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A New Beginning for Compound Semiconductor

Dear readers,

On Wednesday 2nd September 2009 in a mutually agreed transaction, Angel Business Communications Limited (BCL) acquired Compound Semiconductor magazine and its associated website www.compoundsemiconductor.net from IOP Publishing. Angel BCL has a long track record of developing and publishing titles and information sources in the semiconductor and related markets through a wide range of titles in the semiconductor, solar, MEMS and nanotechnology sectors. The flagship publication 'EuroAsia Semiconductor' was first published in 1982 and now has a world-wide distribution of 56,545 copies in 34 countries.

Compound Semiconductor is the leading magazine in its sector and is a perfect synergy with Angel BCL's stable of titles. To ensure continuity Richard Stevenson PhD has joined the Angel team as Consultant Editor and will be an integral part of the magazine as it takes on a new identity and seeks to expand its global reach.

"The deal is a win-win for Compound Semiconductor readers and advertisers, as well as for Angel and ourselves," stated Michael Bray, Finance Director at IOP Publishing. "With a new publisher, Compound Semiconductor will continue to be the primary information resource for professionals working with compound semiconductor materials and devices."

Angel Business Communications anticipates no interruption in the print schedule of Compound Semiconductor magazine, with all of the remaining 2009 issues and the associated advertising schedules going-ahead as planned and looks forward to a long lasting future with the magazine and you our readers. Angel BCL title's have a global reach covering the range of high tech manufacturing opportunities providing the perfect platform to take Compound Semiconductor forward for the industry.

Compound Semiconductor is a market-leading publication that's widely respected for its must-read editorial content and targeted readership. We are certain that the magazine and the website will prove to be compelling additions to Angel's existing B2B portfolio of semiconductor magazines, websites and live events.

Readers and advertisers wishing to contribute ideas for editorial coverage in the magazine should contact me directly on +44 (0)2476 718970 or via email at stephen@angelbc.co.uk

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Commercial Director

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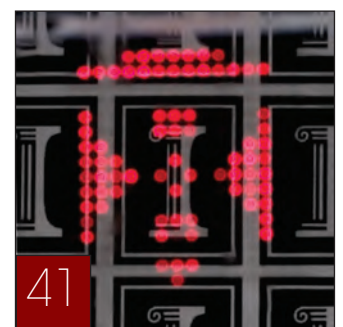
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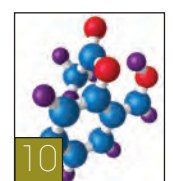
industry & technology

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Consultant Editor

Richard Stevenson PhD
richardstevenson@angelbc.co.uk
+44 (0)1291 629640

Editor-in-Chief

David Ridsdale dr@angelbcl.co.uk
+44 (0)1923 690210

Publisher

Jackie Cannon jc@angelbcl.co.uk
+44 (0)1923 690205

Account Handlers

Shehzad Munshi sm@angelbcl.co.uk
+44 (0)1923 690215
Tommy Beazley tb@angelbcl.co.uk
+44 (0)1923 690222

Design & Production Manager

Mitchell Gaynor mg@angelbcl.co.uk
+44 (0)1923 690214

Circulation Director

Jan Smoothy js@angelbcl.co.uk
+44 (0)1923 690200

Subscriptions Manager

Debbie Higham dh@angelbcl.co.uk
+44 (0)1923 690220

Commercial Director

Stephen Whitehurst stephen@angelbc.co.uk
+44 (0)2476 718970

Directors

Stephen Whitehurst, Jan Smoothy
Bill Dunlop Uprichard

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

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

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Bolt from the Blue

Most of us delight in watching a great race unfold. There is the thrill of seeing Usain Bolt hurtle down the track and smash the world 100 m record, or a great middle-distance runner timing their kick to perfection, leaving the pack, and crossing the finishing line first. There are also the longer races – marathons, round-the-world sailing competitions, and first ascents of mountains – that leave time for leaders to come and go, and those that were once flailing to snatch victory. Our community also has its races. They include the race for the first blue LED with a p-n junction – a feat accomplished 20 years ago and recounted in this issue – and the first terahertz laser. But recently, the most exciting race has been for the first truly green nitride laser.

I expected Rohm to grab this crown, because it has been the leading light in the push of non-polar lasers to longer wavelengths. Its rival in this domain, the University of California, Santa Barbara, also had an outside chance, particularly after strengthening its squad by poaching Hiroaki Ohta from Rohm about a year ago. And it is always dangerous to write off Nichia – conventional nitride lasers appeared to hit a wall at around 490 nm until the company announced a 510 nm variant this spring, and if they quickly repeated that stretch they could have snatched the title.

But none of these won - it was Sumitomo of Japan that grabbed that accolade with its 531 nm semi-polar laser. This gave me quite a shock, because as far as I'm aware, the company had kept this development under wraps. But should we really be that surprised? The foundation to success with polar and semi-polar lasers is a high-quality gallium nitride substrate, and Sumitomo definitely knows a thing or two about that.

Although the race is now over, plenty more work must be done before we can go out and buy laser TVs and pocket-sized projectors that feature these sources. Performance specs will need a massive hike and production costs will have to fall substantially.

Substrates are one of the biggest barriers to commercial success. I don't know the size of the substrates that Sumitomo used, but I imagine they were comparable to non-polar pieces used by the likes of Rohm that are no bigger than your fingernail. However, there is hope. Mitsubishi is now developing 2 inch non-polar GaN substrate production, and if this is successful it will be a very welcome breakthrough.

