creation, serve as an example of tribal energy self-sufficiency and sustainability, and encourage further renewable energy projects on tribal land.

Wafer bonding enables 44.7 percent efficiency record solar cell

The modified III-V structure has four solar subcells and was grown using a new technology. The process allows the connection of two semiconductor crystals, which otherwise cannot be grown on top of each other with high crystal quality

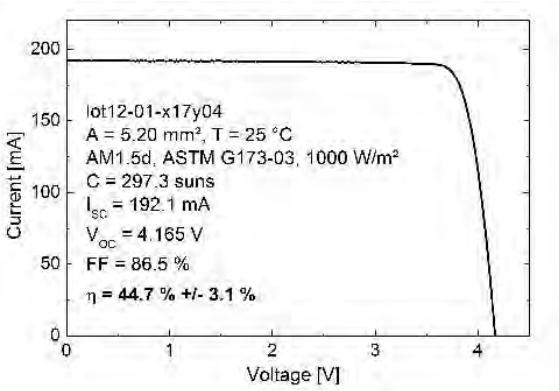
The Fraunhofer Institute for Solar Energy Systems ISE, Soitec, CEA-Leti and the Helmholtz Centre Berlin have achieved a new world record for the conversion of sunlight into electricity.

They used a new solar cell structure with four solar subcells.



World record solar cell with 44.7 percent efficiency, made up of four solar subcells based on III-V compound semiconductors for use in concentrator photovoltaics (©Fraunhofer ISE)

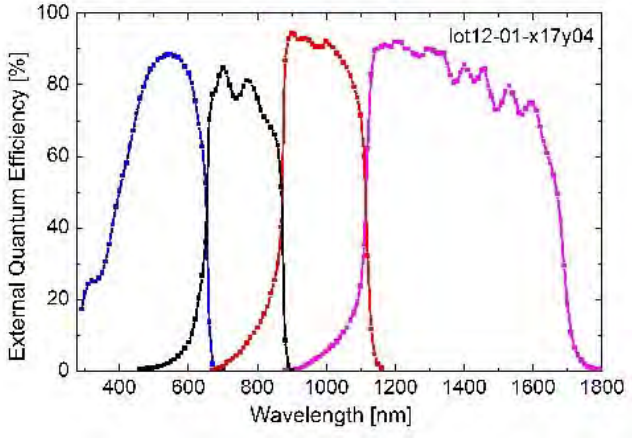
Surpassing competition after only over three years of research, and entering the roadmap at world class level, a new record efficiency of 44.7 percent was measured at a concentration of 297 suns. This indicates that 44.7 percent of the solar spectrum's energy, from ultraviolet through to the infrared, is converted into electrical energy. This is a major step towards reducing further the costs of solar electricity and continues to pave the way to the 50 percent efficiency roadmap.



IV-characteristic for the current best four-junction solar cell under AM1.5d ASTM G173-03 spectrum at a concentration of 297 suns. The measurements were carried out at the Fraunhofer ISE CalLab (©Fraunhofer ISE)

Back in May 2013, the German-French team of Fraunhofer ISE, Soitec, CEA-Leti and the Helmholtz Centre Berlin had already announced a solar cell with 43.6 percent efficiency. Building on this result, further intensive research work and optimisation steps led to the present efficiency of 44.7 percent.

These solar cells are used in concentrator photovoltaics (CPV), a technology which achieves more than twice the efficiency of conventional PV power plants in sun-rich locations. The terrestrial use of so-called III-V multi-junction solar cells, which originally came from space technology, has prevailed to realise highest efficiencies for the conversion of sunlight to electricity.



External quantum efficiency of the four-junction solar cell. The measurements were carried out at the Fraunhofer ISE CalLab

In this multi-junction solar cell, several cells made out of different III-V semiconductor materials are stacked on top of each other. The single subcells absorb different wavelength ranges of the solar spectrum.

“We are incredibly proud of our team which has been working now for three years on this four-junction solar cell,” says Frank Dimroth, Department Head and Project Leader in charge of this development work at Fraunhofer ISE.

“This four-junction solar cell contains our collected expertise in this area over many years. Besides improved materials and optimisation of the structure, a new procedure called wafer bonding plays a central role. With this technology, we are able to connect two semiconductor crystals, which otherwise cannot be grown on top of each other with high crystal quality. In this way we can produce the optimal semiconductor combination to create the highest efficiency solar cells,” he explains.

“This world record increasing our efficiency level by more than 1 point in less than 4 months demonstrates the extreme potential of our four-junction solar cell design which relies on Soitec bonding techniques and expertise,” says André-Jacques Auberton-Hervé, Soitec’s Chairman and CEO.

“It confirms the acceleration of the roadmap towards higher efficiencies which represents a key contributor to competitiveness of our own CPV systems. We are very proud of this achievement, a demonstration of a very successful collaboration.”

“This new record value reinforces the credibility of the direct semiconductor bonding approaches that is developed in the frame of our collaboration with Soitec and Fraunhofer ISE. We are very proud of this new result, confirming the broad path that exists in solar technologies for advanced III-V semiconductor processing,” says Leti CEO Laurent Malier.

Concentrator modules are produced by Soitec (started in 2005 under the name Concentrix Solar, a spin-off of Fraunhofer ISE). This particularly efficient technology is employed in solar power plants located in sun-rich regions with a high percentage of direct radiation. Presently Soitec has CPV installations in 18 different countries including Italy, France, South Africa and California.

Smit Ovens and SoLayTec to develop CIGS/CZTS large area ALD tool

Cooperation between the firms will accelerate development of a cost efficient solution for large area ALD in the thin film PV & display market
Smit Ovens and SoLayTec have joined forces to develop a system for large area applications of spatial ALD.

The cooperation creates maximum leverage of the experience of both companies to allow for a fast market introduction. Applications foreseen include buffer and barrier layers for Thin film PV and layers for improved TFT structures as required for OLED displays.

The process development tool which will be integrated in the existing CIGS development line is part of the CIGS/CZTS Solliance program. It will be used for development of alternative buffer layers as well as other layers that can improve device structure and performance.

Smit Ovens and SoLayTec have agreed that both parties will contribute on technical aspects that best match their experience. SoLayTec will focus on the injector head development in order to maximise the experience of their extremely successful product in the c-Si PV market, InPassion ALD. Smit Ovens will take the role of machine integrator and act as contract partner to the customers.

“We are very excited about this cooperation since it allows us to achieve two strategic targets at the same time,” says Wiro Zijlmans, CEO of Smit Ovens. “We are able to offer an advanced process solution for the buffer layer to our existing customers for CIGS crystallisation. On top of that we are able to expand our market penetration in the Display market which we were already addressing with drying & sintering solutions.”

“After having successfully launched our first products in the market for crystalline PV, we now are able to use the proven deposition technology for the next market opportunity,” according to Huib Heezen, managing director of SoLayTec. “Also, we are very enthusiastic about our cooperation with an experience player as Smit ovens as this enables us to market both our combined areas of expertise within a short time frame.”

Piranha etching boosts InP solar cell efficiency

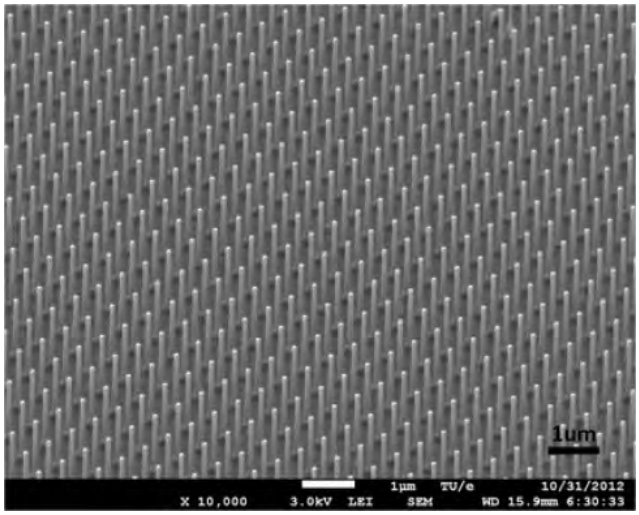
A novel etching method can make the surface of indium

phosphide nanowires much smoother, and with fewer imperfections

Energy losses in nanowire solar cells can be significantly reduced by 'cleaning' the surface of the cells with a special etching method.

This has been shown by researchers at Eindhoven University of Technology (TU/e), Delft University of Technology and Philips in a paper published in the journal *Nano Letters*.

The solar cell has an efficiency of 11.1 percent, which the research say put it just below the current world record, but it was reached with much less use of material. This is the latest step forward in the rapid development of this type of solar cell in recent years.



A nanowire array in the solar cell. (Photo: Eindhoven University of Technology)

The nanowire solar cell is a relatively new type of cell in which a bundle of semiconducting wires, each with a thickness of around 100nm, collect light and convert it into electricity. Big advances have been made in the development of this type of solar cell in recent years, and the efficiencies achieved are increasing rapidly by around 5 percent per year - much stronger growth than that of competing solar cell technologies.

Relatively large surface area

A big advantage of thin nanowires is the greatly reduced need for costly semiconductor material, which means they can be produced at low cost. However a disadvantage is their large surface area relative to the volume - and the surface is exactly where imperfections in the material lead to high energy losses.

In the publication in *Nano Letters* the researchers, led by Erik Bakkers and Jos Haverkort, describe a method to make the surface of InP nanowires much smoother, with fewer imperfections. They do this using an etching method that they have developed themselves - called 'piranha etching' - in which the surface is 'cleaned' by a chemical reaction.

Efficiency boost

Their solar cell reaches an efficiency of 11.1 percent - slightly less than the current world record of 13.8 percent which was achieved earlier this year by a group of Swedish, German and Chinese researchers using nanowires made of the same material.

However the nanowires of the Dutch researchers are only 40 percent as thick. Since the efficiency normally falls as the wires become thinner, the expected efficiency should be only around 4.5 percent. Which means the 'cleaning job' in fact gives a significant boost in efficiency.

The researchers see opportunities to raise efficiency further in the near future with little extra use of resources. "By varying the thickness of the nanowires and improving the way the crystals inside them are stacked, we think we should soon be able to approach an efficiency of 20 percent", says Bakkers. In the longer term, it should in theory even be possible to reach efficiencies of 65 percent by stacking multiple subcells.

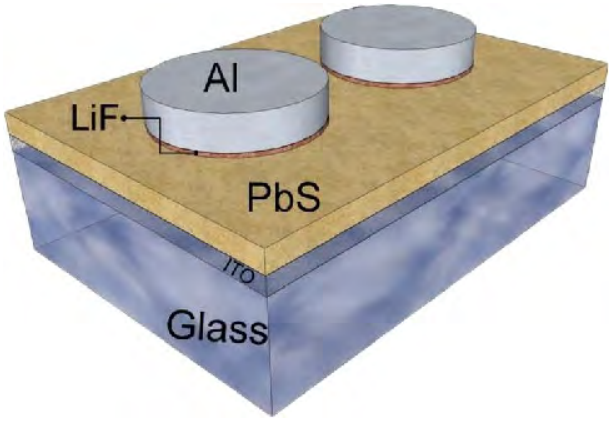
This work is described in further detail in the paper, «Efficiency Enhancement of InP Nanowire Solar Cells by Surface Cleaning,» by Yingchao Cui *et al* in *Nano Letters* (2013).http://pubs.acs.org/doi/abs/10.1021/nl4016182

NRL achieves highest open-circuit voltage for QD solar cells

It is possible to improve the passivation of PbS QDs by using an optimised lithium fluoride thickness

U.S. Naval Research Laboratory (NRL) research scientists and engineers in the Electronics Science and Technology Division have demonstrated what they say is the highest recorded open-circuit voltages for quantum dot solar cells to date.

Using colloidal lead sulphide (PbS) nanocrystal quantum dot (QD) substances, researchers achieved an open-circuit voltage (VOC) of 692 millivolts (mV) using the QD bandgap of a 1.4 electron volt (eV) in QD solar cell under one-sun illumination.



Schematic of metal-lead sulphide quantum dot Schottky junction solar cells (glass/ITO/PbS QDs/LiF/Al). Novel Schottky junction solar cells developed at NRL are capable of achieving the highest open-circuit voltages ever reported for colloidal QD based solar cell. (Photo: U.S. Naval Research Laboratory)

"These results clearly demonstrate that there is a tremendous opportunity for improvement of open-circuit voltages greater than one volt by using smaller QDs in QD solar cells," says Woojun Yoon, NRC postdoctoral researcher, NRL Solid State Devices Branch.

"Solution processability coupled with the potential for multiple exciton generation processes make nanocrystal quantum dots promising candidates for third generation low-cost and high-efficiency photovoltaics," he continues.

Despite this remarkable potential for high photocurrent generation, the achievable open-circuit voltage is fundamentally limited due to non-radiative recombination processes in QD solar cells.

To overcome this boundary, NRL researchers have reengineered molecular passivation in metal-QD Schottky junction (unidirectional metal to semiconductor junction) solar cells capable of achieving the highest open-circuit voltages ever reported for colloidal QD based solar cells.

Experimental results have improved the passivation of the PbS QD surface through tailored annealing of QD and metal-QD interface using lithium fluoride (LiF) passivation with an optimised LiF thickness.

This proves critical for reducing dark current densities by passivating localised traps in the PbS QD surface and metal-QD interface close to the junction, therefore minimising non-radiative recombination processes in the cells.

Harvesting energy from light in a new way

A new discovery could enhance optoelectronic devices and solar cell performance
Researchers from the University of Pennsylvania have demonstrated a new mechanism for extracting energy from light.

This could improve technologies for generating electricity from solar energy and lead to more efficient optoelectronic devices used in communications.

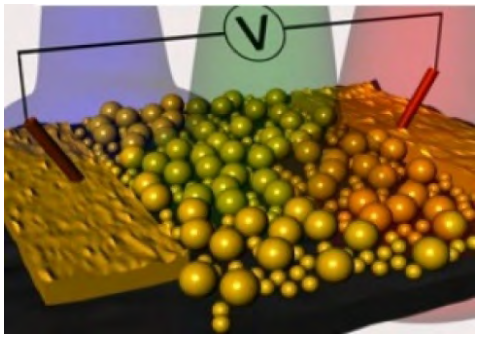
Dawn Bonnell, Penn's vice provost for research and Trustee Professor of Materials Science and Engineering in the School of Engineering and Applied Science, led the work, along with David Conklin, a doctoral student.

"We're excited to have found a process that is much more efficient than conventional photoconduction," Bonnell comments. "Using such an approach could make solar energy harvesting and optoelectronic devices much better."

The new work centres on plasmonic nanostructures, specifically, materials fabricated from gold particles and light-sensitive molecules of porphyin, of precise sizes and arranged in specific patterns.

Plasmons, or a collective oscillation of electrons, can be excited in these systems by optical radiation and induce an electrical current that can move in a pattern determined by the size and layout of the gold particles, as well as the electrical properties of the surrounding environment.

Because these materials can enhance the scattering of light, they have the potential to be used to advantage in a range of technological applications, such as increasing absorption in solar cells.



Researchers fabricated nanostructures with various photoconduction properties

In 2010, Bonnell and colleagues published a paper in *ACS Nano* reporting the fabrication of a plasmonic nanostructure, which induced and projected an electrical

current across molecules.

In some cases they designed the material, an array of gold nanoparticles, using a technique Bonnell's group invented, known as ferroelectric nanolithography.

The discovery was potentially powerful, but the scientists couldn't prove that the improved transduction of optical radiation to an electrical current was due to the "hot electrons" produced by the excited plasmons. Other possibilities included that the porphyin molecule itself was excited or that the electric field could focus the incoming light.

"We hypothesised that, when plasmons are excited to a high energy state, we should be able to harvest the electrons out of the material," Bonnell explains. "If we could do that, we could use them for molecular electronics device applications, such as circuit components or solar energy extraction."

To examine the mechanism of the plasmon-induced current, the researchers systematically varied the different components of the plasmonic nanostructure, changing the size of the gold nanoparticles, the size of the porphyin molecules and the spacing of those components. They designed specific structures that ruled out the other possibilities so that the only contribution to enhanced photocurrent could be from the hot electrons harvested from the plasmons.

"In our measurements, compared to conventional photoexcitation, we saw increases of three to 10 times in the efficiency of our process," Bonnell comments. "And we didn't even optimise the system. In principle you can envision huge increases in efficiency."

Devices incorporating this process of harvesting plasmon-induced hot electrons could be customized for different applications by changing the size and spacing of nanoparticles, which would alter the wavelength of light to which the plasmon responds.

"You could imagine having a paint on your laptop that acted like a solar cell to power it using only sunlight," Bonnell says. "These materials could also improve communications devices, becoming part of efficient molecular circuits."

This work is described further in the paper, «Plasmon-Induced Electrical Conduction in Molecular Devices,» by Parag Banerjee *et al* in *ACS Nano*, 2010, 4 (2), pp 1019 - 1025. DOI: 10.1021/nn901148m

The research was supported by the U.S. Department of Energy and the National Science Foundation.

CdTe innovator First Solar and Belectric form joint venture

The solar industry innovators have launched a JV to fulfil projects in Europe, North Africa and US

First Solar and Belectric Holding, GmbH have announced the launch of a Joint Venture (JV) that will realise solar energy projects on three continents.

The JV - PV Projects GmbH & Co. KG - is based in Germany and will be tasked with developing selected photovoltaic (PV) power projects independently acquired or developed by either of the two companies in Europe, North Africa, as well as projects of fewer than 20 megawatts (MW), in the United States.

Under the terms of the JV - which is subject to approval from the relevant governmental merger control authorities - First Solar will supply its advanced cadmium telluride thin-film modules, selected components such as the First Solar Tracker and value-added services; while Belectric will provide its advanced Balance of Systems (BoS) and a range of service capabilities.