Reliability is another massive issue. Aside from Nichia, it never gets a mention in the papers by long-wavelength nitride laser developers. And a race for reliability targets is anything but sexy. However, if these lasers are going to enjoy commercial success, then it is essential that we also have a winner in that race category.

Richard Stevenson PhD
Consultant Editor



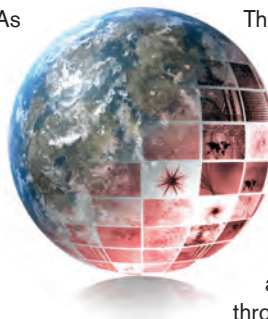
Slower recovery for GaAs industry

According to the Strategy Analytics annual industry forecast and outlook for the GaAs (gallium arsenide) industry, the global economic meltdown slowed year-on-year GaAs industry growth from its previous forecast of 9% down to 6% in 2008. With the market projected to contract again 5% year-on-year in 2009, gains made in 2008 will be effectively wiped out and the GaAs industry is projected to generate revenues of \$3.5 billion in 2009.

"The GaAs industry effectively shut down as handset manufacturers turned off the taps in the final quarter of 2008," observed Asif Anwar at Strategy Analytics. "However, Strategy Analytics believes that the market

has bottomed out and multiple GaAs device insertions in cellular handsets will be augmented by demand from other wireless markets as well as requirements from defense, consumer, fiber optic and automotive sectors."

Demand from wireless markets, including cellular handsets, will continue to be the primary growth engine for the GaAs industry. While Strategy Analytics expects growth to return in 2010, with all major end demand sectors growing through 2013, industry revenues will fall short of previous expectations of \$5 billion.



The overall growth will be tempered as a result of the economic downturn and growth will show signs of flattening out in 2013. Overall, the GaAs, RF and microelectronic device market will grow at a CAAGR (compound annual average growth rate) of 4% through 2013, to be worth \$4.5 billion.

The GaAs industry forecast and outlook reports and datamodels are available on Strategy Analytics' GaAs and ADS service pages at <http://www.StrategyAnalytics.com>

TriQuint acquires TriAccess Technologies

TriQuint Semiconductor, Inc has announced its acquisition of TriAccess Technologies, a provider of Cable TV (CATV) and Fiber-to-the-Premise (FTTP) integrated circuits for the amplification of high quality multimedia content.

Previously, TriQuint served as TriAccess' foundry supplier. "The TriAccess team is a great fit for TriQuint," said Brian Balut, Vice President of TriQuint's Network Products. "TriAccess brings a portfolio of products for the CATV and FTTP markets, with strong design and market understanding, which accelerates TriQuint's strategy of serving these applications.

The combined resources of TriQuint and

TriAccess put the company in a leadership position in these growing markets."

Cable and telecom operators are competing to provide the consumer with triple-play services (Internet, video and voice) and are upgrading their networks to provide the bandwidth needed for high-speed Internet, multiple HDTV streams, and applications such as Video-on-Demand (VOD).

These services require RF components that provide higher performance – such as higher bandwidth, better linearity, lower noise, reduced power consumption, and higher integration – all at reduced cost. It's not just a U.S. focus; Europe and the Asia-Pacific region are deploying similar

systems. "We're eager to join TriQuint and believe that together we can accelerate our success in multiple CATV and fiber optic video markets worldwide. We are anxious to further utilize TriQuint's process technology and assembly and test resources.

TriQuint is well known and highly respected by our customers, providing additional confidence that we are a dependable and stable source of supply," said Chris Day, TriAccess' president and CTO. Mr. Day will now manage this TriQuint Santa Rosa Design Center focused on the growing CATV and fiber optic video markets. Terms of the acquisition were not disclosed. TriAccess' results are not expected to materially impact TriQuint's net income.

A new publisher for Compound Semiconductor

Angel Business Communications Limited (Coventry/Watford, UK) has acquired Compound Semiconductor magazine and its associated website from IOP Publishing (Bristol, UK). Financial details of the transaction were not disclosed.

Stephen Whitehurst, Commercial Director at Angel Business Communications, added: Compound Semiconductor is a market-leading publication that's widely respected. We're certain that the magazine and the website will prove to be compelling



additions to Angel's existing B2B portfolio of semiconductor magazines, websites and live events.

Angel Business Communications anticipates no interruption in the print schedule of Compound Semiconductor magazine, with all of the remaining 2009 issues and the associated advertising schedules going ahead as planned. After a brief hiatus, the daily news service on <http://compoundsemiconductor.net> will be up and running again, said Whitehurst. Readers and advertisers wishing to

contribute ideas for editorial coverage in the magazine or online should contact: Stephen Whitehurst directly. Tel: +44 (0)2476 718970. Email to: stephen@angelbc.co.uk.

Additional information

Angel Business Communications is an industry-leading B2B publisher as well as conference and exhibition organizer. Established originally in 1971, ABC has developed skills in market sectors - including semiconductor manufacturing, IT/storage networking and MEMS.

RFMD anticipates production revenue

RF Micro Devices, has announced the Company is engaged with two leading handset manufacturers and two leading baseband manufacturers in the development of fourth generation (4G) Long Term Evolution, or LTE, mobile broadband handsets. Specifically, RFMD is supplying the RF6276 and the RF3280, both of which are 4G LTE power amplifiers (PAs) designed to meet or exceed the data-centric performance requirements of the 4G LTE mobile broadband standard. RFMD anticipates production revenue related to 4G LTE PAs will begin in the second half of fiscal 2010, ending April 3, 2010.