Both companies' engineering, procurement and construction (EPC) contributions will vary by project and geography. The JV's emphasis on the sub-20MW segment in the United States will include Belectric's existing 280MWp pipeline in the country, along with other opportunities. The non-exclusive agreement will also allow both companies to independently and competitively pursue development prospects and corresponding EPC work.

The announcement is the latest milestone in a longstanding partnership that spans over a decade: the two companies recently marked the inauguration of the 128MWp Templin solar power plant in Germany, the largest deployment of First Solar modules in Europe. An estimated 80 percent of the 1,400 MWp of solar electricity generation capacity installed by Belectric, is powered by First Solar modules.

"With its industry-leading capabilities, this joint venture will ensure that our individual project obligations are delivered to the highest standards," says Jim Hughes, First Solar's Chief Executive Officer. "First Solar and Belectric share a long history of excellence and we are confident about the future of this initiative, which is based on a firm foundation of mutual trust, expertise and a track record that is unrivalled in the solar energy industry."

"We are happy to celebrate this important new milestone in our long-term partnership with First Solar," comments

Bernhard Beck, Chief Executive Officer of Belectric Holding. “By joining forces to create a world-class project delivery platform, we hope to strengthen both companies’ relationships with key stakeholders including project developers and investors at a time when prices of electricity from solar power plants can already compete with the prices for conventionally generated electricity in a growing number of regions.”

Belectric is a vertically integrated company and develops and constructs utility-scale ground-mounted solar power plants and roof-mounted photovoltaic systems. The firm has a presence in more than 20 countries and a global pipeline of 5GWp in different stages of development.

Novel way to grow thin films of germanium

A new method to grow germanium crystals at low temperatures may lead to next-generation large-scale integrated circuits and future flexible electronics

Researchers have developed a new technique to produce thin films of germanium crystals - key components for next-generation electronic devices such as advanced large-scale integrated circuits and flexible electronics, which are required for gadgets that move or bend.

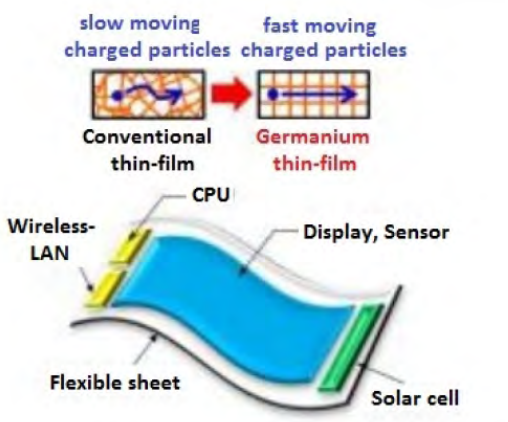
Unlike conventional methods, the new approach does not require high temperatures or other crystals to act as seeds to grow the germanium crystal. And, the researchers say, the new method can be used to produce germanium films with a very large area, allowing for more potential applications.

“This is the realisation of the dreams of crystal-growth researchers,” says Taizoh Sadoh of Kyushu University. “This unique method will open new ways to create advanced flexible electronics.”

Sadoh is an author of the paper describing the new work, which appears in the AIP Publishing journal *Applied Physics Letters*.

Charged particles move through germanium more readily than they do through silicon, making germanium a good material for electronics. In particular, it is a promising material for the thin-film transistors that are needed for flexible electronics.

However, for use in flexible electronics, the germanium would have to be grown on malleable materials, which tend to soften at temperatures above 300°C. The challenge, says Sadoh, is to grow germanium at lower temperatures.



High-speed germanium thin-film transistors enable next-generation electronics

Using gold as a catalyst, Sadoh and his colleagues were able to grow germanium crystals at a temperature of about 250°C. They were also able to grow them in such a way that their crystal structure has the proper orientation and electrical properties necessary for technological applications.

This work is described in detail in the paper, “Nucleation controlled gold-induced-crystallization for selective formation of Ge(100) and (111) on insulator at low-temperature (~250°C)” by Jong-Hyeok Park *et al* in the journal *Applied Physics Letters*. The paper can be accessed via http://dx.doi.org/10.1063/1.4819015.

Stacked solar cells can handle energy of 70,000 suns

With a new connection, the overall efficiency of solar energy devices, including GaAs based ones, can reduce the cost of solar energy production

North Carolina State University researchers have come up with a new technique for improving the connections between stacked solar cells.

This discovery should improve the overall efficiency of solar energy devices and reduce the cost of solar energy production. The new connections can allow these cells to operate at solar concentrations of 70,000 suns worth of energy without losing much voltage as “wasted energy” or heat.

Solar field on the roof of the Keystone Science Centre (Photo: NC State University)

Stacked solar cells consist of several solar cells that are stacked on top of one another. Stacked cells are currently the most efficient cells on the market, converting up to 45 percent of the solar energy they absorb into electricity.

But to be effective, solar cell designers need to ensure the connecting junctions between these stacked cells do not absorb any of the solar energy and do not siphon off the voltage the cells produce - effectively wasting that energy as heat.

"We have discovered that by inserting a very thin film of gallium arsenide into the connecting junction of stacked cells we can virtually eliminate voltage loss without blocking any of the solar energy," says Salah Bedair, a professor of electrical engineering at NC State and senior author of a paper describing the work.

This work is important because photovoltaic energy companies are interested in using lenses to concentrate solar energy, from one sun (no lens) to 4,000 suns or more. But if the solar energy is significantly intensified - to 700 suns or more - the connecting junctions used in existing stacked cells begin losing voltage. And the more intense the solar energy, the more voltage those junctions lose - thereby reducing the conversion efficiency.

"Now we have created a connecting junction that loses almost no voltage, even when the stacked solar cell is exposed to 70,000 suns of solar energy," Bedair says. "And that is more than sufficient for practical purposes, since concentrating lenses are unlikely to create more than 4,000 or 5,000 suns worth of energy. This discovery means that solar cell manufacturers can now create stacked cells that can handle these high-intensity solar energies without losing voltage at the connecting junctions, thus potentially improving conversion efficiency."

"This should reduce overall costs for the energy industry because, rather than creating large, expensive solar cells, you can use much smaller cells that produce just as much electricity by absorbing intensified solar energy from concentrating lenses. And concentrating lenses are relatively inexpensive," Bedair continues.

This work is described in detail in the paper, "Effect of GaAs interfacial layer on the performance of high bandgap tunnel junctions for multijunction solar cells," by Joshua P. Samberg *et al* published online on September 5th in *Applied Physics Letters.* DOI: 10.1063/1.4819917

St. Petersburg researchers to be awarded for III-V solar cell developments

The two professors from the Russian university will be awarded for their semiconductor compounds with superior efficiencies and increased lifetime

Zhores I. Alferov, Nobel Laureate, professor and president of the St. Petersburg Academic University of the Russian Academy of Sciences, and Viacheslav M. Andreev, professor and head of the laboratory of the A.F. Ioffe Physico-Technical Institute in St. Petersburg, will receive the 2013 Karl Böer Solar Energy Medal of Merit.

The medal and a cash award of $60,000 is funded by the Karl W Böer Solar Energy Medal of Merit Trust. It is given every two years to an individual who has made significant pioneering contributions to the promotion of solar energy as an alternate source of energy through research, development or economic enterprise or to an individual who has made extraordinarily valuable and enduring contributions to the field of solar energy in other ways.

The award is given in honour of Karl Wolfgang Böer, a long-time University of Delaware faculty member, founder of UD's Institute of Energy Conversion and a distinguished scientist in the field of solar cells.

George C. Hadjipanayis, executive director of the Karl W. Böer Solar Energy Medal of Merit Trust and the Richard B. Murray Professor of Physics and Astronomy, explains that the award is given to Alferov and Andreev "for their pioneering work in the design of new solar cells and concentrator modules based on III-V semiconductor compounds with superior efficiencies and increased lifetime."

The recipient of the award is chosen by a panel of commissioners composed of scientists and presidents of several solar energy-related professional societies, a representative from the U.S. Department of Energy, a

past recipient of this award, and a member of the Böer family.

Contributions of Alferov and Andreev

The scientific activity of Alferov and Andreev has been focused for more than 40 years on research and development of III-V semiconductor heterostructures - combining group III elements such as aluminium, gallium and indium with group V elements such as nitrogen, phosphorus and arsenic specifically to improve solar cells.

In the late 1960s and early 1970s, they carried out multifaceted investigations in the field of semiconductor device technology and physics, based on heterojunctions, or semiconductor interfaces.

They developed what are considered the ideal aluminium gallium arsenide/gallium arsenide (AlGaAs/GaAs) lattice matched heterojunctions, allowing for the proposal and realisation of a number of semiconductor devices, including:

High-voltage and high-temperature rectifiers for power electronics;

Heterolasers;

Powerful light-emitting diodes in the visible and infrared spectrum regions;

Radiation detectors;

Solar cells for space and terrestrial application.

While the majority of solar cells are made from silicon, Alferov and Andreev were ahead of their time in working with the III-V semiconductor compounds, which demonstrated greater performance and opened the door to increased efficiency in solar cells and arrays.

The improvements were put into practice in the 1970s as the new solar cells were used to equip the Soviet Mir space station.

Subsequent years saw further modifications of the solar cells, with the researchers improving the radiation tolerance and increasing the lifetime of space solar cells almost two times over.

Their developments in solar energy systems resulted in wide international cooperation with organisations including the Instituto de Energia Solar in Madrid, the Fraunhofer Institute for Solar Energy Systems in Freiburg, NASA's Glenn Research Center and the Toyota Technological Institute.

Previous recipients

The first Karl W Böer Solar Energy Medal of Merit Award was presented in 1993 to former President Jimmy Carter, who was cited as an individual who spurred development and focused world attention on solar energy.

Other recipients of the Böer Medal include:

1995, David E. Carlson, chief scientist, BP Solar;

1997, Adolf Goetzberger, founder of the Fraunhofer Institute for Solar Energy Systems;

1999, Stanford R. Ovshinsky, a pioneer in the science of amorphous semiconductors resulting in the development of low-cost, thin film silicon solar cells;

2001, Allen M. Barnett, a pioneer in high-performance, thin-crystalline silicon solar cells and currently professor in UD's Department of Electrical and Computer Engineering;

2003, Martin A. Green, Inaugural Scientia Professor at the Centre for Photovoltaic Engineering in Sydney, Australia, and foundation director for the Centre for Third Generation University of New South Wales in Sydney;

2005, Yoshihiro Hamakawa, adviser professor to the chancellor at Ritsumeikan University in Shiga, Japan and a prominent scholar in the field of solar photovoltaic energy;

2007, Lawrence L. Kazmerski, executive director, Science and Technology Partnerships, National Renewable Energy Laboratory and a pioneer and leader in the field of solar electricity;

2009, Hermann Scheer, a member of German Parliament, president of EUROSOLAR and chairperson of the World Council for Renewable Energy, who has made an outstanding contribution to the worldwide understanding of the necessity to replace fossil and nuclear resources by renewable energies, especially solar energy; and

2011, Richard M. Swanson, president and chief technical officer at SunPower Corp., San Jose, California, for the invention of the point contact solar cell, and further innovations that make solar energy ever more efficient and cost effective.

Ascent Solar to debut new EnerPlex CIGS chargers

The firm has added two new products to its Kickr line of solar chargers. The Kickr I is suited to charging batteries and power banks while the Kickr II is capable of charging most smartphones in under five hours

Ascent Solar Technologies has announced the debut of the company's newest additions to the Kickr line of personal solar chargers, the EnerPlex Kickr I and II.

The Kickr I portable solar charger

The Kickr I, with a 1.5 watt output is perfect for charging batteries and power banks; while the Kickr II is capable of charging most smartphones in under five hours with a 3 watt output.

Both the Kickr I & II are lightweight, flexible and compact, allowing for easy attachment to anything imaginable, from a bike to a backpack.

The Kickr II charging a Samsung Galaxy S III

The Kickr line of personal solar chargers is uniquely enabled by the flexible, rugged, lightweight and thin form factor of Ascent's proprietary CIGS solar cells. EnerPlex Kickr products are ideal for consumers who desire a robust, durable and rugged charging solution when off the grid, unlike chargers manufactured by competitors using traditional rigid mono-crystalline solar panels which are heavy, fragile and cumbersome.

Ascent Solar's Vice President of Product Development, Robert Meck says, "The Kickr I & II and the expansion of the Kickr line represents another step forward for Ascent's consumer brand, EnerPlex as we continue to deliver rugged and innovative solutions to consumers who require the absolute best in portable charging solutions, whether they are working in a remote oil field or summiting a treacherous peak."

Both the Kickr I & II are available to purchase via Ascent's retail locations in the Denver metropolitan area as well as online through www.goenerplex.com.

Cheaper and more accessible solar cells

New research paves way for nanoparticle-based 'ink' to make printable or spray-on solar cells

(Edmonton) University of Alberta researchers have found that abundant materials in the Earth's crust can be used to make inexpensive and easily manufactured nanoparticle-based solar cells.

The discovery is an important step forward in making solar power more accessible to parts of the world that are off the traditional electricity grid or face high power costs, such as the Canadian North, says researcher Jillian Buriak.

Buriak is a chemistry professor and senior research officer of the National Institute for Nanotechnology based on the U of A campus.

UAlberta researcher Jillian Buriak (centre) worked with post-doctoral fellows Erik Luber (right) andHosnay Mobarok to create nanoparticles that could lead to printable or spray-on solar cells

Buriak and her team have designed nanoparticles that absorb light and conduct electricity from two very common elements: phosphorus and zinc. Both materials

are more plentiful than scarce materials such as cadmium and are free from manufacturing restrictions imposed on lead-based nanoparticles.

“Half the world already lives off the grid, and with demand for electrical power expected to double by the year 2050, it is important that renewable energy sources like solar power are made more affordable by lowering the costs of manufacturing,” Buriak says.

Her team’s research supports a promising approach of making solar cells cheaply using mass manufacturing methods like roll-to-roll printing (as with newspaper presses) or spray-coating (similar to automotive painting). “Nanoparticle-based ‘inks’ could be used to literally paint or print solar cells or precise compositions,” Buriak continues.

Buriak collaborated with U of A post-doctoral fellows Erik Luber of the U of A Faculty of Engineering and Hosnay Mobarok of the Faculty of Science to create the nanoparticles. The team was able to develop a synthetic method to make Zn3P2nanoparticles, and demonstrated that the particles can be dissolved to form an ink and processed to make thin films that are responsive to light.

Buriak and her team are now experimenting with the nanoparticles, spray-coating them onto large solar cells to test their efficiency. The team has applied for a provisional patent and has secured funding to enable the next step to scale up manufacture.

This work is described in detail in the paper, “Solution-Processed Zinc Phosphide (α-Zn3P2) Colloidal Semiconducting Nanocrystals for Thin Film Photovoltaic Applications, “ by Erik J. Luber *et al* in *ACS Nano.* DOI: 10.1021/nn4034234

The research was supported by the Natural Sciences and Engineering Research Council of Canada.

Power Electronics

PVA TePla brings SiC crystals into mass production

The baSiC-T tool is suited for the growth of silicon carbide for high-performance electronics

SiC crystals are mainly required by customers working in high-tech markets.

Typical applications include high-performance electronics such as hybrid and electric cars, air conditioning systems, LED applications and DC/AC converters for photovoltaics. The major advantage in SiC material lies in the enormous energy-saving potential of over 40 percent compared to conventional silicon components.

In addition to this, the future will bring completely new prospects in the semiconductor industry as the product can also be used at high temperatures and high voltages in excess of 10,000 volts; this dramatically exceeds the potential of the silicon used today.

Modular structure and high degree of automation

The design of the innovative crystallisation system ‘baSiC-T’ is based on a modular concept and allows substrates with a diameter of up to 150 mm to be used. Low operating costs and a high degree of automation in the baSiC-T facilitate inexpensive mass production of SiC.

Successful use in industrial production

Systems to manufacture SiC crystals have already been delivered to several customers in Europe and Asia and been successfully accepted, providing proof of the systems’ outstanding performance.

New Generation SiC PVT Crystal Growth Furnace

In addition to the baSiC-T, a series of other PVA TePla systems are already being used in the field of power electronics. The SiCube is an industrially tested system for SiC volume crystal production by means of PVT and HTCVD. The firm’s Floatzone (FZ35) and Czochralski (EKZ) systems are used to crystallise high-purity silicon.

The recycling of susceptors using GaN epitaxy processes is performed in special PVA TePla vacuum furnaces. Different innovative metrology technologies for non destructive quality control are also available.

Emcore awarded for III-V multi-junction solar cells

The AURP has honoured Emcore for its III-v solar cell technology development

Emcore Corporation, a provider of compound semiconductor-based components and subsystems for the fibre optics and solar power markets, has received the Association of University Research Parks' (AURP) Innovation Award.

The firm was honoured for its pioneering work in the development and commercialisation of high-efficiency III-V multi-junction solar cells for space and terrestrial solar power applications.

Emcore started its efforts to design and manufacture radiation-hardened, high-efficiency multi-junction solar cells for satellite and space power applications at the Sandia Science & Technology Park (SS&TP) in early 1998.

The research and development team led by Hong Hou, who had come to Emcore from Sandia National Laboratories, licensed background intellectual properties related to multi-junction solar cells from Sandia, the Air Force Research Laboratory, and the National Renewable Energy Laboratory.

From there Emcore formed its PV division in Albuquerque, New Mexico and built its 160,000 square foot state-of-the-art semiconductor wafer fabrication facility. Today that facility is one of the largest multi-junction solar cell manufacturing plants in the world.

Emcore's high-efficiency multi-junction solar cells have led the way in the transformation of the space solar power industry over the past 15 years. Emcore's entry into the industry has advanced solar cell efficiency from 17 percent, the standard for silicon-based technology prior to 1998, to 37 percent conversion efficiency for its latest generation Inverted Metamorphic Multi-Junction (IMM) solar cells that are currently being introduced to volume production.

With the success of the commercialisation of high-efficiency multi-junction solar cells for space power applications, Emcore relocated its corporate headquarters from New Jersey to the SS&TP in Albuquerque in 2006.