"These expanding customer engagements with leading industry partners clearly demonstrate our commitment to advancing new technologies and accelerating the wide scale deployment of next-generation mobile broadband," said Eric Creviston, president of RFMD's Cellular Products Group (CPG). "RF Micro Devices has a proven history in technology leadership and the support of new air interface standards, including 2G, 2.5G and 3G. Now, with these customer engagements, we are pleased to support the early field deployment of next-generation 4G LTE handsets."

The RF6276 linear LTE power amplifier (PA) is tuned for operation in LTE bands 12 (698 to 716 MHz) and 13 (777 to 792 MHz) and delivers a blend of high-power efficiency and lower current consumption as output power levels decrease. The RF6276 features two digital power modes that adjust bias current and optimize the PA for the desired range of output power, while maintaining the stringent linearity requirements of LTE modulation.

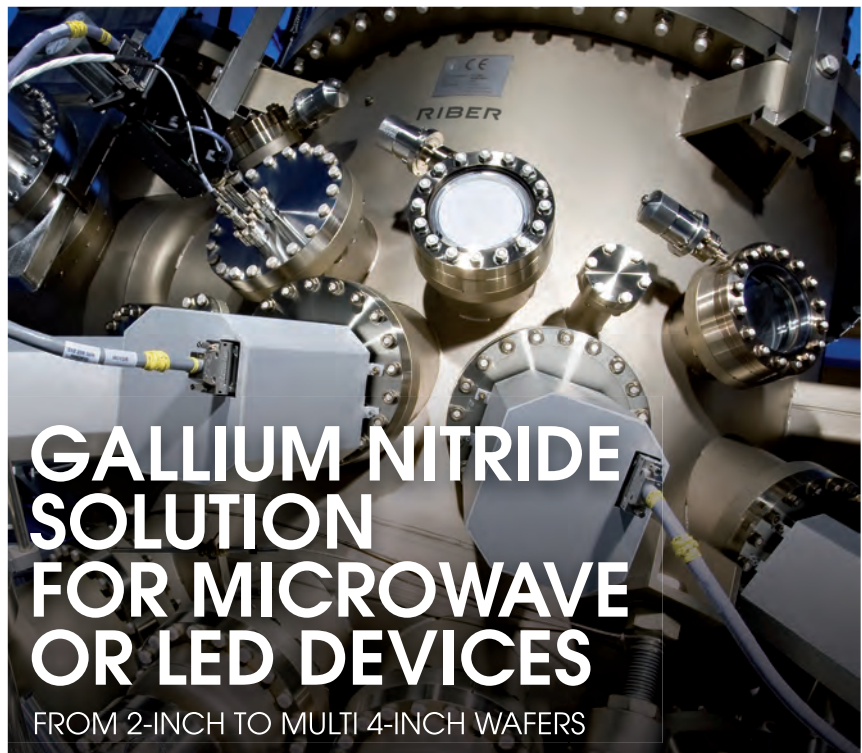
RFMD's RF3280 linear LTE PA is tuned for operation in LTE band 7 (2500 to 2570 MHz) and is optimized for use in linear multimode WCDMA/LTE mobile devices. The RF3280 leverages RFMD's proven quadrature PA technology, which improves end-product immunity to VSWR (otherwise known as "antenna mismatch") and eases end-product implementation.

The RF3280 is designed for RF front end architectures utilizing analog bias control in combination with a mated DC-DC converter. This architecture enables dynamic PA loadline adjustments which optimize

performance whether the handset is operating in WCDMA or LTE.

The combination of analog bias control and a DC-DC converter also optimizes efficiency, at all power levels, and minimizes

overall thermal impact. The RF3280 includes an integrated output power detector that supplies a voltage signal relative to the output power level of the PA, thereby reducing board area and simplifying implementation.



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Next generation materials

IMPORTANT developments by the ATOMICS team were made in modelling the activation or deactivation of dopants in silicon. Dopants are impurities added in small quantities to modify semiconductors' electrical conductivity. Semiconductors such as silicon or germanium are crystalline lattices in which each atom shares electrons with four neighbours.

Replacing some atoms with atoms of other elements, such as phosphorus or arsenic that have five bonding electrons, makes extra electrons available. Because of the additional negative charges, these are called n-type (for negative). Doping with acceptor atoms such as boron, which have only three electrons available, creates "holes" that are positively charged (p-type for positive). The performance of microprocessors depends on extremely precise methods of ion implantation for almost all doping in silicon integrated circuits. (Ion implantation is more precise, reliable and repeatable than the older thermal diffusion of deposited dopants used previously.) To dope a semiconductor wafer, a stream of ions is fired into the substrate so that the ions come to rest around a defined depth beneath the silicon surface.

"As long as ion implantation remains the standard technique for doping, especially in this context, you will need very high doping concentrations, requiring very high dose ion implantations," says Pichler. "However, ion implantation does a lot of damage to the crystal and a damaged crystal does not give you good performance in devices." Therefore "annealing" is used to repair

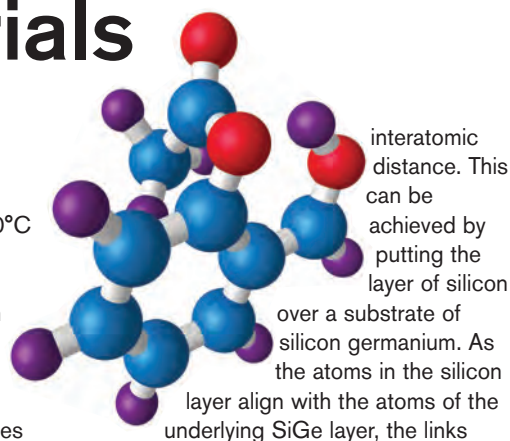
implantation-induced crystal damage through the application of very high temperatures. The earliest annealing procedures were at temperatures of 900°C and above for hundreds of minutes. Miniaturisation required a continuous reduction of the "thermal budget", which originally referred to the product of annealing time and temperature.