"We are very pleased and honoured to receive the AURP's Innovation Award for our work in multi-junction solar cell technology development and commercialization," says Hong Hou.

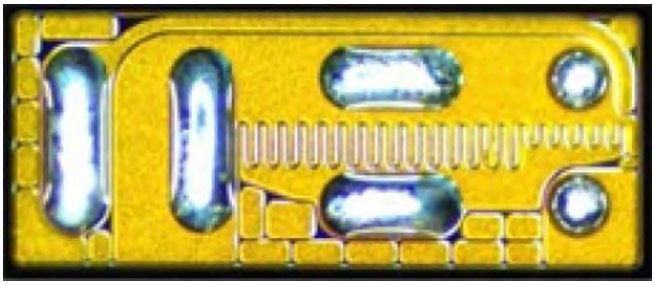
"I would also like to thank the Sandia National Laboratories and the SS&TP for their superb resources and support of our efforts from the very beginning. And, I would especially like to thank our employees in the PV division for their dedication and innovative work all these years, paving the way for Emcore's success in the industry," adds Hong Hou.

"Emcore is more than deserving of the AURP's Innovation Award," comments Jackie Kerby Moore, Executive Director of the SS&TP. "They are creating products used in the global marketplace, and they are doing most of that right here in the Sandia Science &Technology Par

EPC's multiple GHz eGaN FETs blend RF with Power

Power systems and RF designers now have access to gallium nitride power transistors capable of amplification into the low GHz ranges not achievable with silicon

Efficient Power Conversion Corporation (EPC) has extended its family of high-speed, high performance transistors with the EPC8000 family of products.



EPC8004

Cutting new ground for power transistors, these third generation devices have switching transition speeds in the sub nano-second range, making them capable of hard switching applications above 10 MHz.

Even beyond the 10MHz for which they were designed, these products exhibit very good small signal RF performance with high gain well into the low GHz range, making them a competitive choice for RF applications.

"We are very excited about how our innovative new family of eGaN FETs will change the industry. These products take EPC and GaN transistor technology to a level of performance that enables applications that were previously beyond the capability of MOSFETs. We now have eGaN FETs that can be used in both power semiconductor and RF applications," says Alex Lidow, EPC's co-founder and CEO.

Products in the family are available with on-resistance values from 125 mΩ through 530 mΩ, and three blocking voltage capabilities, 40 V, 65 V and 100 V. These new transistors have several new features that further enable designers to take full advantage of the high performance GaN FETs have to offer.

These features include reduction in QGD thereby reducing voltage transient switching losses, improved Miller ratio providing high dv/dt immunity, low inductance pads for improved connection to both gate and drain circuits, orthogonal current flow between the gate and drain circuits for enhanced CSI reduction, and a separate gate return connection also for enhanced CSI reduction.

Examples of applications benefiting from the low power, compact, high frequency EPC8000 family of devices include hard-switching power converters operating in the multi-megahertz range, envelope tracking in RF power amplifiers, highly resonant wireless power transfer systems for wireless charging of mobile devices.

The EPC9027 development board, featuring the EPC8007 devices and the LM5113 gate driver IC in a half bridge configuration, is available now. Additional development boards will be available to support designers in evaluating and incorporating other EPC8000 family products into their power conversion.

Evaluation units of the EPC8000 family of products are immediately available in 10-piece packs starting at $430 through Digi-Key Corporation.

GaN Systems and APEI win $2 million to revolutionise transportation

The US Department of Energy has provided the funding to the firms to design power-saving GaN (gallium nitride) and SiC (silicon carbide) semiconductors for next generation vehicles

Toyota Prius 2013 (Credit Toyota)

GaN Systems has partnered with Arkansas Power Electronics International (APEI) in a successful bid for funding from the $45 million US DoE programme.

The project is aimed at developing new vehicle technologies to improve fuel efficiency and reduce transportation costs.

The APEI-led team, also including Toyota Motor Engineering and Manufacturing North America Inc, the University of Arkansas National Centre for Reliable Electric Power Transmission and the US National Renewable Energy Laboratory, has been awarded $2 million as one of the 38 different projects the DoE is funding across the US.

The team will develop new electric motor traction drives for hybrid electric vehicles based on GaN and silicon carbide SiC power semiconductors. These new technologies will replace traditional silicon semiconductors in automotive power electronics to herald a new generation of highly efficient and lower cost systems.

Girvan Patterson, CEO of GaN Systems comments, ”We’re delighted to be part of the APEI team and to be collaborating on such an important programme. The DoE initiative is a very exciting opportunity for the industry. HEVs are full of power electronics for functions like battery management, auxiliary power, braking, instrument clusters and many more. Over the next few years we will see dramatic improvements in all these systems which will be designed into vehicles such as Toyota’s next generation Prius.”

MACOM launches first surface mount L-Band 90W GaN power module

A novel modular, SMT-optimised approach unlocks the full promise of gallium nitride in plastic for radar applications

M/A-COM Technology Solutions Inc. (MACOM) has announced the newest entry in its portfolio of GaN in Plastic packaged power products.

Optimised for L-Band commercial air traffic control, military radar, and long range perimeter monitoring applications at 1.2 to 1.4 GHz, MACOM's new 2-stage, fully matched GaN in Plastic power module scales to peak pulse power levels of 100W in a 14 x 24 mm package size - delivering twice the power of comparably sized competing products

MACOM says its new high gain GaN in Plastic power modules are the first and only GaN-based modules to support surface mount technology (SMT) assembly, providing significant cost and process advantages compared to ceramic-packaged flange-mount components.

Delivering clear benefits in size, weight and power (SWaP) while enabling high volume manufacturing efficiency, MACOM's new GaN power modules extend the performance attributes of its discrete GaN in Plastic power transistors and establish new standards for GaN module integration.

Under pulsed conditions, these modules deliver output power greater than 90W, with 30 dB typical associated power gain and 58 percent typical power added efficiency. Supporting 50V operation and up to 3 ms pulse width/duration for improved time on target, MACOM's GaN in Plastic power modules reduce overall power consumption and cooling requirements compared to existing options.

The module features a Land Grid Array pattern for enhanced thermal flow and 'True SMT' assembly. All inputs and outputs are formed on the back of the module and include edge castellations for ease of assembly inspection.

The module's flexible design allows for gate and/or drain pulsing, and includes a gate voltage sense port for use in temperature compensation or pulse droop compensation. Leveraging sophisticated thermal management techniques to ensure high reliability, the calculated mean-time-to-failure at 200□C is approximately 600 years.

"Building on a long history of providing similarly sized, very high power LGA module solutions in GaAs, MACOM's GaN in Plastic power modules represent a pivotal evolution in GaN semiconductor technology, providing high overall power performance in a light, ultra-compact 14 x 24 mm package while enabling the greatest possible ease of assembly," says Damian McCann, Engineering Director, MACOM. "This modular, SMT-optimised approach unlocks the full promise of GaN in Plastic for radar applications and introduces unprecedented efficiencies from design to manufacturing."

The table below outlines typical performance:

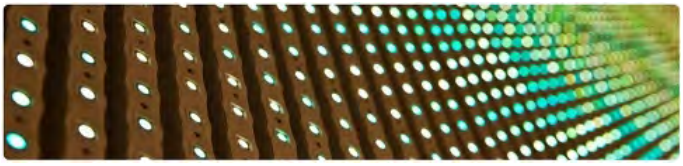
Test condition for the below table: 1ms pulses, 10% duty cycle P_{IN}= 20dBm

Parameter	MAMG-001214-090PSM
Frequency	1.2-1.4 GHz
Output Power	50 dBm
Power Added Efficiency	58 %
Pulse Droop	0.3 dB
Power Gain	30 dB
2nd Harmonic	-40 dBc
3rd Harmonic	-52 dBc
Load Mismatch Stability	5:1
Load Mismatch Tolerance	6:1
Package Size	14 x 24 mm

MACOM's new GaN in Plastic L-Band 90W power modules are sampling to customers today.

Nitride Solutions ships first AT-50 AlN templates

The aluminium nitride templates, produced using HVPE, have been sold to a major Asian LED manufacturer



Nitride Solutions has achieved the first commercial sales of its new AT-50 AlN template.

Nitride is manufacturing the product in volume at its manufacturing facility in Wichita, Kansas, using its proprietary advanced HVPE process.

Troy Baker, Nitride's research and development director, presented data at the 2013 International Conference on Nitride Semiconductors that showed commercial template properties far superior to any presented before. This data accelerated requests for sampling by major manufacturers of LEDs and power-switching devices.

"Our templates are by far the best in the market, and our manufacturing processes are designed for volume production and tight statistical process control. We offer customers the best commercially available XRD specs (average (002): 135 arc sec and (102): 513 arc sec), low defect densities, and wafer uniformity," says Jeremy Jones, Nitride Solutions CEO.

He continues, "We believe that our recent sales and growing sample requests validate the quality and value of our products and technology. We realise that customer's make decisions on substrates based on performance, quality, consistency, value delivered and supply assurance. Our combination of a superior product in the AT-50 plus a growing global distribution and technical support channel will provide the best solution for these customers. The planned introduction of four-inch aluminium nitride templates and the expansion of our template product line to GaN will bring additional value to device markets."

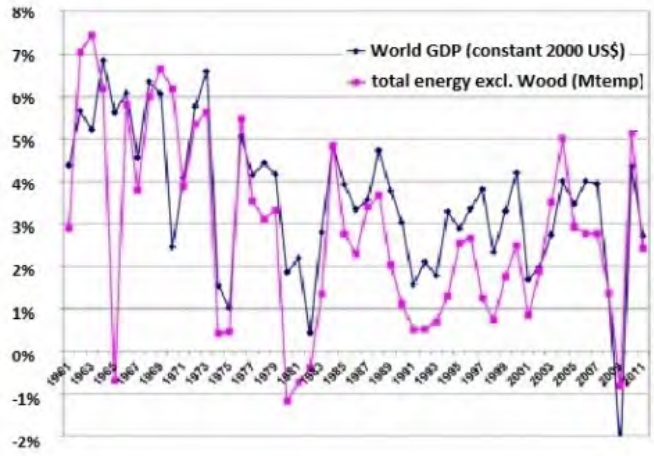
James H. Edgar, department head of chemical engineering and university distinguished professor at Kansas State University comments, "The AlN on sapphire templates offered by Nitride Solutions are a much lower-cost alternative of high-quality material compared to bulk AlN substrates. That these substrates are available in two-inch diameter size greatly facilitates their use by standard device fabrication tools. The availability of these AlN templates creates exciting new opportunities for improved short-wavelength optoelectronic and high-power electronic devices."

Nitride Solutions develops and manufactures bulk and template nitride materials for the LED, laser diode and the power electronics markets. Founded in 2009, the firm's leadership has over 35 years of experience in supplying advanced materials to global manufacturers of semiconductor, display and memory devices, combined with a total of more than 35 years in nitride process development. The company maintains strong ties to Kansas State University in Manhattan, with key employees and advisors hailing from the university, as well as UC Santa Barbara.

GaN in power electronics applications

Bandgap materials GaN and SiC are generating significant buzz globally. Strategy Analytics expects SiC to be the primary replacement technology for silicon power devices, while GaN seeks initial commercial traction in applications with breakdown voltages of less than < 600V and power requirements of less than 5kW

Many studies have shown the direct relationship between energy and Gross Domestic Product (GDP). This seems entirely plausible since a growing economy entails more production, as well as increasing levels of consumption. Policy makers in countries around the globe are realizing that a future overwhelmingly dependent on carbon-based sources of energy is likely to put the brakes on growth as these energy resources become scarcer and more expensive. Figure 1 shows how closely energy consumption trends track GDP. *Figure 1: Global GDP Growth vs. Energy Consumption Growth*



Source: The Shift Project

As regional and global economies grow, they are also becoming "digital". This means there is much more reliance on electronic data and devices by consumers, enterprises and governments in the course of normal activities. For these devices and networks to function reliably, electric grid networks must be upgraded and expanded where they exist and built out where the networks do not exist. A robust, efficient grid is necessary to ensure growth, while minimizing the amount of energy required meeting these demands.

These requirements have provided the impetus for the growth of the power electronics industry. To sustain growth in the face of shrinking supplies of fossil fuel sources and minimize the by-products of these fuels, countries are turning to alternative energy sources, along with replacement technologies. In addition to finding alternative sources to generate electricity and

minimize fossil fuel consumption, development efforts are underway to increase the efficiency of components in devices and the electrical grid. Opportunity The power electronics or power management market addresses electronic components used in the efficient delivery of electrical power to the end user.

Typical applications include DC-DC and AC-DC power conversion for consumer devices such as PCs, cellular handsets and power supplies. The increasing consumption of data by enterprises and cloud storage is driving the need for high performance servers and server arrays. Applications requiring much higher power handling include inverters used to convert DC power into AC for grid connectivity and electric motor drives used in electric and hybrid electric vehicles (HEVs), as well as a number of other applications. Any power management technology incurs loss when converting current. With the growing emphasis on energy efficiency and renewable energy sources, there is a strengthening demand for devices that optimize the efficiency of this conversion, even if by only a few percent.

The migration towards micro-generation of energy through a distributed grid, with production on a much smaller scale will require large numbers of inverter modules and systems to feed the electricity into the grid as efficiently as possible. In addition to the benefits of a future that is not so dependent on fossil fuels, the electric grid provides an enormous opportunity. The U.S. electric grid, alone is estimated to contain more than 200,000 miles of high-voltage transmission lines and 5.5 million miles of local distribution lines, connecting many thousands of generating power plants to factories, homes and businesses1. Various estimates place the size of the global semiconductor device market (discrete devices, ICs and modules) for power electronics applications at somewhere between $15 billion and $20 billion dollars in 2012! This value is expected to grow in the future as power generation sources increase, companies become more conscious of energy consumption and the usage of consumer devices continues to increase quickly.

Technology Currently, the power management device market is dominated by silicon MOSFETs and IGBTs, technologies that replaced the vacuum tubes of the 1940 and 1950s. There is still a lot of development activity aimed at improving the performance of devices using these technologies. There is also a growing concern that these legacy technologies will not support the anticipated evolution of the grid. In some applications, requirements for blocking voltages, switching frequencies and efficiency already exceed the capability of silicon-based devices. With this as the backdrop, wide bandgap materials, primarily GaN and SiC are generating significant interest. The hope is devices using these materials will increase the efficiency and the reliability of the electric grid as it evolves.

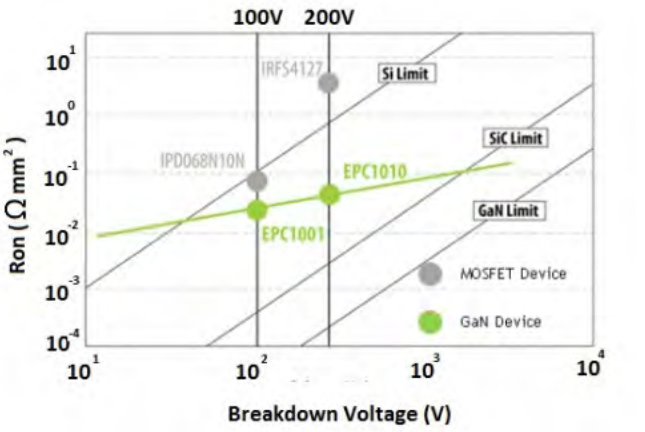
The electrical properties of these materials should enable higher switching frequencies, higher blocking voltages, lower switching losses, better thermal conductivity and higher operating temperatures. At present, SiC is farther along than GaN for these high power electronics applications. In the near term, Strategy Analytics expects SiC to be the primary replacement technology for silicon power devices, while GaN seeks initial commercial traction in applications with breakdown voltages of less than < 600V and power requirements of less than 5kW. Generic advantages of wide bandgap materials over silicon in power electronics device applications include:

- Lower on-resistances, which result in lower conductivity losses and higher overall efficiency
- Higher breakdown voltages: available Si Schottky diodes have breakdown voltage up to 300V, the first commercial SiC Schottky diodes are rated at 600V
- Higher thermal conductivity compared to Si: this leads to a lower junction-to-case thermal resistance, allowing more efficient heat transfer
- Higher temperature operation: SiC devices can operate up to 600°C, while Si devices can operate at a maximum junction temperature of only 150°C
- Forward and reverse characteristics that vary only slightly with temperature and time
- Lower reverse recovery current, reducing switching losses and electromagnetic interference (EMI)
- Operation at frequencies >20 kHz, which is not possible with Si-based devices at power levels of more than a few tens of kilowatts
- Higher voltage input/output ratios that allow a single stage for DC-DC conversion from 48V to 1V, compared with a silicon power MOSFET converter that would normally require two or more stages

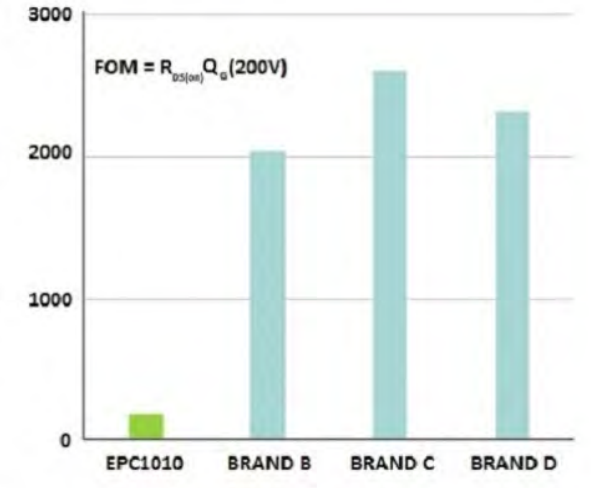
Initially, GaN-based devices seemed a likely fit for applications where the high voltage and power handling capability, coupled with conversion efficiencies than were higher than the silicon equivalents, would create a high-value niche. The advantages of wide bandgap materials for power electronics applications have partly been borne out by the deployment of SiC devices in hybrid electric vehicles, but the penetration of GaN-based power devices may be more likely in lower-voltage applications, where SiC is proving to be too expensive. In the power management segment, power conversion applications

offer the greatest potential for GaN.