Annealing in today's production processes usually means a rapid increase to the peak temperature of around 1050°C followed by immediate cooling. New techniques such as "flash annealing" or non-melt laser annealing will reduce the annealing process from seconds to milliseconds.

The work undertaken by ATOMICS has also helped to define the research route to computer modelling of processes such as flash annealing, according to Pichler. For many years, silicon dioxide has been the material of choice in field-effect transistors because of its uniformity and high interface quality. But with the 32nm process, silicon dioxide and related materials, such as nitrided oxides, are reaching their limits and new materials need to be introduced. That adds complexity to the manufacturing process.

The ATOMICS team established quantitative models for new materials. Most important is probably "strained" silicon. But also silicon-germanium alloys and advanced point-defect engineering methods were investigated.

Silicon is strained when the silicon atoms are stretched beyond their normal



interatomic distance. This can be achieved by putting the layer of silicon over a substrate of silicon germanium. As the atoms in the silicon layer align with the atoms of the underlying SiGe layer, the links

between the silicon atoms become stretched – or strained. Moving the atoms apart reduces the atomic forces that interfere with the movement of electrons through the transistor. They can move 70% faster through a strained silicon transistor and switch 35% faster, resulting in better chip performance and lower energy consumption. The models created by the ATOMICS team have been validated by STMicroelectronics, a globally acting manufacturer of very advanced integrated circuits. And the lessons learnt in ATOMICS are already being applied by industry. The models have been integrated into 'Sentaurus Process', the industry-leading process simulation software from Synopsys. The ATOMICS project received funding from the ICT strand of the EU's Sixth Framework Programme for research. Media note: This feature can be republished without charge provided ICT Results is acknowledged as the source at the top or the bottom of the story. You must request permission before you use any of the photographs on the site. If you do republish, we would be grateful if you could link back to the ICT Results site <http://cordis.europa.eu/ictresults>

GaN design win

For the third consecutive year, an amplifier using the Cree, Inc. CGH40010 GaN HEMT transistor won the best power amplifier competition at the 2009 IEEE/MTT-S International Microwave Symposium. David Yu-Ting Wu, representing the University of Waterloo, received the award for best performance amplifier designed and demonstrated as judged on efficiency, power and frequency of operation. Wu's Inverse Class-F amplifier was designed using Cree's proprietary non-linear GaN HEMT model. The accuracy of

the model in precisely predicting the required impedance conditions for high-efficiency operation was instrumental in achieving first-pass design success. The winning 3.27 GHz amplifier produced 7.1 watts of RF output power at a power added efficiency (PAE) of 71%.

The second- and third-place student teams also used the CGH40010 in Inverse Class-F circuit architectures. They were, respectively, Paul Saad, Hossein Mashad Nemati and Mattias Thorsell from Chalmers

University of Technology, Sweden, and Junghwan Moon and Jungjoon Kim from Pohang University of Science and Technology (POSTECH), Korea.

"This is a hat trick, of sorts, for Cree," said Jim Milligan, Cree director of RF and Microwave products. "It's exciting for us to see the next generation of engineers creating innovative designs based on our industry-leading technology. Cree congratulates the students for their efforts and wishes them continued success."



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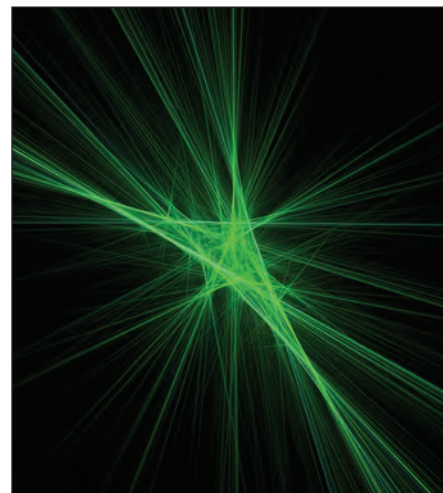
Breakthrough green laser

OSRAM Opto Semiconductors has overcome the previous limits of the InGaN material system. At the pre-development stage, the company succeeded in manufacturing the first direct emitting green laser diode from the InGaN (indium-gallium-nitride) material system with a high optical output. The diode emits a "true green", which is defined by the spectral range of 515 to 535 nm. In this range, efficient high-quality semiconductor lasers have been commercially available only as frequency-doubled versions. In the medium term, however, direct emitting green lasers could replace frequency-doubled lasers for numerous applications. They are easier to control, and also offer greater temperature stability, a smaller form factor and higher modulation capability at several 100 MHz.

Preliminary performance data are impressive. In pulsed mode at room temperature the laboratory prototype has achieved an optical output of 50 mW; the threshold current density is around 9 kA/cm². Dr. Christian Fricke, Chief

Technology Officer at OSRAM Opto Semiconductors, said: "With this demonstrator we have shown that green lasers can be manufactured from indium-gallium-nitride. We are therefore on course to produce compact, cost-effective, high-quality green laser light sources." Green lasers are used in numerous medical and industrial applications, but also as light sources in mobile mini-projectors. A direct emitting green laser can help make these projectors even smaller with even better performance. OSRAM Opto Semiconductors already offers blue emitting InGaN laser diodes for commercial applications.

German Ministry for Education and Research is sponsoring the MOLAS research project (until March 2011, FKZ 13N9373) which involves technologies for ultra-compact and mobile laser projection systems. The great advantage of laser projectors – a consistently sharp, true-color, high-contrast image irrespective of the projection distance and projection surface –



should one day be available also to users of cell phones and cameras. As part of this project, OSRAM is developing efficient laser light sources based on the InGaN material system (indium-gallium-nitride) for mobile projection systems. With the first direct emitting green laser the company has achieved an important early objective.

New Navy contract

Raytheon Company was awarded a \$7 million follow-on contract from the Office of Naval Research for work on the Compound Semiconductor Materials on Silicon (COSMOS) program. Funded by the Defense Advanced Research Projects Agency, this phase two contract will focus on improving the yield and integration density of compound semiconductor and silicon complementary metal oxide semiconductor (CMOS) transistors fabricated on the same silicon wafer.

"The COSMOS program focuses on integrating high-performance compound semiconductors, such as Indium phosphide or Gallium arsenide, with low-cost silicon transistors to achieve superior cost benefits and performance than what is available today," said Michael Del Checcolo, vice president of Engineering for Raytheon Integrated Defense Systems (IDS). "These technological advances allow us to provide more complex and highly sophisticated solutions for our warfighters."

During phase one, the Raytheon-led team demonstrated that high performance compound semiconductor devices (InP HBTs) can be directly grown and fabricated on silicon substrates and monolithically integrated with Silicon CMOS transistors on the same substrate. The team will use these findings in phase two to design and fabricate high speed, low power consumption digital-to-analog converters whose performance cannot be realized with today's existing semiconductor technology.

Using its OpenAIR business model for assembling talent and capabilities, Raytheon IDS is partnering with Raytheon Systems Limited, Glenrothes, Scotland; Soitec, Bernin, France; Teledyne Scientific Imaging Company, Thousand Oaks, Calif.; Massachusetts Institute of Technology, Cambridge, Mass.; Paradigm Research LLC, Windham, N.H.; IQE, Bethlehem, Penn.; and Silicon Valley Technology Center, San Jose, Calif.



Painting on a solar cell

Solar cells could soon be produced more cheaply using nanoparticle "inks" that allow them to be printed like newspaper or painted onto the sides of buildings or rooftops to absorb electricity-producing sunlight. Researchers apply the nanoparticle "inks" as a spray on the solar cells. Brian Korgel, a University of Texas at Austin chemical engineer, is hoping to cut costs to one-tenth of their current price by replacing the standard manufacturing process for solar cells—gas-phase deposition in a vacuum chamber, which requires high temperatures and is relatively expensive. "That's essentially what's needed to make solar-cell technology and photovoltaics widely adopted," Korgel said. "The sun provides a nearly unlimited energy resource, but existing solar energy harvesting technologies are prohibitively expensive and cannot compete with fossil fuels."

For the past two years, Korgel and his team have been working on this low-cost, nanomaterials solution to solar cell manufacturing. Korgel is collaborating with professors Al Bard and Paul Barbara, both of the Department of Chemistry and Biochemistry, and Professor Ananth Dodabalapur of the Electrical and Computer Engineering Department. They recently showed proof-of-concept in the *Journal of the American Chemical Society*. The inks could be printed on a roll-to-roll printing process on a plastic substrate or stainless steel. The prospect of being able to paint the "inks" onto a rooftop or building

is not far-fetched. "You'd have to paint the light-absorbing material and a few other layers as well," Korgel said. "This is one step in the direction towards paintable solar cells."

Korgel uses the light-absorbing nanomaterials, which are 10,000 times thinner than a strand of hair, because their microscopic size allows for new physical properties that can help enable higher-efficiency devices. In 2002, he co-founded a company called Innovalight, based in California, which is producing inks using silicon as the basis. This time, Korgel and team are using copper indium gallium selenide (CIGS) which is both cheaper and benign in terms of environmental impact. "CIGS has some potential advantages over silicon," Korgel said. "It's a direct band gap semiconductor- you need much less material to make a solar cell, and that's one of the biggest potential advantages."

His team has developed solar-cell prototypes with efficiencies at one percent; however, they need to be about 10 percent. "If we get to 10 percent, then there's real potential for commercialization," Korgel said. He also said that the inks, which are semi-transparent, could help realize the prospect of having windows that double as solar cells. Korgel said his work has attracted the interest of industrial partners. Funding for the research comes from the National Science Foundation, the Welch Foundation and the Air Force Research Laboratory.