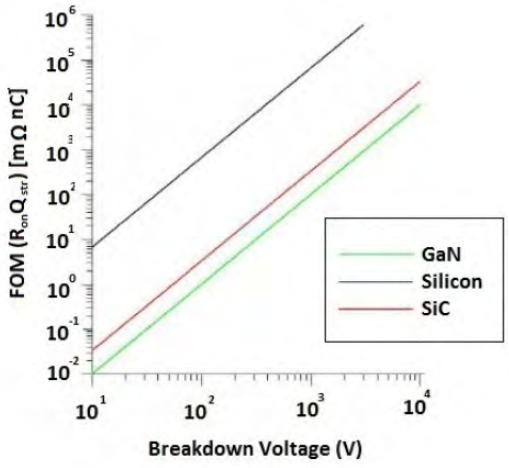
These applications typically require fast, efficient switches, where the higher carrier mobility inherent to GaN transistors is advantageous. While silicon devices are widely regarded to be at or approaching their performance limits, GaN offers opportunity for improvement, particularly in form factor and electrical efficiency. A key figure of merit used in power management applications is the combination of on-resistance and switching speed. There is a lot of development underway to improve the performance of GaN FET devices. Figure 2 shows the Ron performance for two GaN devices from EPC Corporation. It is evident from the curves that the GaN devices maintain lower on-resistance for a given breakdown voltage versus the silicon MOSFET devices listed. The chart also shows that the theoretical maximum performance for GaN devices is superior to SiC. *Figure 2: Resistance versus Breakdown Voltage*



The advantage goes beyond the on-resistance, however. The gate charge required to switch a GaN FET is much lower than that of a silicon device. The product of on-resistance and gate charge is a useful figure of merit for power transistors. A lower figure indicates a low resistance to turn-on, combined with a fast switching speed. As shown in Figure 3, EPC Corporation claims their GaN devices have an RQ product more than 10 times lower than silicon alternatives. *Figure 3: "RQ" Product Comparison: GaN vs. Silicon MOSFET*



Source: EPC Corporation EPC Corporation is one of the leading proponents of GaN for power management applications, and they make a compelling case for this technology. In Figure 4, they illustrate the theoretical performance comparison for GaN technology versus the incumbent silicon MOSFET technology and SiC technology. *Figure 4: Theoretical "RQ" Performance*



Source: EPC Corporation In practice, a low RQ figure of merit means that circuit designers do not have to sacrifice low on-resistance for fast switching, as is normally the case. A side benefit of this performance is that GaN DC-DC converter devices will operate at higher bandwidths. Silicon power MOSFETs have difficulty with pulse widths below 100ns (corresponding to a 250 KHz bandwidth), while GaN FETs can be turned on or off in as little as 4ns. Figure 5 summarizes these metrics with the performance of an EPC GaN device versus some representative silicon MOSFET devices. Note that the "RQ" product of the GaN device is almost an order of magnitude lower than best MOSFET. *Figure 5: "RQ" Product Comparison: GaN vs. Silicon MOSFET*

Manufacturer	Part #	V	$R_{DS(on)}$max (on-resistance)	$Q_g$max (gate charge)	"RQ"
IR	IRLB4030	100	4.5	130	585
Fairchild	FDP054N10	100	5.5	203	1117
Infineon	IPP050N10LG	100	6.4	163	1043
Vishay	SUD06N 10-225L	100	225	3	608
EPC (GaN)	EPC1001	100	7	11	77

Source: EPC Corporation The implication is that a point-of-load (POL) converter using GaN can convert from 48V to 1V in a single stage, while an equivalent silicon converter would typically require one stage to convert to 12V and a second stage to convert to 1V. At higher drain-source voltages, the superiority of GaN becomes even more apparent, enabling entirely new architectures in power management, according to proponents such as EPC and International Rectifier. In the past several years, there has been a concerted effort to develop enhancement-mode (normally off) GaN transistors, especially for power management applications. These enhancement-mode devices are attractive for these applications because they operate in a similar fashion to the incumbent MOSFET technology, but have much better performance characteristics.

A number of Japanese companies, including Sanken Electric, a collaboration between Fuji and Furukawa Electric, Panasonic and NEC, have all invested in the development of E-mode GaN HEMTs. In March 2010, Efficient Power Conversion (EPC) Corporation introduced a number of E-mode GaN-on-silicon power management devices, branded as eGaN, which they continue to refine and improve. These E-mode devices have different driver requirements than their depletion-mode GaN and silicon MOSFET counterparts. Companies like National Semiconductor and Texas Instruments have developed lines of compatible drivers for E-mode GaN devices.

These driver efforts are likely to speed adoption of E-mode GaN devices by making the final package of driver and transistor as easy to use as MOSFET devices. For all the inherent material and performance advantages, developers of GaN transistor technology continue to address a number of challenges. The lack of suitable native GaN substrates complicates production of GaN devices because it is very difficult to grow lattice-matched, defect-free epilayers analogous to the processes used for GaAs or silicon transistor fabrication. There is substantial activity using a hydride vapor phase epitaxy (HVPE) method to produce thick layers that can serve as quasi-bulk substrates. Shortfalls with this technique have given rise to development of ammonothermal growth techniques.

In August 2012, Soraa, a developer of GaN-on-GaN solid-state lighting technology, was selected by Advanced Research Projects Agency-Energy (ARPA-E) to lead a project on the development of bulk GaN substrates. The attraction of native GaN substrates lies in an anticipated performance improvement that may result in significant energy savings for LEDs. The LED market can provide the high-volume pull to develop a technology that can benefit other market segments with the availability of native GaN substrates. Even with a production ready process, GaN substrates are not expected to compete with silicon substrates purely on wafer cost. However, proponents of native GaN substrates point out that a simplified process will result in cost savings that may make the product cost more manageable. In the absence of production-scale, single-crystal GaN wafers, manufacturers must instead use foreign host materials such as sapphire, SiC or silicon. To date, semi-insulating SiC has been the material of choice for microelectronic components, thanks to its relatively close lattice match to GaN and its excellent thermal conductivity properties.

However, the quality of epitaxial layers depends on both the lattice-match and the underlying substrate quality. Historically, suppliers of semi-insulating SiC have struggled to produce material with defect density levels comparable to substrates such as silicon or GaAs. More recently, improvements to semi-insulating SiC material quality, along with the availability of larger substrates, have made SiC a more viable economic choice for GaN growth. This has helped to improve the reliability of GaN microelectronic devices.

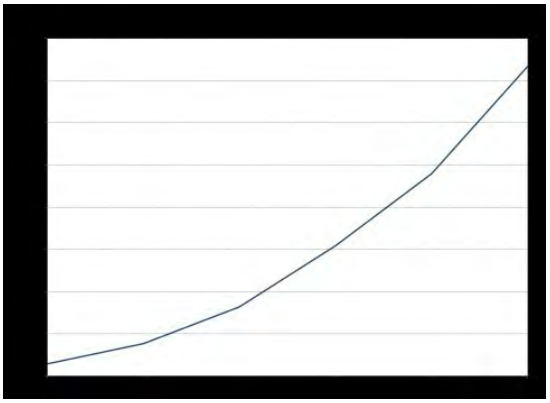
However, SiC remains a difficult and expensive material to produce and it provides cost challenges for cost-sensitive, high-volume applications. In recent years, high-resistivity (HR) silicon has become a viable alternative to SiC in certain applications. Although it does not have as close a lattice match with GaN and possesses poorer thermal properties, silicon can offer a lower-cost path for some applications. GaN-on-Si also shows potential to transition to high-volume manufacturing processes because it is amenable to existing CMOS (Complementary Metal-Oxide-Semiconductor) semiconductor fabrication technology using commercially available, large diameter silicon wafers. There is a lot of development work in this area with manufacturers like AZZURRO Semiconductors developing 150mm GaN-on-silicon wafers with a roadmap to 300mm diameter wafers in the future.

Future The size of the power electronics component market and the perceived advantages of wide bandgap technologies are leading to significant process and product development efforts. The US government realizes the importance of improvements in the efficiency and reliability of the electrical grid network and the US Department of Energy's Office of Electricity Delivery and Energy Reliability (OE) has requested slightly more than $169 million in the FY2014 US budget to address issues and developments in this area. The budget request is up nearly 25% from 2012 spending as the OE recognizes the importance of the topic and realizes that industry will need some help to enable significant advances. In April 2011, the OE released their "Power Electronics Research and Development Program Plan" that details the vision, activities, challenges, needs and partnership strategies for this market segment. The activities focus clearly on wide bandgap materials, with a heavy emphasis on

developing and refining GaN-on-silicon processes and devices.

By 2016, the program hopes to have GaN-on-silicon devices operating at 5kV and 15A performance levels, with a goal of 20kV and 50A device performance by 2026. Market Estimates It appears clear that increasing demands for energy and an emphasis on alternative energy sources will lead to a very large market opportunity for power electronics components. The advantages of wide bandgap technologies appear very compelling, but there are challenges that must be addressed before these technologies will displace incumbent silicon technologies with any sort of production scale.

The promising development for GaN usage in this market segment is that industry and government agencies are recognizing the importance of this technology and devoting significant resources to technology and process development. Considering all these factors, we estimate revenues for GaN devices used in power electronics applications will grow strongly, reaching slightly more than $73 million in 2017. While this revenue level represents only a very small portion of the total high power electronics market, the CAAGR (Compounded Average Annual Growth Rate) for GaN technology will be greater than 108%, indicating the revenue will roughly double every year, on average. GaN technology usage is in its infancy for high power electronics applications and we anticipate continued strong growth throughout the decade. Figure 6 shows this estimate. *Figure 6: GaN Device Revenue in High Power Electronics Applications*



Conclusions Increasing energy consumption, the shift to a “digital economy” and the evolution to more efficient, more distributed sources of energy generation will all increase the available market for power electronics devices. The incumbent technology is silicon IGBTs and MOSFETS, but there are concerns that the limitations of these devices and technologies will hamper the growth and refinement of the electric grid. Wide bandgap materials, most notably SiC and GaN offer promising performance advantages and these technologies are generating a lot of interest. Both these technologies have challenges to overcome and while SiC devices have made early advances, we believe GaN-on-silicon products will grow quickly to reach slightly more than $73 million in revenue in 2017. Author : Eric Higham - Director - GaAs Strategic Technologies Practice Strategy Analytics . References 1Jennifer Weeks and The Daily Climate, “U.S. Electrical Grid Undergoes Massive Transition to Connect to Renewables,” Scientific American, April 28, 2010, http://www.scientifi camerican.com/article.cfm?id=what-is-the-smart-grid&print=true.

Rohm’s 1200V SiC MOSFETs raise the bar

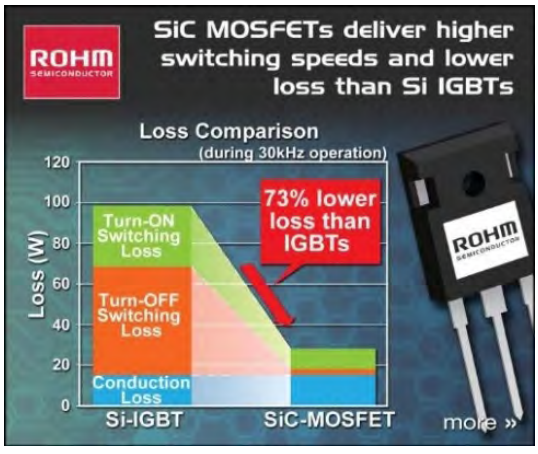
The firm’s new silicon carbide MOSFETs provide higher efficiency, power density and lower system BOM for power conversion systems

Rohm Semiconductor has released two new 80-milliohm 1200V SiC MOSFETs, designated SCT2080KE and SCH2080KE, that are designed to deliver cost-effective, breakthrough performance.

Rohm says the SCH2080KE is the industry’s first SiC MOSFET co-packaged with a discrete anti-parallel SiC Schottky Barrier Diode (SBD. It features a forward voltage three times smaller than that of the body diode.

The combination of excellent switching performance, low on resistance, and high breakdown voltage make these devices ideal replacements for silicon power MOSFETs and IGBTs in solar inverter, DC-DC converter, UPS and motor drive applications.

Rohm SiC MOSFETs offer as much as 90 percent lower switching loss compared to silicon devices thanks to the absence of tail current and the diode’s fast recovery performance. This allows designers to increase switching frequency to reduce size, cost, and weight of passives.



What’s more, these benefits enable the design of

higher efficiency systems by implementing simpler, less expensive cooling systems.

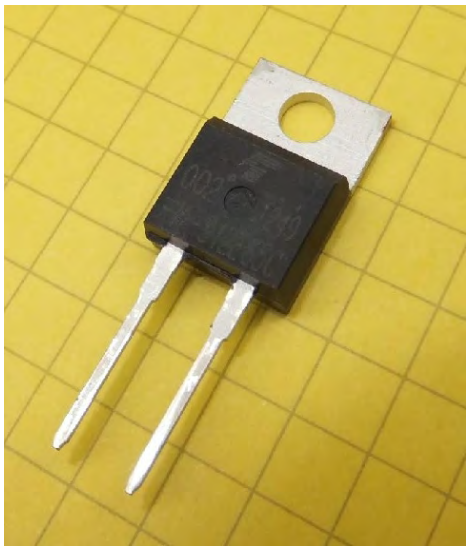
“Rohm’s SiC MOSFETs help customers save board space, simplify layout, and reduce BOM costs,” says David Doan, Senior Product Marketing Manager at Rohm Semiconductor. “Importantly, Rohm’s SiC MOSFETs are free from issues related to gate oxide breakdown, Vth stability, and degradation of the body diode during reverse conduction.”

The SCT2080KE and SCH2080KE MOSFETs are available now in mass production quantities. Rohm Semiconductor has plans to expand its SiC MOSFET product line with lower on resistance and higher breakdown voltage models.

Toshiba extends SiC Schottky barrier diode family

The firm’s latest silicon carbide power device is suited to power factor correction circuits, photovoltaic inverters and uninterruptible power supplies

Toshiba Corporation is expanding its portfolio of 650V SiC Schottky barrier diodes (SBD) with the addition of a 10A product to the existing line-up of 6A, 8A and 12A products.



Toshiba SiC Schottky Barrier Diode

Mass production shipments will start from today.

SiC is a wide-bandgap semiconductor and SiC SBDs provide high breakdown voltage that has never been possible with silicon SBDs. Being unipolar devices, SiC SBDs have very short reverse recovery time and temperature-independent switching behaviour, making them the ideal replacements for silicon fast-recovery diodes, According to Toshiba, SiC SBDs improve power supply efficiency by as much as 50 percent.

What’s more, SiC power devices offer more stable operation than current silicon devices - even at high voltages and currents - as they significantly reduce heat dissipation during operation. They meet diverse industry needs for smaller, more effective communications devices and their industrial applications range from servers to inverters.

EPC expands eGaN FET portfolio with 150 V power transistor

The new gallium nitride power transistor delivers high frequency switching for exceptional performance in DC-DC power conversion and Class D Audio applications

Efficient Power Conversion Corporation (EPC) is introducing the EPC2018 as the newest member of its family of enhancement mode gallium nitride power transistors.

The EPC2018 is a 5.76 mm2, 150 VDS, 12 A device with a maximum RDS(on) of 25 milliohms with 5V applied to the gate. This GaN power transistor delivers high performance due to its ultra high switching frequency, extremely low RDS(on), exceptionally low QG and in a very small package.

Compared to a state-of-the-art silicon power MOSFET with similar on-resistance, the EPC2018 is much smaller and has many times superior switching performance.

Applications that benefit from eGaN FET performance include high-speed DC-DC power supplies, point-of-load converters, class D audio amplifiers, as well as many other circuits needing nanosecond switching speeds.

“The EPC2018 is an excellent complement to our existing family of eGaN FETs. The low on resistance, low output capacitance, fast switching, and no reverse recovery reduce the switching losses in power conversion applications and allow for higher efficiency and improved sound quality in Class D audio applications,” notes Alex Lidow, co-founder and CEO.

In 1k piece quantities, the EPC2018 is priced at $6.54 and is immediately available through Digi-Key Corporation

Summary of EPC2018 Specification Ratings

	New EPC2018
Package (mm)	LGA 3.6 x 1.6
RoHS and Halogen Free	Yes
$T_{J(MAX)}$ (°C)	125
V_{DS}	150
V_{GS} (max)	6
Max $R_{DS(ON)}$ @5V_{GS}	25
Q_G typ (nC)	5
Q_G max (nC)	7.5
Q_{GS} typ (nC)	1.3
Q_{GS} max (nC)	2
Q_{GD} typ (nC)	1.7
Q_{GD} max (nC)	2.6
Q_{OSS} typ (nC)	40
Q_{OSS} max (nC)	50
V_{TH} typ	1.4
Q_{RR} (nC)	0
I_D (A) Pulsed	60
I_D (A)	12

MACOM unveils 600 W GaN-on-SiC power transistor for avionics

The internally-matched gallium nitride-on-silicon carbide pulsed device provides high gain, efficiency and ruggedness over the 1030 to 1090 MHz bandwidth

M/A-COM Technology Solutions (MACOM), a supplier of high-performance RF, microwave and millimetre wave products, has announced a new ceramic GaN-on-SiC HEMT power transistor for avionics applications.

The MAGX-001090-600L00 is a gold-metalised, matched GaN-on, RF power transistor optimised for pulsed avionics applications, such as secondary surveillance radar in air traffic control systems.

MAGX-001090-600L00

The MAGX-001090-600L00 provides 600 W of output power with a typical 21.4 dB of gain and 63 percent efficiency. The device has very low thermal resistance of 0.05 °C/W and best-in-class load mismatch tolerance of 5:1. What’s more, the device has the lowest pulse droop of 0.2 dB and also can be used effectively under more demanding Mode-S ELM operating conditions.