Strengthening partnership

As part of its development strategy for solar energy, Saint-Gobain is acquiring Shell's share of Avancis, a joint venture between the two companies. Avancis has developed highly competitive technology for thin-film CIS (Copper, Indium and Selenide) to manufacture photovoltaic modules. With an annual capacity of 20 megawatts, the company's first plant is already operating in Torgau, Germany. This extremely promising technology necessitates expertise in glass coating and in glass thermal treatment, two processes belonging to the core portfolio of Saint-Gobain, a worldwide leader in flat glass for the building and automotive industries. Saint-Gobain intends to accelerate the industrial development of

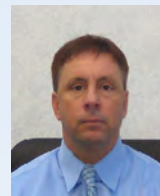
Avancis. Saint-Gobain provides a vast range of products and services in solar energy via Saint-Gobain Solar, its new entity which groups all of Saint-Gobain's solar businesses. Present across the whole value chain, Saint-Gobain Solar's strategy hinges on three independent activities. The making and selling of high-tech components for PV modules (special glass, performance plastics, etc.) and high-performance mirrors for solar thermal plant operators. The production by its Avancis company of thin-film PV modules using CIS (Copper, Indium, Selenide) technology, for distributors and integrators. The design and marketing of PV solutions for homes, offices, industrial installations and farm buildings.

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Tiny rays of hope

The University of California has reported a new milestone in laser physics by creating the world's smallest semiconductor laser, capable of generating visible light in a space smaller than a single protein molecule. This breakthrough, described in an advanced online publication of the journal *Nature* breaks new ground in the field of optics. The UC Berkeley team successfully squeezed light into such a tight space and found a novel way to keep that light energy from dissipating as it moved along, thereby achieving laser action. "This work shatters traditional notions of laser limits, and makes a major advance toward applications in the biomedical, communications and computing fields," said Xiang Zhang, director at UC Berkeley of a National Science Foundation (NSF) Nanoscale Science and Engineering Center.

The achievement helps enable the development of such innovations as nanolasers that can probe, manipulate and characterize DNA molecules; optics-based telecommunications many times faster than current technology; and optical computing in which light replaces electronic circuitry with a corresponding leap in speed and processing power. While it is traditionally accepted that an electromagnetic wave - including laser light - cannot be focused beyond the size of half its wavelength, research teams around the world have found a way to compress light down to dozens of nanometers by binding it to the electrons that oscillate collectively at the surface of metals. This interaction between light and oscillating electrons is known as surface plasmons.

Scientists have been racing to construct surface plasmon lasers that can sustain and utilize these tiny optical excitations. However, the resistance inherent in metals causes these surface plasmons to dissipate almost immediately after being generated, posing a critical challenge to achieving the buildup of the electromagnetic field necessary for lasing.

Zhang, a professor of mechanical engineering, and his team took a novel approach to stem the loss of light energy by pairing a cadmium sulfide nanowire - 1,000 times thinner than a human hair - with a silver surface separated by an insulating gap of only 5 nanometers, the size of a single protein molecule. In this structure, the gap

region stores light within an area 20 times smaller than its wavelength. Because light energy is largely stored in this tiny non-metallic gap, loss is significantly diminished.

With the loss finally under control through this unique "hybrid" design, the researchers could then work on amplifying the light. "When you are working at such small scales, you do not have much space to play around with," said Rupert Oulton, the research associate in who first theorized this approach and the study's co-lead author. "In our design, the nanowire acts as both a confinement mechanism and an amplifier. It's pulling double duty." The UC Berkeley researchers used semiconductor materials and fabrication technologies that are commonly employed in modern electronics manufacturing. By engineering hybrid surface plasmons in the tiny gap between semiconductors and metals, they were able to sustain the strongly confined light long enough that its oscillations stabilized into the coherent state that is a key characteristic of a laser.

"What is particularly exciting about the plasmonic lasers is that they are solid state and fully compatible with semiconductor manufacturing, so they can be electrically pumped and fully integrated at chip-scale,"



said Volker Sorger, a Ph.D. student and study co-lead author. "Plasmon lasers represent an exciting class of coherent light sources capable of extremely small confinement," said Zhang. "This work can bridge the worlds of electronics and optics at truly molecular length scales."

Scientists hope to shrink light down to the size of an electron's wavelength, which is about a nanometer, or one-billionth of a meter, so that the two can work together on equal footing. In addition to the three co-lead authors, other co-authors of the paper are Renmin Ma and Lun Dai from Peking University, and Christopher Gladden and Guy Bartal from Zhang's research group.

This work is supported by the U.S. Air Force Office of Scientific Research and the NSF.

Dicing greater yield

Veeco Instruments has announced the introduction of its Optium ADS-800TM Series Advanced Dicing System, delivering dicing solutions for a broad range of applications, including high brightness light emitting diodes (HB-LEDs), solar cells, optics, and microelectronics.

Robert P. Oates, Executive Vice President, commented, "Our new ADS-800 Series Advanced Dicing System incorporates over 30 years of dicing expertise, offering high throughput and precise cutting of premium devices, critical for emerging markets such as LED and solar.

We are able to reduce manufacturers' dicing saw capital costs by over 40% due to our tool's highly rigid cast iron structure, high performance air bearing spindle and



multi-blade cutting technology." The Optium ADS-800 Series has been designed for R&D environments, pilot line production and high volume production.

New solar power world record

UNSW solar cell researchers have played the key role in achieving the highest efficiency for solar power, setting a new world record of 43 per cent of sunlight converted into electricity.

The UNSW team, led by Scientia Professor Martin Green, Research Director of the UNSW ARC Photovoltaics Centre of Excellence, combined with two US groups to demonstrate a multi-cell combination which has set the new benchmark for converting sunlight into electricity by any possible approach.

“Because sunlight is made up of many colours of different energy, ranging from the high energy ultraviolet to the low energy infrared, a combination of solar cells of different materials can convert sunlight more efficiently than any single cell,” Professor Green said. Professor Green, with colleague Dr Anita Ho-Baillie, led the team that developed a silicon cell optimised to capture light at the red and near-infrared end of the spectrum.

That cell was able to convert up to 46 per cent of light into electricity. When combined



with four other cells, each optimised for different parts of the solar spectrum, the five-cell combination converted 43 per cent of the sunlight into electricity, bettering the previous world record by 0.3 per cent.

“Our group’s silicon cell was the key contributor to the new result,” Professor Green said. Professor Stuart Wenham, Director of the ARC Centre, said the new record was not directly comparable to the 25 per cent efficiency world record for

an individual solar cell set by UNSW last year. However it was an important pointer for the future potential of solar photovoltaic power.

“This latest record involves an expensive combination of cells and the sunlight was focused to produce a much higher intensity than standard sunlight for these measurements. It does show, however, what eventually may be practical,” Professor Wenham said.

Material changes gets the Jazz

Jazz Semiconductor, Inc., a Tower Group Company, has announced it is targeted at replacing GaAs components in high growth markets such as millimeter wave and front-end components of cellular phones with its enhanced SiGe BiCMOS process, IP and design enablement offerings. SiGe provides significant integration and cost advantage over GaAs, enabling products in the emerging markets of automotive collision avoidance, phased-array radar, and HDTV wireless distribution as well as established markets such as optical network and cellular phone front-end components.

Jazz is working with more than half of the top 10 IC providers in several of these market segments on SiGe solutions. According to data from Strategy Analytics, the combined millimeter wave and FEM market is estimated to grow from \$400 million in 2009 to over \$750 million in 2012, a CAGR of over 23%, outpacing most other

sectors in the semiconductor industry.

The company’s process technology includes a SiGe transistor with demonstrated performance of up to 200GHz as well as noise and power performance that is competitive with GaAs while offering as much as 40% lower die cost. Also included are CMOS options to enable mixed-signal and digital functions on the same chip further reducing cost of the complete system.

To facilitate the transition from GaAs to SiGe-based designs, Jazz partnered with Agilent to provide a SiGe design kit in ADS (Advanced Design System), a leading design platform for GaAs-based products, speeding time-to-market for customers targeting applications up to and beyond 60 to 77GHz.

An example of a successful transition from GaAs to SiGe is the recently announced

collaboration between Jazz and UCSD to develop a 2-antenna quad-beam 11-15 GHz phased array receiver that enables high-performance phased arrays for satellite communications by integrating many functions on the same silicon chip and replacing 8 GaAs ICs, drastically lowering the cost of phased array assembly. First time success was achieved using Jazz’s 0.18-micron SiGe BiCMOS process and its own proprietary models, kit and DIRECT MPW (Multi-project Wafer) program. “We continue to see migration of GaAs products into SiGe as an exciting growth opportunity for our technology.

This transition is largely complete in optical front-end components but just beginning in cellular phone front-ends and millimeter-wave applications,” said Dr. Marco Racanelli, Senior Vice President and GM of RF/HPA and Aerospace and Defense Business Groups. “We will continue to invest in high performance processes as well as design enablement infrastructure to speed time-to-market for our customers in these emerging applications.”

Strong position for next growth

IQE plc has announced its Interim Results for the half year ended 30 June 2009. The company saw sales of £21.4m (H1 2008: £30.2m) with a gross profit of £3.8m (H1 2008: £4.3m) with a net debt of £18.9m, that was better than expectations.

The company saw a sharp increase in orders from May 2009 as destocking began to reach its conclusion. There has been a continued strength in smartphone and advanced wireless shipments (e.g. notebooks) despite global recession. This combined with management actions in Q4 2008 to restructure the business and reduce costs have underpinned a solid H1 performance.

The company has also actively sought opportunities during the downturn that has enabled them to capture market share, attract new talent, and drive operational efficiencies. IQE sees further evidence of the trend towards outsourcing as their customers seek to control capital and operating expenditure.

IQE is reporting that trading has already returned to pre-recession levels in Q3 2009, positioning the Group for a strong

second half performance. There has also been significant progress in high-growth emerging markets of solar and solid state lighting. IQE's industry-leading CPV solar cell products gaining market share, contributing to H2 sales.

Dr Drew Nelson, IQE Chief Executive, commenting on the results said: "IQE is in a strong position, having taken decisive action to cut costs and restructure for growth.

Our core smartphone market has recovered quickly and is now growing rapidly as phones become more connected and multi-functional, demanding ever more of our products. Furthermore, we have significant opportunities ahead of us in the emerging solar cell and solid state lighting markets.

"Even at the lowest point of the destocking cycle, IQE remained EBITDA positive, demonstrating the effectiveness of our restructuring and the resilience of our business. Now that trading has recovered, our high level of operational gearing should produce a strong second half with substantial free cash flow generation."

IQE will continue to focus on fast growing, large volume technologies and in particular high-speed wireless communications and advanced optoelectronics.

The Group continues to develop advanced solar cell technology, high-efficiency solid-state light sources, advanced lasers and ultra-high-speed microprocessor and memory-chip materials technologies for these large-volume emerging markets.

Increasing material use

Neo Material Technologies has announced the closing of the acquisition of 100 % of all issued and outstanding shares of Recapture Metals Limited ("Recapture"). Neo has issued 4.5 million new common shares and paid CDN\$6.5 million in cash to Recapture shareholders.

Of the total consideration, 2.25 million of the new common shares and CDN\$3.0 million will be held in escrow and released by an escrow agent in accordance with the terms of an escrow agreement in place, and subject to certain post closing adjustments.