MACOM’s GaN transistor technology has been fully qualified with accelerated, high-temperature lifetime tests and this device has a predicted MTTF of over 600 years at a maximum junction temperature of 200 0C. The device also boasts very high breakdown voltages, which provides customers with reliable and stable operation even in extreme load mismatch conditions.

“MACOM’s GaN power technology offers a significant advantage in higher gain, higher efficiency and improved reliability compared to similar silicon Bipolar and LDMOS power transistors,” says Paul Beasly, Product Manager. “The device also provides the highest load mismatch tolerance in its class - a critical parameter to ensure the highest reliability and performance in demanding avionics applications.”

The table below outlines typical performance:

Parameter	Units	MAGX-001090-600L00
Frequency	MHz	1030-1090
P_{out}	W	600
Vd	V	50
Power Gain	dB	21.4
Drain Efficiency	%	63
Pulse/Duty	µs/%	32/2
Pulse Droop	dB	0.2
Load Mismatch Tolerance	VSWR	5:1
Rth	°C/W	0.05
MTTF	Hours	5.2×10^6

Evaluation boards of MAGX-001090-600L00 are available from stock and samples may be ordered now.

New GaN power devices to drive electric & hybrid vehicle technology

GaN Systems will explain how technology and trends in wide-bandgap gallium nitiride devices means smaller, lighter and more efficient electronics

GaN Systems, a developer of GaN power switching semiconductors, is presenting a paper on new wide-bandgap semiconductors and their role in transforming automotive power electronics.

According to IMS Research, manufacturers are currently designing vehicles to be launched onto the market in 2018. This coincides with the timeframe leading forecasters are predicting that GaN semiconductors will attain price parity with silicon devices. This development will overcome the limitations of silicon and transform power electronics in EHVs.

Julian Styles, Director Business Development USA, will join speakers from leading players in the EHV industry for the 3-day conference. Styles will explain the technological advances in semiconductor materials which herald the replacement of traditional silicon in power converters for new generation electric and hybrid vehicles.

The audience will gain insight into how wide-bandgap power semiconductors based on GaN bring benefits including greater efficiency, weight reduction and lower cost to power electronics for EHVs.

He will also give the audience a valuable insight into devices available now and in the near future, plus share the trends which are driving technological advances in semiconductors for electric and hybrid vehicle applications.

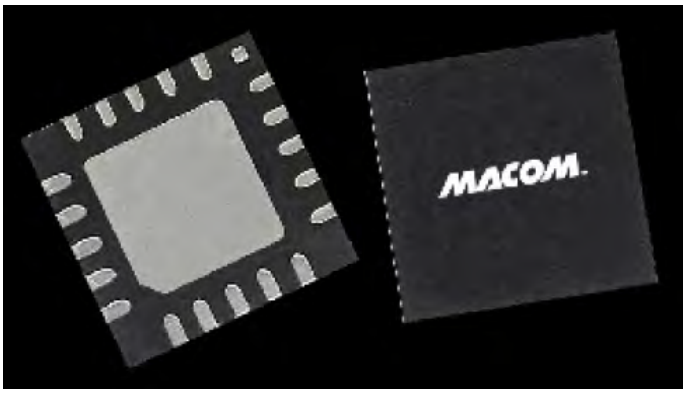
Comments Girvan Patterson, CEO of GaN Systems "EHVs are full of power electronics, from battery management, auxiliary power, braking, valve timing, cruise control, security systems, instrument clusters - all of which are currently suffering the limitations imposed by silicon, as it doesn't switch quickly or cope with elevated temperatures."

He continues," New generation GaN and SiC semiconductors overcome these difficulties and are lighter, smaller and easier to package. These new devices will lead to dramatic improvements in automotive power electronics and present a major opportunity for the industry."

MACOM releases high power C-Band GaAs MMIC power amplifier

The 8W plastic packaging power amplifier operating between the 5.2 - 5.9 GHz frequency band offers customers a small sized, fully matched solution

M/A-COM Technology Solutions has launched a new high power amplifier that is ideally suited for C-Band radar and communication applications.



MAAP-011027

The MAAP-011027 is ideal for customers who need a fully matched, small size and simplified packaged solution for high power pulsed applications.

Operating over the 5.2 - 5.9 GHz frequency bandwidth, the device is a two stage, 8 W saturated C-band power amplifier with 37 percent power added efficiency.

The MAAP-011027 is packaged in a lead free 5mm x 5mm 20 lead PQFN and offers a fully matched solution

which can be used as a power amplifier stage or as a driver stage in high power pulsed applications.

"The MAAP-011027 belongs to a new family of high power GaAs MMIC amplifiers that cover L-, S-, C- and X-Band,"says Paul Beasly , Product Manager. "These new products offer best-in-class performance for high power applications while leveraging MACOM's commercial manufacturing expertise to reduce the size, weight and cost of our customers' system designs."

The table below outlines typical performance:

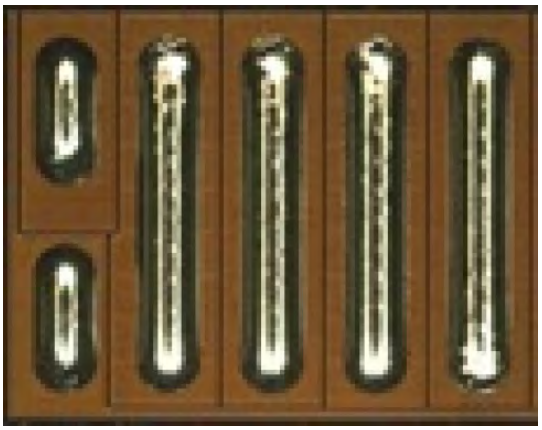
Parameter	Units	MAAP-011027
Frequency Range (RF)	GHz	5.2-5.9
Gain	dB	20
Input Return Loss	dB	10
Output Return Loss	dB	10
PSAT	dBm	39
Efficiency	%	37

Production quantities and samples of MAAP-011027 are available from stock.

EPC expands eGaN FET family with 100 V power transistor

The firm's latest gallium nitride power transistor delivers high frequency switching for exceptional performance in DC-DC power conversion

Efficient Power Conversion Corporation has introduced the EPC2016 as the newest member of EPC's family of enhancement GaN power transistors.



EPC2016

The EPC2016 is a 3.36 mm2, 100 VDS, 11 A device with a maximum RDSON of 16 milliohms with 5 V applied to the gate. This GaN power transistor delivers high performance due to its ultra high switching frequency, extremely low RDSON, exceptionally low QG and in a very small package.

Compared to a state-of-the-art silicon power MOSFET with similar on-resistance, the EPC2016 is much smaller and has many times superior switching performance. Applications that benefit from eGaN FET performance include high-speed DC-DC power supplies, point-of-load converters, class D audio amplifiers, and high frequency circuits.

"The EPC2016 is an excellent complement to our existing family of eGaN FETs. The lower gate charge and output capacitances significantly reduce the switching losses in power conversion applications," notes Alex Lidow, co-founder and CEO.

What's more, the EPC9010 development board, featuring the EPC2016 devices and the LM5113 gate driver IC in a half bridge configuration, is available now. Development boards support designers in evaluating and incorporating eGaN FETs into their power conversion systems.

In 1k piece quantities, the EPC2016 is priced at $1.61 and is immediately available through Digi-Key Corporation.

More details of the eGaN FET are shown in the table below.

	New EPC2016
Package (mm)	LGA 2.1x 1.6
RoHS and Halogen Free	Yes
$T_{J(MAX)}$ (°C)	125
V_{DS}	100
V_{GS} (max)	6
Max $R_{DS(ON)}$ @5V_{GS}	16
Q_G typ (nC)	3.8
Q_G max (nC)	5.2
Q_{GS} typ (nC)	0.99
Q_{GS} max (nC)	1.5
Q_{GD} typ (nC)	0.70
Q_{GD} max (nC)	1.4
Q_{OSS} typ (nC)	20
Q_{OSS} max (nC)	30
V_{TH} typ	1.4
Q_{RR} (nC)	0
I_D (A) Pulsed	45
I_D (A)	11

Microsemi 750 W GaN on SiC devices power up amplifiers

The firm has expanded its family of radio frequency power transistors based on gallium nitride HEMTs

Microsemi Corporation has expanded its family of radio frequency (RF) power transistors based on GaN high electron mobility transistor (HEMT) on SiC technology with a new 750 watt (W) RF transistor.

The MDSGN-750ELMV delivers outstanding, highest power performance in a full range of air traffic control and collision avoidance equipment. Targeted applications include commercial secondary surveillance radar (SSR), which is used globally to interrogate and identify aircrafts in airport locales and regional centres within about a 200 mile range.

“Microsemi’s reputation as a leader in RF solutions is founded on 30 years of experience, a stellar engineering team, and a dedication to delivering new products that push the envelope in terms of performance and reliability,” says David Hall, vice president and general manager of RF Integrated Solutions for Microsemi.” From components to assemblies and custom packaging, we will continue to invest in the technologies and equipment required to further solidify our leadership position and better serve our customers.”

The MDSGN-750ELMV transistor delivers unparalleled performance of 750 W of peak power with 17 decibel (dB) of power gain and typical 70 percent drain efficiency when operating at 1030/1090 megahertz (MHz) to provide the most power in one single-ended device of its type covering this band.

n addition, the new RF device is capable of handling the demanding commercial Mode-S ELM (Extended Length Message) pulsing conditions for both the 1030MHz ground based interrogators and 1090MHz airborne transponders and can be used in the output stage of high performance ground.

ELM makes air travel safer by facilitating the communication of shared weather and air traffic situational awareness information to aircrafts within a regional locale. It is also ideal for use in commercial air-to-air traffic alert and collision avoidance systems (TCAS) and in IFF (Identify Friend or Foe) systems, which are essential in protecting friendly aircrafts within a specific area.

GaN on SiC HEMT provide several advantages over alternative process technologies including higher power performance, bill-of-material cost savings, and a reduced device-size footprint. For example, the MDSGN-750ELMV offers the following benefits:

Single-ended design with simplified impedance matching, replacing lower power devices that require additional levels of combining

Highest peak power and power gain for reduced system power stages and final stage combining

Single output stage pair provides 1.5 kilowatt (kW) peak output power with margin

Combining four output stage pairs delivers a full system >5 kW peak output power

50 volts bias allows use of existing power supply rail with reduced DC current demand

Extremely rugged performance improves system yields

Amplifier size is 50 percent smaller than devices built with silicon bipolar junction transistors (Si BJT) or laterally diffused metal oxide semiconductor (LDMOS) devices

Greatly more breakdown voltage headroom than Si bipolar and Si LDMOS and the ability to operate at higher junction temperatures gives more rugged operation and greater MTTF

Excellent stable over temperature operation -55C to +85C

In addition to RF components, Microsemi’s commercial aviation product portfolio includes: FPGAs; TVS diodes; integrated standard and custom products; integrated circuits; power conditioning and management components and modules; application specific integrated circuits (ASICs); microwave devices and components; high-density memory products; custom semiconductor packaging; and integrated power distribution systems.

Packaging and Availability:

The MDSGN-750ELMV is offered in a single-ended package and is built with 100 percent high-temperature gold (Au) metallisation and wires in a hermetically solder-sealed package for long-term reliability.

Loaner demonstration units are available to qualified customers and technical datasheets are available on the Microsemi website at www.microsemi.com.

Fraunhofer GaN transistors hit 98 percent efficiency

Gallium nitride devices for efficient power electronics can handle currents of up to 100 A and breakdown voltages beyond 600 V

To increase the efficiency of voltage converters and minimise heat losses, researchers at the Fraunhofer Institute for Applied Solid State Physics IAF have developed a transistors based on GaN.

The devices have a low on-resistance and high switching speed.

Gallium-nitride-based voltage converters are intended to minimise power losses of electric cars in the future. (credit Robert Bosch GmbH)

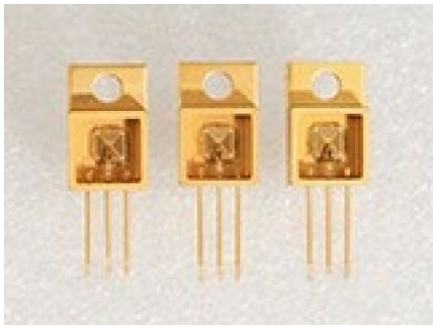
Voltage converters have recently achieved an efficiency level of 98 percent. And this saves energy in electromobility and photovoltaics.

In order to foster the development of electromobility it is critical to reduce the energy consumption caused by electric cars. Efficient voltage converters can minimise losses and thus save energy during operation and the charging of batteries.

Researchers of the Fraunhofer Institute for Applied Solid State Physics IAF and the Ferdinand-Braun-Institut in Berlin have now managed to develop GaN devices for applications in electromobility and photovoltaics.

“We have increased the efficiency level of the transistors in our voltage converters to 98 percent. Practical tests have shown a performance of up to 1 kW. Thereby we have closed the gap to the international state-of-the-art,” explains Michael Schlechtweg, head of department at Fraunhofer IAF.

In contrast to conventional devices based on silicon, GaN transistors allow the reduction of losses in voltage converters by more than half.



GaN transistors for efficient power electronics: currents of up to 100 A and breakdown voltages beyond 600 V are possible (© Fraunhofer IAF)

The new devices are the result of the research project “PowerGaNPlus”, which was supported by the German Federal Ministry of Education and Research (BMBF) for a period of over three years providing three million Euros of funding.

The funding was part of different research and development projects on the topic of “Power Electronics for Increased Energy Efficiency« in the program called »IKT 2020 – Research for Innovation”.

The goal is to establish Germany as the leading provider for technologies of electromobility and to contribute to a future-oriented mobility. Therefore, the BMBF supports particularly innovative partnerships between science and industry.

Practical tests show robust gallium nitride devices

Concerning the development of gallium nitride technology, Fraunhofer IAF cooperates, among others, with Robert Bosch GmbH in order to test the real-life behaviour of the devices. Stress tests conducted so far have not only shown the devices’ good performance, but gave also a first indication of high short-circuit strength.

“Validation of the devices developed within the project with a breakdown voltage of more than 600 V showed encouraging performance. Already in this early development stage, low conduction and switching losses comparable to considerably more mature and commercially available silicon carbide transistors were demonstrated during operation of the GaN devices in circuits ready for application. The stress tests conducted so far have also hinted at high short-circuit strength and thermal stability,” confirms Walter Daves, who supervised the project at Robert Bosch GmbH. The devices reached maximum currents of up to 100 A during on-resistance

operation.

The transistors have already been tested for applications in battery chargers for electric cars, and, together with KACO new energy GmbH, also in photovoltaic inverters. The following partners also cooperate with Fraunhofer IAF in this research project, IXYS Semiconductor GmbH, United Monolithic Semiconductors GmbH, Universität Erlangen-Nürnberg, RWTH Aachen.

New opportunities for GaN technology

Whereas silicon-based devices are slowly reaching their physical limits, gallium nitride technology offers new opportunities for power electronics. Gallium nitride devices can be operated under higher voltages and temperatures than conventional power devices based on silicon.

This allows a reduction of the cooling efforts; compact, light-weight and cost-effective voltage converters become possible. In comparison with silicon transistors, gallium nitride allows to increase the switching frequency by at least a factor of three.

Due to the higher breakdown strength and power density of the material, the devices are considerably more efficient than their silicon equivalent. This will reduce the energy consumed in order to charge the battery of an electric car or to feed in energy from solar parks into the grid.

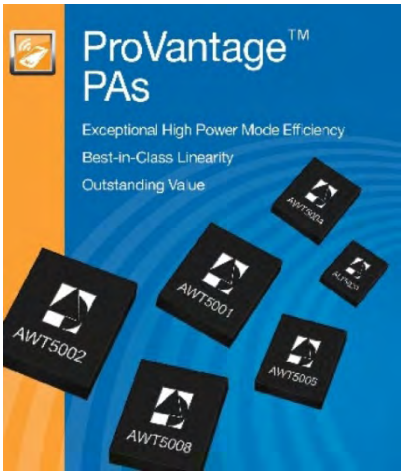
“Besides using GaN transistors in electromobility and photovoltaics, they will also be able to increase efficiency and save energy in household applications, production technology or in generators for plasma and laser systems. Our continuous goal will be to increase reliability, thermal stability and switching frequency in order to use the full potential offered by gallium nitride technology,” explains Patrick Waltereit, project leader at Fraunhofer IAF.

Anadigics unveils InGaP power amplifier series

The company’s ProVantage indium gallium phosphide PAs are suited to 3G & 4G high power mode efficiency

Anadigics has introduced the new ProVantage power amplifier (PA) product family.

The company’s ProVantage solutions deliver excellent efficiency and linearity to extend battery life and ensure high data throughput in LTE, WCDMA/HSPA, CDMA/EVDO, and TD-SCDMA mobile devices.



“We recognise the tremendous diversity in mobile device requirements, ranging from voice-centric feature phones to power-hungry smartphones and tablets,” says Navi Miglani, product marketing director of Cellular Products at Anadigics.

“Our new ProVantage power amplifiers are optimised to deliver outstanding value by providing a best-in-class combination of high power mode efficiency, linearity, and reduced system costs. This, addition to our world-class cellular products portfolio, complements our industry-leading ProEficient and ProEficient-Plus solutions and enables Anadigics to target the needs of a wider range of market segments,” Miglani continues.

Anadigics ProVantage power amplifiers leverage the company’s InGaP-Plus technology to achieve outstanding performance and integration. These power amplifiers help extend battery life by offering three selectable bias modes that optimise efficiency for low, medium and high output power levels, as well as a shutdown mode with low leakage current.

ProVantage solutions are also designed for use with an external switch mode power supply (SMPS), such as average power tracking (APT), to further increase efficiency and reduce current consumption at low and medium operating powers.

Anadigics’ ProVantage power amplifiers provide world-class linearity to ensure stable cellular connectivity and high data throughput. The complete family of ProVantage solutions are offered in compact 3 mm x 3 mm x 0.9 mm packages and feature internal voltage regulation to save valuable PCB space.

Details of the packages are shown in the table below.

ANADIGICS ProVantage PA Family Key Specifications:

Product	Frequency Band	Efficiency
AWT5001	Band 1 (1920 to 1980 MHz)	48% @ +28.2 dBm (WCDMA)
AWT5002	Band 2 (1850 to 1915 MHz)	48% @ +28.6 dBm (WCDMA)
AWT5004	Band 4 (1710 to 1755 MHz)	48% @ +28.5 dBm (WCDMA)
AWT5005	Band 5 (824 to 849 MHz)	48% @ +28.6 dBm (WCDMA)
AWT5008	Band 8 (880 to 915 MHz)	47% @ +28.5 dBm (WCDMA)
ALT5020	Band 20 (832 to 862 MHz)	42% @ +27.7 dBm (LTE)

APEI awarded $2 million to drive GaN and SiC forward

The new gallium nitride and silicon carbide power devices will be used in hybrid-electric vehicles

The U.S. Department of Energy (DOE) has awarded $2 million to a collaborative partnership led by Arkansas Power Electronics International, Inc. (APEI, Inc.).

This is a team which also includes Toyota Motor Engineering and Manufacturing North America, Inc., GaN Systems, Inc., the University of Arkansas' National Centre for Reliable Electric Power Transmission, and the U.S. National Renewable Energy Laboratory.

The award was announced by the DOE as one of thirty-eight new projects across the country in a $45 million effort to develop new technologies that will reduce transportation costs and improve fuel efficiencies.

"By partnering with universities, private industry, and our national labs, the Energy Department is helping to build a strong 21st century transportation sector that cuts harmful pollution, creates jobs, and leads to a more sustainable energy future," says Energy Secretary Ernest Moniz. "By improving the fuel economy of our cars and trucks, we can save families and businesses money at the pump and better protect our air and water."

The APEI led team will be developing new electric motor traction drives for hybrid electric vehicles, with technology based on newly emerging SiC and GaN power semiconductors.

"Our motor drive technology reduces power losses by more than 50 percent, and we can reduce the size and weight of the motor drive electronics by up to 90 percent," says APEI, Inc. President and CEO Alex Lostetter. "These improvements lead to significant savings in vehicle cost, increases driving distances, and reduces fuel expense. We're very excited to be working with Toyota to get this technology into the next generation of Prius hybrid-electric vehicles. It's an amazing opportunity."

APEI, Inc. says it is dedicated to advancing power electronics systems, electronic motor drives, and power packaging.

Imec and Veeco unite on GaN-on-Si development

The gallium nitride on silicon R&D will concentrate on LED and power electronics applications

Nanoelectronics research centre imec of Belgium and Veeco Instruments are collaborating on a project aimed at lowering the cost of producing gallium nitride-on-silicon based power devices and LEDs.

Barun Dutta, imec's Chief Scientist, comments, "The productivity, repeatability, uniformity and crystal quality of Veeco's MOCVD equipment has been instrumental in helping us meet our development milestones on GaN-on-Si for power and LED applications.

The device performance enabled by the epi has helped us realise state-of-the-art D-mode (depletion mode) and E-mode (enhancement mode) power devices. Our goal is to establish an entire manufacturing infrastructure that allows GaN-on-Si to be a competitive technology."

Imec's multi-partner GaN-on-Si research and development program gathers the industry to jointly develop world-class GaN LED and power devices on 200 mm silicon substrates compatible with a 200 mm CMOS-compatible infrastructure. By joining forces at imec, companies share costs, talent and intellectual property to develop advanced technologies and bring them to the market faster.

Jim Jenson, Senior Vice President, General Manager, Veeco MOCVD, says, "We have been working with imec on this program since 2011 and are encouraged by our progress. Our work is mutually rewarding, as we are both focused on being able to realize lower costs while

maintaining world-class performance on GaN-on-Si devices. This technology can be used to create lower cost LEDs that enable solid state lighting, more efficient power devices for applications such as power supplies and adapters, PV inverters for solar panels, and power conversion for electric vehicles."

Veeco's MOCVD equipment incorporates the firm's Uniform FlowFlange technology for superior uniformity and excellent run-to-run repeatability. Low maintenance TurboDisc technology enables highest system availability, excellent particle performance and high throughput.

Equipment and Materials

PVA TePla brings SiC crystals into mass production

The baSiC-T tool is suited for the growth of silicon carbide for high-performance electronics

SiC crystals are mainly required by customers working in high-tech markets.

Typical applications include high-performance electronics such as hybrid and electric cars, air conditioning systems, LED applications and DC/AC converters for photovoltaics. The major advantage in SiC material lies in the enormous energy-saving potential of over 40 percent compared to conventional silicon components.

In addition to this, the future will bring completely new prospects in the semiconductor industry as the product can also be used at high temperatures and high voltages in excess of 10,000 volts; this dramatically exceeds the potential of the silicon used today.

Modular structure and high degree of automation

The design of the innovative crystallisation system 'baSiC-T' is based on a modular concept and allows substrates with a diameter of up to 150 mm to be used. Low operating costs and a high degree of automation in the baSiC-T facilitate inexpensive mass production of SiC.

Successful use in industrial production

Systems to manufacture SiC crystals have already been delivered to several customers in Europe and Asia and been successfully accepted, providing proof of the systems' outstanding performance.

New Generation SiC PVT Crystal Growth Furnace

In addition to the baSiC-T, a series of other PVA TePla systems are already being used in the field of power electronics. The SiCube is an industrially tested system for SiC volume crystal production by means of PVT and HTCVD. The firm's Floatzone (FZ35) and Czochralski (EKZ) systems are used to crystallise high-purity silicon.

The recycling of susceptors using GaN epitaxy processes is performed in special PVA TePla vacuum furnaces. Different innovative metrology technologies for non destructive quality control are also available.

SEMI-GAS delivers low vapour pressure liquefied gases for MOCVD

The firm's source system features integrated heating and control useful in LED and solar cell growth

SEMI-GAS Systems, a provider of ultra-high purity gas source and distribution systems, has introduced a new Xturion custom gas source system that safely and continuously delivers low vapour pressure liquefied process gases in vapour phase.

SEMI-GAS Systems Xturion VaporX tool

VaporX is suitable for hazardous and non-hazardous gas applications and is designed to accommodate many of the low vapour pressure gases used in semiconductor, LED and solar cell production as well as in research and development and other high purity markets.

Xturion VaporX systems are available in one and two process cylinder models, each featuring a GigaGuard PLC controller and an ergonomically positioned 8" touch screen. The unit's intuitive display schematics enable easy control over all the system's operations including gas delivery, system alarms, automatic cylinder switchover and auto-purge capabilities.

The GigaGuard controller automatically interrupts gas flow and initiates a shutdown in the event of a sensor alarm trip, while an Emergency Shutoff (EMO) button offers immediate manual operator shutdown. LED lights display the systems' status, while an audible alarm accompanies flashing lights alerting the operator should a hazardous condition occur.

Each system is CE certified and is manufactured with ultra-high purity components to guarantee long term, reliable and consistent service. The system features pneumatically operated valves, Magnehelic and pressure switch exhaust monitoring as well as an optional point-of-use mass flow controller box with heated low vapour pressure mass flow controllers.

To guard against undesirable process gas liquefaction and to help sustain the system's cylinder temperatures and flowrates, VaporX is designed with an integrated fully automatic multi-zone heat control package which includes process gas cylinder heating blankets, gas manifold heat tracing, and process gas line heat tracing. All heat zones are independently controlled and employ redundant temperature measurement with over-temperature protection.

The standard two cylinder (2CE) model is 86" tall, 33" wide and 23" deep, including the external side-mounted heater controller enclosure. Various safety features come standard, such as a UL-approved fire sprinkler, a 1/4" thick safety glass window, a self-closing, self-latching door, and a stainless steel cylinder scale. Heavy cast aluminium cylinder brackets and adjustable cylinder shelves ensure safe and secure gas cylinder fit-up.

"We are pleased to be able to continuously offer new and versatile Xturion custom gas equipment solutions," says Todd Bell, SEMI-GAS Systems' engineering director and VaporX's system designer. "Our customers work in a variety of industries with various gas requirements so we've created VaporX specifically for our customers who require delivery of low vapour pressure process gases.

He adds, "As with all our Xturion systems, VaporX is engineered to be flexible, offering many additional mechanical, electrical and enclosure features to meet each customer's exact needs. We constantly strive to provide our customers with top quality customised products they have come to trust from SEMI-GAS Systems."

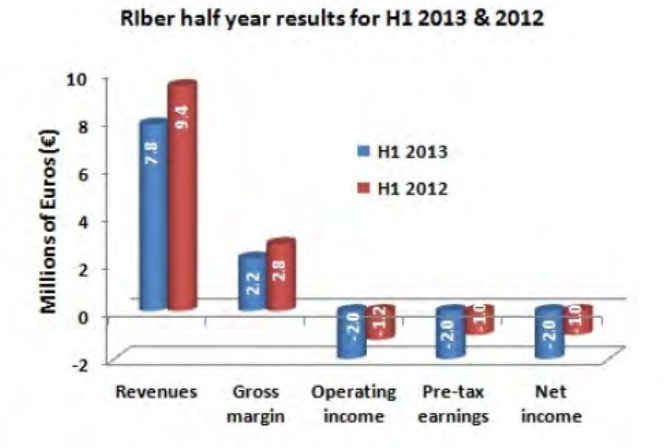
Riber half yearly revenues plunge 17 percent

The firm received many of its orders from Research laboratories

Riber, a manufacturer of MBE reactors used in the growth of III-V semiconductors, has released its earnings for the first half of 2013.

HALF-YEAR EARNINGS

Factoring in the change in revenues, the half-year gross margin was €2.2 million on June 30th, 2013 as compared to €2.8 million on June 30th, 2012, representing 28 percent of revenues. Provisioning for inventories led to a net charge of €0.2 million, identical to the half year ended June 30th, 2012.



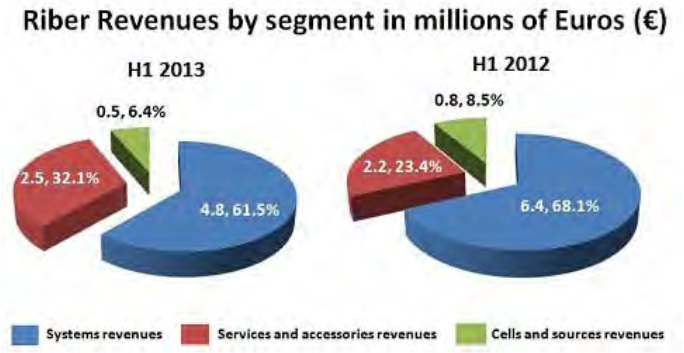
Operating expenses were stable but consolidated net income showed a loss of €2.0 million, as compared to a loss of 1.0 million on June 30th, 2012. The strong seasonality of production plan (focused in 2013 at the end of the year) has an adverse effect on half-yearly earnings

In the first half of 2013, the firm concentrated its business on R&D markets. Marked by the slowdown in demand from industrial customers, revenues totalled €7.8 million for the first half of 2013.

During the first half of the year, five MBE machines were delivered, compared with six one year previously (including a production machine).

Sales of services and accessories were up 14 percent, driven by the sales action plan rolled out since 2012. They reflect the development of sales to research laboratories, offsetting the slowdown in supplies of services to industrial customers.

The evaporation sources and cells business were affected by the current lack of investments in the production of OLED flat screens or thin-film solar cells. Nevertheless, Riber is maintaining a major research effort on these high potential markets.



The company currently has a capital of €3,091,349.

The cash position represented €4.1 million on June 30th, 2013, down €1.2 million compared with December 2012. Cash flow from operations was unable to cover the investments and innovation drive during the first half of the year, as well as the payment of dividends for 2012. Riber remains free of debt.

2013 OUTLOOK

At the end of August 2013, the order book represented €13.5 million as compared to €12.1 million at the end of 2012, with 13 research systems to be delivered, mostly in 2013.

In view of the program for deliveries between now and the end of the year, 2013 revenues are expected to reach €24 to 26 million for 2013, enabling Riber to record a profit over the full year.

To further strengthen its commercial positions in Asia, Riber opened a subsidiary in South Korea at the start of September 2013. A representation office in China was set up in 2009.

Praxair China opens Global Technology Centre in Shanghai

The new Praxair China Technology Centre is a state-of-the-art facility for applications engineers and Research and Development

Praxair China Investment Company, a subsidiary of Praxair, Inc. has announced the opening of its state-of-the-art Global Technology Centre in Shanghai, supporting the company's development and implementation of innovative applications technologies.

Praxair supplies gases such as nitrogen, hydrogen, arsine, phosphine, silane and ammonia used in III-V and III-nitride MOCVD growth.

The Praxair China Technology Centre is located in the Jinqiao Development Zone of Pudong New Area.

The centre houses laboratories, including pilot and demonstration facilities, to support a growing team of Praxair engineers and scientists who work with customers in China in the steel, combustion, metal fabrication, metals and materials processing, pharmaceuticals, water treatment and electronics segments.

"The new Praxair China Technology Center is a state-of-the-art facility for our applications engineers and R&D organisation," says Minda Ho, president of Praxair China.

"These laboratories enable us to work closely with our business partners and customers to develop innovative products that meet their unique needs. In addition, Chinese regulations for emissions reduction are becoming more stringent and are world-class in several areas. Praxair's experience will allow us to quickly replicate our applications technologies to contribute to our customers' needs for cleaner air and water. We look forward to delivering novel gas applications from this centre to our customers across China," adds Ho.

"The inauguration of the Praxair China Technology Centre builds on our rich tradition of innovation," comments Amitabh Gupta, executive director of Praxair Asia R&D and Applications. "Praxair technical teams are developing applications to help customers increase productivity, achieve energy savings and improve environmental performance through emissions reductions. The development and application of these innovative products and services enables sustainable development, while truly making our planet more productive."

"China is our largest and fastest growing market in Asia and this center is developing technology that will not only be used in China but also in Praxair's businesses around the world," adds Ray Roberge, Praxair's senior vice president and chief technology officer.

"In addition, we are collaborating with several respected universities across China on important areas of research, which is a strategic advantage for Praxair. The innovation stemming from these projects and our ability to attract and recruit top talent from these and other educational institutions are key reasons we chose to open our facility here," he continues.

Smit Ovens and SoLayTec to develop CIGS/CZTS large area ALD tool

Cooperation between the firms will accelerate development of a cost efficient solution for large area ALD in the thin film PV & display market

Smit Ovens and SoLayTec have joined forces to develop a system for large area applications of spatial ALD.

The cooperation creates maximum leverage of the experience of both companies to allow for a fast market introduction. Applications foreseen include buffer and barrier layers for Thin film PV and layers for improved TFT structures as required for OLED displays.

The process development tool which will be integrated in the existing CIGS development line is part of the CIGS/CZTS Solliance program. It will be used for development of alternative buffer layers as well as other layers that can improve device structure and performance.

Smit Ovens and SoLayTec have agreed that both parties will contribute on technical aspects that best match their experience. SoLayTec will focus on the injector head development in order to maximise the experience of their extremely successful product in the c-Si PV market, InPassion ALD. Smit Ovens will take the role of machine integrator and act as contract partner to the customers.

"We are very excited about this cooperation since it allows us to achieve two strategic targets at the same time," says Wiro Zijlmans, CEO of Smit Ovens. "We are able to offer an advanced process solution for the buffer layer to our existing customers for CIGS crystallisation. On top of that we are able to expand our market penetration in the Display market which we were already addressing with drying & sintering solutions."

"After having successfully launched our first products in the market for crystalline PV, we now are able to use the proven deposition technology for the next market opportunity," according to Huib Heezen, managing director of SoLayTec. "Also, we are very enthusiastic about our cooperation with an experience player as Smit ovens as this enables us to market both our combined areas of expertise within a short time frame."

Novel way to grow thin films of germanium

A new method to grow germanium crystals at low temperatures may lead to next-generation large-scale integrated circuits and future flexible electronics

Researchers have developed a new technique to produce thin films of germanium crystals - key components for next-generation electronic devices such as advanced large-scale integrated circuits and flexible electronics, which are required for gadgets that move or bend.

Unlike conventional methods, the new approach does not require high temperatures or other crystals to act as seeds to grow the germanium crystal. And, the researchers say, the new method can be used to produce germanium films with a very large area, allowing for more potential applications.

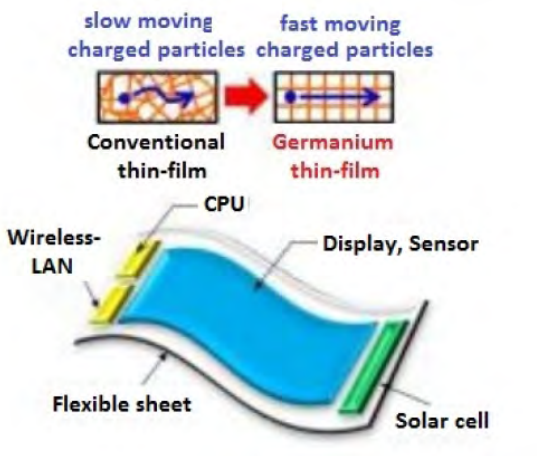
"This is the realisation of the dreams of crystal-growth researchers," says Taizoh Sadoh of Kyushu University. "This unique method will open new ways to create

advanced flexible electronics."

Sadoh is an author of the paper describing the new work, which appears in the AIP Publishing journal *Applied Physics Letters*.

Charged particles move through germanium more readily than they do through silicon, making germanium a good material for electronics. In particular, it is a promising material for the thin-film transistors that are needed for flexible electronics.

However, for use in flexible electronics, the germanium would have to be grown on malleable materials, which tend to soften at temperatures above 300°C. The challenge, says Sadoh, is to grow germanium at lower temperatures.



High-speed germanium thin-film transistors enable next-generation electronics

Using gold as a catalyst, Sadoh and his colleagues were able to grow germanium crystals at a temperature of about 250°C. They were also able to grow them in such a way that their crystal structure has the proper orientation and electrical properties necessary for technological applications.

This work is described in detail in the paper, "Nucleation controlled gold-induced-crystallization for selective formation of Ge(100) and (111) on insulator at low-temperature (~250°C)" by Jong-Hyeok Park *et al* in the journal *Applied Physics Letters*. The paper can be accessed via http://dx.doi.org/10.1063/1.4819015.

Bruker reveals electroluminescence tool for HB-LED wafer analysis

The firm's new technology for optical and electrical characterisation delivers fast and repeatable measurements for epi process quality control

A the 15th China International Optoelectronic Exposition (CIOE 2013), Bruker introduced the new LumiMap Electroluminescence System for HB-LED epi wafer process metrology.

LumiMap Instrument

LumiMap joins a suite of other Bruker HB-LED epi metrology tools, and it incorporates many of the advanced features of Bruker's flagship metrology products. Proprietary, patent-pending features of the new system include the durable conducting probe, a unique wafer edge contact solution, and advanced I-V curve modelling for accurate and repeatable forward voltage value measurement.

These features enable LumiMap to deliver accurate and repeatable forward and reverse IV characteristics, spectral intensity, wavelength and spectral width measurements on 2- to 6-inch epi wafers, with a wide range of current settings.

"LumiMap provides more accurate and reliable electrical and optical epi wafer measurements than the traditional indium dot method," says. Ryan Lee, Executive VP and CTO of Foshan Nationstar Optoelectronics Co. Ltd. "A reliable electro-luminescence quality check immediately after MOCVD will help us further improve epi wafer yield and reduce costs."

"Bruker is pleased to bring a new technology solution to HB-LED manufacturing, rounding out our other HB-LED metrology technologies in 3D optical microscopy, atomic force microscopy and XRD/XRF for PSS wafers and epi wafer multi-quantum layer characterisation," adds Xiaomei Li, Vice President of Segment Marketing of the

Bruker Nano Surfaces division. “LumiMap ideally serves stringent HB-LED manufacturing cost reduction goals at a time when the industry is poised for unprecedented growth.”

“LumiMap electroluminescence technology fills the current lack of fast, non-destructive, reliable and repeatable optical and electrical measurement solutions to improve epi wafer yield and LED device quality at the epi wafer stage,” concludes Robert M. Loiterman, Executive Vice President and General Manager of Bruker’s Stylus and Optical Metrology Business. “With LumiMap, the HB-LED industry can now get accurate electrical and optical feedback in minutes rather than days, reducing scrap events and operating costs.”

LumiMap is a value-oriented alternative to conventional, multistep, operator-dependent indium dot methods of epi (made by epitaxial growth) wafer characterisation. The system features rapid, non-destructive, no post measurement chemical cleaning, software-controlled measurement locations, and repeatable optical and electrical measurement capabilities through forming a temporary LEDdevice on an epi wafer.

The results obtained by LumiMap are well correlated with those on the final HB-LED device, providing an early warning of process shifts, which in turn reduces the risk of expensive scrap events and improves yields.

Simple wafer exchange and intuitive software provides the industry’s easiest to use interface for production quality control, as well as epi process development. The long measurement lifetime of the proprietary conducting probe meets the strictest industry cost of ownership requirements. A the 15th China International Optoelectronic Exposition (CIOE 2013), Bruker introduced the new LumiMap Electroluminescence System for uncompromised HB-LED epi wafer process metrology.

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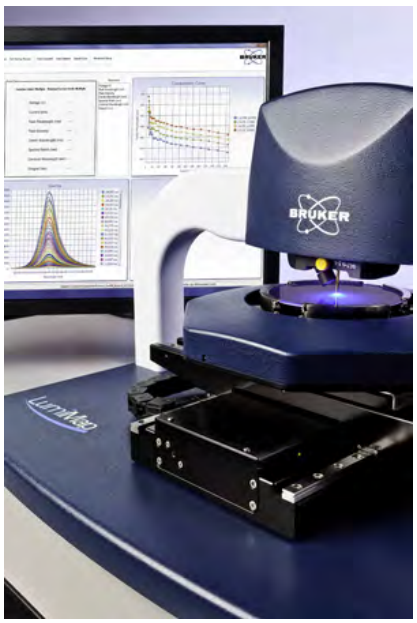

LumiMap Electroluminescence System lights up wafer with non-destructive proprietary probe

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Rudolph expands macro defect inspection series

The new NSX 220 tool is designed for semiconductor, MEMS and LED packaging and test facilities to achieve productivity at a low price

Rudolph Technologies has launched its new NSX 220 automated macro defect inspection system.

The company says its system, pictured below, provides fast, easy defect inspection for traditional back-end processes including the LED market at a reduced price.

NSX220 system

The NSX 220 tool joins the NSX 320 system in the NSX family of automated macro defect inspection and metrology systems for final manufacturing facilities.

The first NSX 220 system was installed in July at a major outsourced assembly and test (OSAT) facility in Asia.

Mike Jost, vice president and general manager of Rudolph's Inspection Business Unit says, "The NSX 220 system is a streamlined version of our NSX 320 system. The NSX 220 system is designed for traditional macro defect inspection of wafers up to 300mm at conventional semiconductor, MEMS and LED final manufacturing facilities, while the NSX 320 System serves next-generation advanced packaging processes with defect inspection and three-dimensional metrology for wafers up to 450mm."

He continues, "The NSX 220 system benefits from many of the hardware and software innovations that made the NSX 320 system the market leader in advanced packaging, but is targeted for back-end facilities that do not need the full suite of capabilities offered by the NSX 320 System. Adding the NSX 220 system to the NSX family gives our customers a choice of best-in-class capabilities."

The NSX 220 is an automated macro defect inspection system that uses grey-scale image analysis (with colour image capture) to provide fast, accurate inspection and metrology in final manufacturing applications for wafers up to 300mm. It can detect traditional advanced macro defects such as scratches, mechanical damage, foreign materials, voids and probe damage, while also performing two-dimensional measurements on bumps, probe marks and edge trim processes.

The tool operates over a range of resolutions (10µm - 0.5µm) with both brightfield and optional darkfield illumination. The software platform, leveraged from the NSX 320 system's success, uses host-based image processing and delivers significant improvements in usability and productivity over older-generation NSX series equipment. Using centrally-managed recipe creation and editing, multiple NSX 220 tools can share a single recipe and be matched across the fab.

An optional suite of yield management software optimises the productivity of both the NSX 220 and 320 systems and minimises the need for operator assistance. Discover Software is designed for use with Rudolph inspection systems to allow real-time analysis for faster solutions and intelligent defect sampling for reduced offline review.

Nanoplus orders Oxford Instruments tool for laser etching

The Ionfab300 Plus will be used for laser bar facet coating with anti-reflective and high-reflection multilayers, and the PlasmaPro System100 RIE system will be used for GaAs and InP compound etching

Oxford Instruments Plasma Technology (OIPT) has just received an order from Nanoplus in Germany for an ion

beam deposition and a plasma etch system for use on novel types of semiconductor laser production.

Nanoplus produces semiconductor lasers over several wavelength ranges (some exclusively) for many different customers with a wide range of applications.

The Ionfab300 Plus ion beam deposition is a multi-batch cassette loading tool allowing many devices to be produced for several applications and various customers in one load. The Ionfab300 Plus will be used for laser bar facet coating with anti-reflective and high-reflection multilayers, and the PlasmaPro System100 RIE system will be used for GaAs and InP compound etching.

David Pearson, OIPT's Senior Ion Beam Technologist, comments, "Our Ionfab optical coating tools are becoming the tools of choice for many types of precision optical coatings worldwide, in particular in laser applications."

"Nanoplus is an internationally leading supplier of single mode DFB lasers for sensing, metrology, spectroscopy and telecom applications. We even have one of our sensors on NASA's Mars Curiosity Rover', say sAlfred Forchel, founder of Nanoplus, "We chose Oxford Instruments systems for their versatility, superior process capabilities and excellent customer support."

Frazer Anderson, Business Group Director at Oxford Instruments concludes, "Our tools offer the ideal platform for production as well as research & development in many new application areas, and Laser Bar facet coating is just one of these. Our excellent process applications team and global service support ensure that our customers are supported in every respect and can count on their Oxford Instruments systems for maximum uptime and reliability."

Novel Devices

Nanosys ships 2000kg QD devices for displays

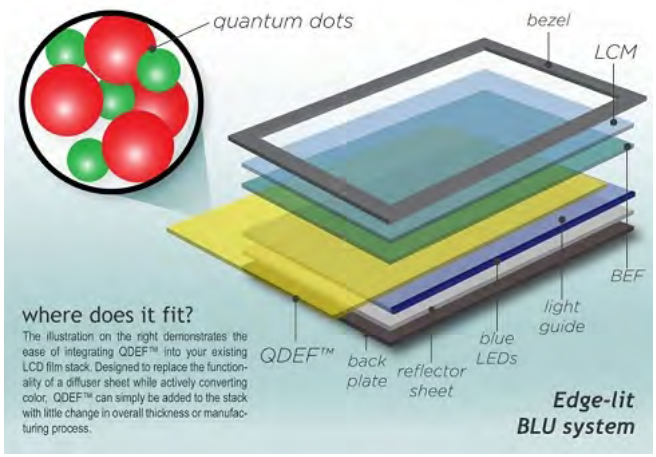
The firm has shipped its QDEF devices to LCD manufacturers to bring perfect colour and high energy efficiency to millions of devices

Nanosys has passed a major production milestone at its recently opened 60,000 square foot manufacturing facility in Milpitas, California.

A shipment of Nanosys Quantum Dot Concentrate bound for a new generation of consumer devices which will provide brighter and more colorful displays this fall

The shipment of more than 2000kg of Nanosys Quantum Dot Concentrate, used to make Quantum Dot Enhancement Film (QDEF), represents a significant step forward in the adoption of quantum dot technology for displays.

QDEF utilises the light emitting properties of quantum dots to create an ideal backlight for LCDs, which is one of the most critical factors in the colour and efficiency performance of LCDs.



Schematic showing how QDEF works

Unlike conventional phosphor technologies such as YAG that emit with a fixed spectrum, quantum dots can actually convert light to nearly any colour in the visible spectrum.

Pumped with a blue source, such as a GaN LED, they can be made to emit at any wavelength beyond the pump source wavelength with very high efficiency (over 90 percent quantum yield) and with very narrow spectral distribution (only 30 - 40nm FWHM.)

The real magic of quantum dots is in the ability to tune the colour output of the dots, by carefully controlling the size of the crystals as they are synthesised so that their spectral peak output can be controlled within 2nm to nearly any visible wavelength.

Nanosys is demonstrating a 55 inch 4K TV utilising QDEF technology at the IHS E&M Quantum Dot Seminar in Seoul, Korea this week. A drop-in optical component for LCDs, QDEF creates a richer, more lifelike colour experience while consuming significantly less power.

Based on a new generation of quantum dots from Nanosys, the 55 inch set on display in Korea achieves about 40% higher colour gamut than commercially available white-LED based 4k televisions while reducing power consumption by more than 35%.

“QDEF is enabling LCD makers to really challenge the newest OLED technology,” says Jason Hartlove, President and CEO of Nanosys. “We are working with display makers to create a new, perfect colour display experience that is more cost effective, efficient and reliable than anything else currently on the market. This is fundamentally changing the economics of high performance displays back in favour of LCD technology, and demand for QDEF has grown to the point that we’ve significantly expanded our manufacturing to keep up.”

Nanosys is working closely with supply chain partners to continue ramping deliveries as demand for QDEF from global display manufacturers increases.

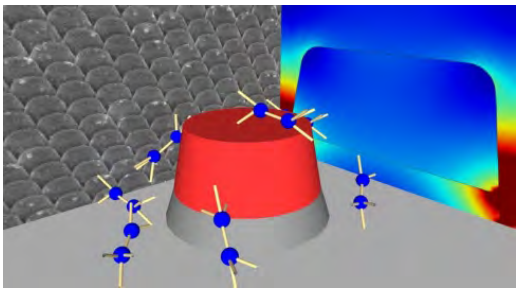
Tiny InAs antennas give long light waves IR vision

The indium arsenide antenna arrays enable the detection of small volumes of materials with a standard infrared spectrometer

University of Illinois at Urbana-Champaign researchers have developed arrays of tiny nano-antennas that can enable sensing of molecules that resonate in the infrared (IR) spectrum.

The antennas are composed of III-V compound semiconductor InAs.

“The identification of molecules by sensing their unique absorption resonances is very important for environmental monitoring, industrial process control and military applications,” says team leader Daniel Wasserman, a professor of electrical and computer engineering. Wasserman is also a part of the Micro and Nano Technology Laboratory at Illinois.



Nanoantennas made of semiconductor InAs can help scientists detect molecules with infrared light (Credit: Daniel Wasserman)

The food and pharmaceutical industries use light to detect contaminants and to ensure quality. The light interacts with the bonds in the molecules, which resonate at particular frequencies, giving each molecule a “spectral fingerprint.” Many molecules and materials more strongly resonate in the IR end of the spectrum, which has very long wavelengths of light - often larger than the molecules themselves.

“The absorption signatures of some of the molecules of interest for these applications can be quite weak, and as we move to nano-scale materials, it can be very difficult to see absorption from volumes smaller than the wavelength of light,” Wasserman says. “It is here that our antenna array surfaces could have a significant impact.”

Other nano-scale antenna systems cannot be tuned to a longer light wavelength because of the limitations of traditional nanoantenna materials. The Illinois team used highly doped semiconductors grown by MBE.

“We have shown that nanostructures fabricated from highly doped semiconductors act as antennas in the infrared,” notes Stephanie Law, a postdoctoral researcher at Illinois and the lead author of the work published in the journal *Nano Letters*. “The antennas concentrate this very long wavelength light into ultra-subwavelength volumes, and can be used to sense molecules with very weak absorption resonances.”

The semiconductor antenna arrays allow long-wavelength light to strongly interact with nano-scale samples, so the arrays could enhance the detection of small volumes of materials with a standard IR spectrometer - already a commonplace piece of equipment in many industrial and research labs.

The researchers further demonstrated their ability to control the position and strength of the antenna resonance by adjusting the nanoantenna dimensions and the semiconductor material properties.

The group will continue to explore new shapes and structures to further enhance light-matter interaction at very small scales and to potentially integrate these

materials with other sensing systems.

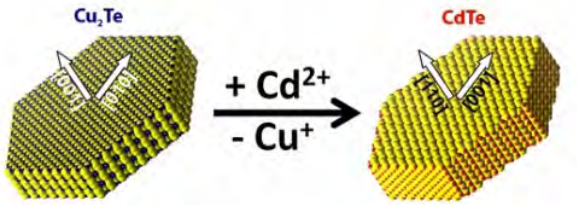
"We are looking to integrate these antenna structures with optoelectronic devices to make more efficient, smaller, optoelectronic components for sensing and security applications," Wasserman concludes.

This work is described in detail the paper, "All-Semiconductor Plasmonic Nanoantennas for Infrared Sensing," by Stephanie Law *et al* in *Nano Letters*, 2013, 13 (9), pp 4569-4574. DOI: 10.1021/nl402766t

Enhancing lasing properties of CdTe quantum disks

Suitable for use in lasers, a novel preparation method of cadmium telluride quantum disks can leads to more stable nanocrystals compared to conventional preparation methods. Tuning the shape of the disks can strongly improve conditions for lasing or single-photon emission

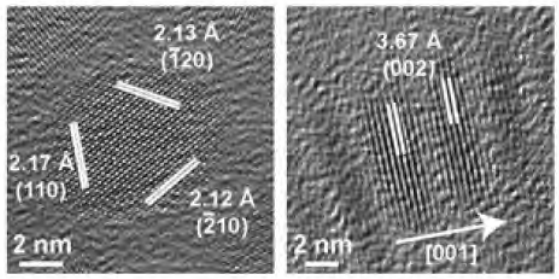
Researchers have used a novel synthesis method to produce hexagonal CdTe nanocrystals from disk-shaped Cu2Te nanocrystals.



Schematic showing disk-shaped hexagonal Cu2Te nanocrystals and subsequent cation exchange of Cu to Cd at high temperature (180 °C) resulting in highly fluorescent CdTe nanocrystals

The Cu2Te nanocrystals have a well-defined stoichiometric composition and tuneable diameter and thickness. The resultantCdTe has less than 1 mol % of residual Cu remaining in the lattice.

The synthesis preserves the overall disk shape, but is accompanied by a substantial reconstruction of the anion sublattice. This results in a reorientation of the *c*-axis from the surface normal in Cu2Te into the disk plane in CdTe nanodisks.



TEM micrographs showing Cu2Te (left) and CdTe (right)

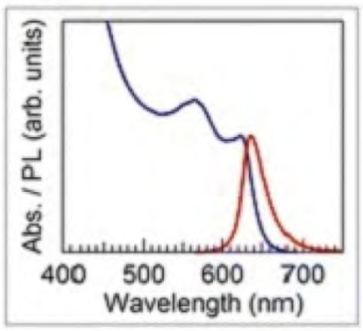
The scientists from the Istituto Italiano di Tecnologia, Genova and IMEM-CNR, Parma in Italy, used the FLS920 photoluminescence spectrometer made by Edinburgh Instruments to measure the photoluminescence (PL) spectral properties, quantum efficiencies and lifetimes of the CdTe disks.

Fluorescent nanocrystals are currently being applied in lasers or displays, and offer exciting prospects for future photonics such as quantum emitters. The nanocrystal shape plays an important role in these applications. The flat CdTe quantum disks with high fluorescence efficiency therefore provide an interesting possibility to explore the shape- and crystal structure-dependent fluorescence properties of semiconductor nanocrystals.

The measurements conditions could be carefully controlled using the FLS920: the PL quantum efficiency of the CdTe quantum disks was measured with an integrating sphere, by exciting the samples at 500 nm.

Band-edge PL lifetime measurements were made with the FLS920 using time-correlated single-photon counting, exciting the samples at 400 nm with a 50 ps laser diode. The repetition rate of the diode was adjusted to 1 MHz to ensure complete decay of the emission between subsequent excitation pulses.

The disks show a PL peak that can be tuned continuously from 600 to 640 nm according to their thickness. The researchers also reached a faster PL decay time compared to spherical CdTe quantum dots, which confirms that simply tuning the shape can strongly improve conditions for lasing or single-photon emission. What's more, the current synthesis also leads to more stable nanocrystals compared to conventional preparation methods, opening up the way for practical application of the quantum dots.



The CdTe nanodisks show a continuously tuneable PL peak position, scaling with the thickness of the disks

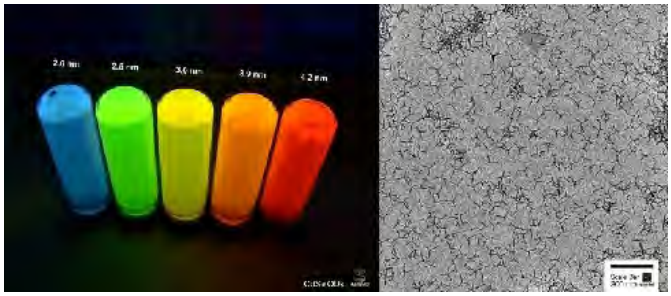
The results were recently published in the paper, "Synthesis of Uniform Disk-Shaped Copper Telluride Nanocrystals and Cation Exchange to Cadmium Telluride Quantum Disks with Stable Red Emission," by Hongbo Li *et al* in *Journal of the American Chemical Society* . http://dx.doi.org/10.1021/ja404694k

QMC sends CdSe samples to Asian LCD display manufacturer

The cadmium selenide samples will be used to enhance the performance and energy efficiency of high-resolution computer, TV and smartphone displays

Quantum Materials says it has shipped CdSe Tetrapod Quantum Dots in sample quantities to a leading Asian-based electronics manufacturer.

Quantum Materials Corporation (QMC) recently developed tetrapod quantum dots to meet the client's performance specifications.



QMC's CdSe Tetrapod Quantum Dots. Left: Luminescent Vials show colour varies with QD size. Right: Tetrapod Quantum Dots by Electron Microscope

Tetrapod Quantum Dots are an advanced nanoscale material that improves the performance and energy efficiency of very high-resolution computer, TV and smartphone displays.

Quantum Materials' patent-pending continuous-flow technology produces uniform, narrow bandwidth tetrapod quantum dots with bright emission, less aggregation, purer colours (including high-luminous red) and precise colour rendition.

Manufacturers are seeking to "print" tetrapod quantum dots onto backplane films in liquid crystal displays (LCD) for brighter images, larger screens and a wider gamut of colours to deliver a new visual experience in image technology.

Thinner, lighter, brighter and less expensive QD-LED displays, including portable and flexible devices, will offer almost infinite contrast levels, deep black levels and high light output with no motion blur or field-of-view issues.

Stephen B. Squires, Quantum Materials Corp's Founder and CEO says, "Tetrapod Quantum Dots ultimately allow for lower display manufacturing costs due to their superior luminescence and much lower incidence of aggregation. Far fewer quantum dots are required to achieve the same level of performance. We believe this performance advantage coupled with our continuous-flow manufacturing technology will ensure the lowest quantum dot cost."

David C. Doderer, vice president of research and development for Quantum Materials wrote the feature article in the July/August 2013 issue of iSP Magazine entitled "Quantum Dots: The Future of Displays". The article details Quantum Materials' ability to reduce the cost of quantum dot creation while ensuring uniformity in quantities sufficient to meet high volume display-manufacturing needs.

Nanomarkets' August article "Key Quantum Dots Markets" highlighted "U.S.-based Quantum Materials Corporation" and the need for "cost-effective large-scale manufacturing techniques, which will be the key to the commercialisation of cost-effective and high-performance QDs".

Susan Eustis of Wintergreen Research stated in their 2013 report, "Quantum Dot and Quantum Dot Display (QLED) - Markets Reach $6.4 billion by 2019" that "Once manufacturers learn to integrate higher efficiency luminescent quantum dots into their products, each vendor will need to follow or dramatically lose market share. This level of change brought by quantum dot and quantum dot displays (QLED) represents a new paradigm that will create new industries, products and jobs in science and industry."

BinOptics' InP laser technology gives more than Moore

The new technology helps overcome cost, yield and performance barriers associated with sources for silicon photonics

BinOptics Corporation, a manufacturer and supplier of semiconductor lasers has successfully incorporated its patented Etched Facet Technology (EFT) into a variety of silicon photonic applications.

Creating InP based lasers and other photonic components using EFT, opposed to the conventional cleaving process, improves performance, reproducibility, reliability and quality while maintaining affordable manufacturing costs.

Silicon photonics has emerged as a key technology to keep Moore›s Law intact for computing in the march towards exaflop (a quintillion or 1018 mathematical operations per second) computing.

Similarly, advances in Datacom infrastructure in recent years have further necessitated cost-effective, highly reliable lasers capable of supporting next-gen high-speed information transfer.

An efficient, reliable, and non-hermetic photonic source is required to provide infrared radiation to silicon photonics circuits.

BinOptics has fabricated semiconductor lasers and other photonic elements on InP that meet these specific requirements.

EFT was first conceived and co-invented by the CEO of BinOptics, Alex Behfar, while pursuing a PhD at Cornell›s School of Electrical and Computer Engineering. Since Behfar co-founded BinOptics in 2000, EFT has been utilised in the manufacturing of more than 40 million lasers shipped.

«Our customers have experienced the benefits of our EFT produced lasers for a long time and across a wide variety of applications, but only recently have they been aggressively exploring the unique benefits of our EFT offerings in silicon photonics applications,» says Behfar. «EFT is solving a new set of unique challenges as organisations look for solutions to enable the next generation of computing. Many industry experts expect chip-to-chip and on-chip photonics to be the most significant technology impacting the future of computing.»

Challenges with reproduction, flexibility, integration, and performance using conventional cleaving processes drive up cost and threaten the sustainability of continuous improvement. The BinOptics EFT design philosophy eliminates those barriers, helping support the rapid advancement of silicon photonics.

Attributes of the technology are listed below.

Reproducibility and Flexibility: EFT allows facets to be defined through high precision photolithography rather than imprecise cleaving. The result is unprecedented uniformity and yield, as well as the capability to build structures that are impossible to realise with conventional techniques. With no dependency on the crystallographic plane of the wafer, unique anti-reflection geometries can be used in place of expensive coatings.

High Yield: Facet cleaving and bar testing is often one of the most costly operations in other factories. BinOptics› lasers are fully fabricated with EFT and automatically tested on the wafer before separation into individual chips. As a result, BinOptics is able to fully evaluate all the lasers on the wafer in an automated, high-throughput test operation, in addition to dramatically reducing the cost of chip handling.

Surface Emission: The BinOptics› technology platform enables etching of angled facets that allow the light from a laser to emerge perpendicular, or at an angle off from perpendicular, to the surface of the InP chip. This is particularly helpful with coupling to grating couplers on silicon photonic chips.

Performance and Reliability: Facet cleaving operation and subsequent coating operations can cause failures and performance issues due to the disruptive nature of the process. EFT eliminates both these sources of failure. Devices made using EFT with proprietary passivation technology are exceptionally robust with respect to temperature and humidity, eliminating the need for costly hermetic packages.

Precision Facet Location: Device facets are formed with extreme precision, enabling low-cost passive alignment with silicon photonics.

«Active alignment of a light source to the silicon photonics chip is a costly process, requiring extremely expensive equipment,» comments Jonathan Klamkin, Director of the Integrated Photonics Laboratory at Boston University. «With EFT, BinOptics found a way to reap the cost and efficiency benefits of passive alignment without sacrificing the accuracy associated with real-time active alignment. This should be a critical factor for companies seeking economical, large-scale rollout of silicon photonics applications.»

«We needed an experienced but innovative InP partner who could provide a reliable, easy-to-integrate, non-hermetic light source for our silicon photonics platform,» concludes Mehdi Asghari, CTO, of Kotura. «BinOptics provided us with the fastest path to market for our new 100 Gbps optical engine, exceeding our expectations in every way.»

Harvesting energy from light in a new way

A new discovery could enhance optoelectronic devices and solar cell performance

Researchers from the University of Pennsylvania have demonstrated a new mechanism for extracting energy from light.

This could improve technologies for generating electricity from solar energy and lead to more efficient optoelectronic devices used in communications.

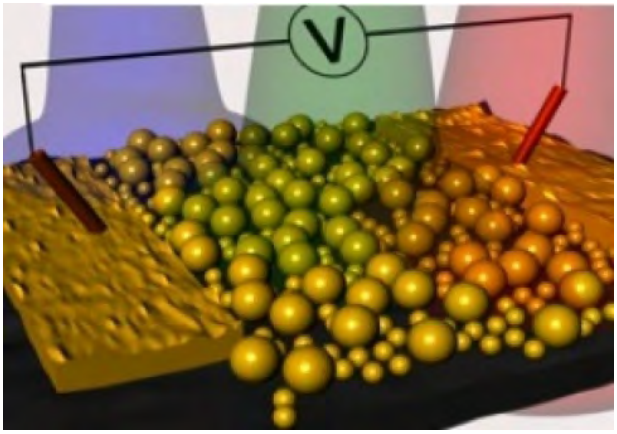
Dawn Bonnell, Penn's vice provost for research and Trustee Professor of Materials Science and Engineering in the School of Engineering and Applied Science, led the work, along with David Conklin, a doctoral student.

"We're excited to have found a process that is much more efficient than conventional photoconduction," Bonnell comments. "Using such an approach could make solar energy harvesting and optoelectronic devices much better."

The new work centres on plasmonic nanostructures, specifically, materials fabricated from gold particles and light-sensitive molecules of porphyin, of precise sizes and arranged in specific patterns.

Plasmons, or a collective oscillation of electrons, can be excited in these systems by optical radiation and induce an electrical current that can move in a pattern determined by the size and layout of the gold particles, as well as the electrical properties of the surrounding environment.

Because these materials can enhance the scattering of light, they have the potential to be used to advantage in a range of technological applications, such as increasing absorption in solar cells.



Researchers fabricated nanostructures with various photoconduction properties

In 2010, Bonnell and colleagues published a paper in *ACS Nano* reporting the fabrication of a plasmonic nanostructure, which induced and projected an electrical current across molecules.

In some cases they designed the material, an array of gold nanoparticles, using a technique Bonnell's group invented, known as ferroelectric nanolithography.

The discovery was potentially powerful, but the scientists couldn't prove that the improved transduction of optical radiation to an electrical current was due to the "hot electrons" produced by the excited plasmons. Other possibilities included that the porphyin molecule itself was excited or that the electric field could focus the incoming light.

"We hypothesised that, when plasmons are excited to a high energy state, we should be able to harvest the electrons out of the material," Bonnell explains. "If we could do that, we could use them for molecular electronics device applications, such as circuit components or solar energy extraction."

To examine the mechanism of the plasmon-induced current, the researchers systematically varied the different components of the plasmonic nanostructure, changing the size of the gold nanoparticles, the size of the porphyin molecules and the spacing of those components. They designed specific structures that ruled out the other possibilities so that the only contribution to enhanced photocurrent could be from the hot electrons harvested from the plasmons.

"In our measurements, compared to conventional photoexcitation, we saw increases of three to 10 times in the efficiency of our process," Bonnell comments. "And we didn't even optimise the system. In principle you can envision huge increases in efficiency."

Devices incorporating this process of harvesting plasmon-induced hot electrons could be customized for

different applications by changing the size and spacing of nanoparticles, which would alter the wavelength of light to which the plasmon responds.

"You could imagine having a paint on your laptop that acted like a solar cell to power it using only sunlight," Bonnell says. "These materials could also improve communications devices, becoming part of efficient molecular circuits."

This work is described further in the paper, «Plasmon-Induced Electrical Conduction in Molecular Devices,» by Parag Banerjee *et al* in *ACS Nano*, 2010, 4 (2), pp 1019 - 1025. DOI: 10.1021/nn901148m

The research was supported by the U.S. Department of Energy and the National Science Foundation.

Novel way to grow thin films of germanium

A new method to grow germanium crystals at low temperatures may lead to next-generation large-scale integrated circuits and future flexible electronics

Researchers have developed a new technique to produce thin films of germanium crystals - key components for next-generation electronic devices such as advanced large-scale integrated circuits and flexible electronics, which are required for gadgets that move or bend.

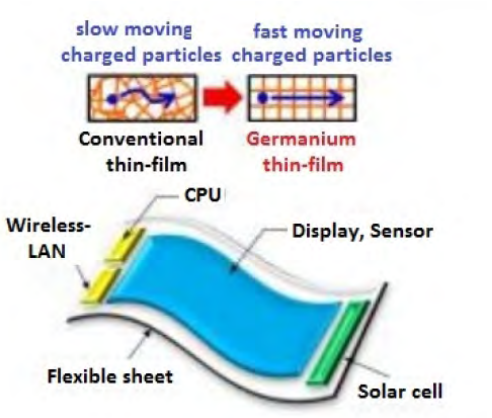
Unlike conventional methods, the new approach does not require high temperatures or other crystals to act as seeds to grow the germanium crystal. And, the researchers say, the new method can be used to produce germanium films with a very large area, allowing for more potential applications.

"This is the realisation of the dreams of crystal-growth researchers," says Taizoh Sadoh of Kyushu University. "This unique method will open new ways to create advanced flexible electronics."

Sadoh is an author of the paper describing the new work, which appears in the AIP Publishing journal *Applied Physics Letters*.

Charged particles move through germanium more readily than they do through silicon, making germanium a good material for electronics. In particular, it is a promising material for the thin-film transistors that are needed for flexible electronics.

However, for use in flexible electronics, the germanium would have to be grown on malleable materials, which tend to soften at temperatures above 300°C. The challenge, says Sadoh, is to grow germanium at lower temperatures.



High-speed germanium thin-film transistors enable next-generation electronics

Using gold as a catalyst, Sadoh and his colleagues were able to grow germanium crystals at a temperature of about 250°C. They were also able to grow them in such a way that their crystal structure has the proper orientation and electrical properties necessary for technological applications.

This work is described in detail in the paper, "Nucleation controlled gold-induced-crystallization for selective formation of Ge(100) and (111) on insulator at low-temperature (~250°C)" by Jong-Hyeok Park *et al* in the journal *Applied Physics Letters*. The paper can be accessed via http://dx.doi.org/10.1063/1.4819015.

Switching a metal into a semiconductor

Turning on a light, a composite can change from a metal to a material that partly conducts current

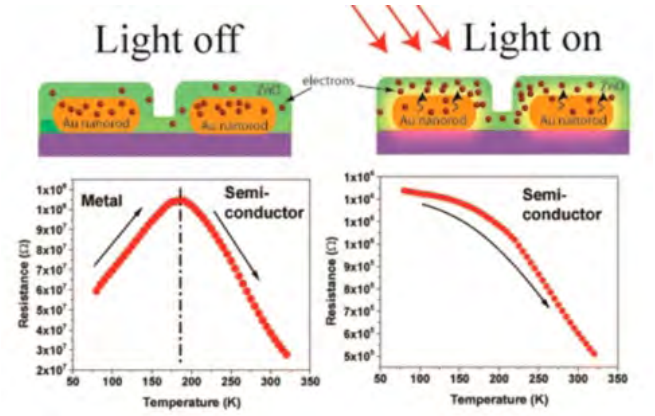
By blending their expertise, two materials science engineers at Washington University in St. Louis changed the electronic properties of new class of materials - just by exposing it to light.

Parag Banerjee and Srikanth Singamaneni, and both assistant professors of materials science, brought together their respective areas of research.

Singamaneni's area of expertise is in making tiny, pebble-like nanoparticles, particularly gold nanorods. Banerjee's area of expertise is making thin films. They wanted to see how the properties of both materials would change when combined.

The research was published online in August in *ACS Applied Materials & Interfaces*.

The research team took the gold nanorods and put a very thin blanket of zinc oxide, a common ingredient in sunscreen, on top to create a composite.



The image above shows how electrons in the gold nanorods get excited when exposed to light, then are absorbed into a thin film of zinc oxide, changing the properties of the composite from a metal into a semiconductor. (Credit: ACS Applied Materials & Interfaces)

When they turned on light, they noticed that the composite had changed from one with metallic properties into a semiconductor, a material that partly conducts current. Semiconductors are commonly made of silicon and are used in computers and nearly all electronic devices.

“We call it metal-to-semiconductor switching,” Banerjee says. “This is a very exciting result because it can lead to opportunities in different kinds of sensors and devices.”

Banjeree says when the metallic gold nanorods are exposed to light, the electrons inside the gold get excited and enter the zinc oxide (ZnO) film, which is a semiconductor. When the ZnO gets these new electrons, it starts to conduct electricity.

“We found out that the thinner the film, the better the response,” he says. “The thicker the film, the response goes away. How thin? About 10 nanometres, or a 10 billionth of a metre.”

Other researchers working with solar cells or photovoltaic devices have noticed an improvement in performance when these two materials are combined, however, until now, none have broken it down to discover how it happens, Banerjee says.

“If we start understanding the mechanism for charge conduction, we can start thinking about applications,” he says. “We think there are opportunities to make very sensitive sensors, such as an electronic eye. We are now looking to see if there is a different response when we shine a red, blue or green light on this material.”

Banerjee also says this same technology can be used in solar cells.

This research has been described in the paper, “Plasmonic Metal-to-Semiconductor Switching in Au Nanorod-ZnO nanocomposite films,” by Wu *et al* in *ACS Applied Materials & Interfaces*.doi.org/10.1021/am402309x.

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