Neo will also make additional payments in cash or new common shares, at Neo's option, conditional upon certain agreed upon EBITDA targets for three calendar years, commencing in 2010, being met or exceeded.

"The expansion of Neo's product line with Recapture's complementary rare elements gives Neo a footprint into new growing and exciting applications. Recapture also diversifies Neo's production base beyond the Asia Pacific region," said Constantine Karayannopoulos, President and CEO. "We welcome Larry Seeley and his team at Recapture to Neo and look forward to growing the business with them."



Recapture produces, reclaims, refines and markets high value niche metals and their compounds which are primarily used in the wireless, LED, flat panel, solar and catalyst industries.

Recapture's current commercial product lines include gallium and indium and it is in the process of commercializing a rhenium recycling operation.

With operations in Canada, the United States and Germany, Recapture has approximately 65 employees. Recapture will become part of the Company's Performance Materials Division (formerly the AMR Performance Materials Division).

Compounding solar efficiency

Sunovia Energy Technologies Inc, a provider of products within the LED lighting and solar markets, has reported the completion of the design and construction of a closed space sublimation (CSS) system for fabrication of polycrystalline cadmium telluride (CdTe) solar cell devices. The work was completed in collaboration with Sunovia's partner EPIR Technologies Inc.

The two companies are developing an ultra high-efficiency, low cost CdTe on silicon photovoltaic product that is based on single-crystal CdTe instead of the polycrystalline material used in CdTe panels on the market today.

20 years and counting for the GaN LED

A commercially viable GaN LED was an incredibly hard nut to crack that required the development of a buffer layer and a novel approach to p-type doping. But 20 years ago it all came together.

Richard Stevenson looks back at the device's birth.

If the readership of Compound Semiconductor were asked to name the inventor of the GaN LED, the most common reply would probably be Shuji Nakamura, the former Nichia researcher who is now an academic at the University of California, Santa Barbara. But this is not the correct answer. The first GaN LED was actually made in 1971 by a team at the laboratories of the Radio Corporation of America (RCA), which included Herb Maruska, Jacques Pankove and Ed Miller.

This device employed a metal-insulator-semiconductor structure, and its incredibly low efficiencies prevented it from ever being a commercial success. The far more important breakthrough is, without doubt, the first LED with a p-n junction, because this is the architecture employed in all of today's blue, green and white-emitting devices. This LED emanated from the Isamu Akasaki's group at Nagoka University, Japan. Nakamura's contribution was to quickly build on this work by optimizing the design, which led to a hike in device efficiencies and enabled Nichia to launch its first commercial LEDs in 1993.

One of the striking things about Akasaki's achievement is that it came when he had just turned 60, a time in most researchers' lives when they have lost their drive for striving for success. But his breakthrough was the culmination of many years of nitride development that stretched back to the early 1970s, when he worked as a research scientist at Matsushita Research Institute Tokyo.

Nitrides were a relatively hot topic back then, thanks to several recent breakthroughs. These included the fabrication of the first single crystals of GaN on sapphire substrates in the late 1960s, which were produced by HVPE. Stimulated emission from optically-pumped GaN

followed a few years later, along with the previously mentioned success at the RCA labs.

But progress was short-lived and by the mid-1970s many researchers were turning their backs on GaN and looking to other materials that might produce more fruitful results. The main problems with GaN were its low crystal quality, and very high residual donor concentrations that made it impossible to realize p-type conduction. Controlling the levels of n-type conduction was not easy, either.

These issues did not deter Akasaki, and throughout the early 1970s he focused on the research and development of a GaN LED while working at Matsushita. And some success came in 1975, when he produced single-crystal GaN by MBE. Material quality was not great, but the advance was still large enough to merit a three-year research grant by Japan's Ministry of International Trade

Blue, green and white LEDs are widely used in the keypads and backlights of mobile phones. Falling average selling prices, coupled to modest rises in the number of handset sales each year, have caused the value of this market to plateau. However, it is still the biggest market for GaN LEDs



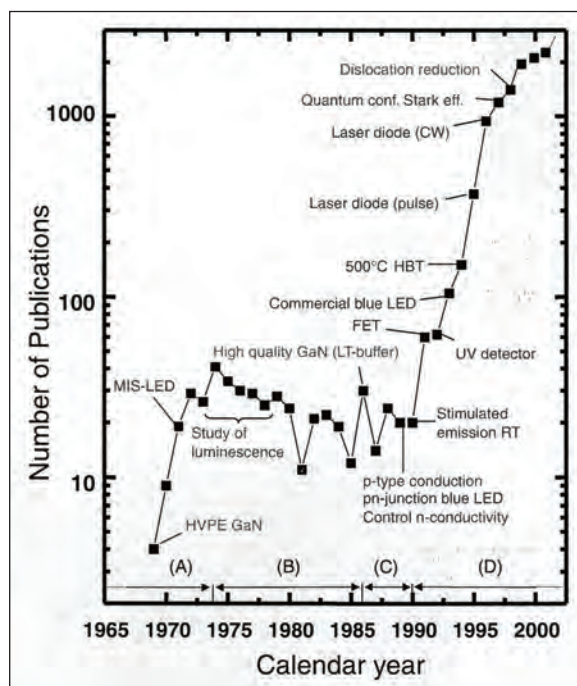
Credit: Nokia



Isamu Akasaki, the inventor of the GaN LED with a p-n junction, is a professor at Nagoya University, Japan. He has been awarded many prizes for his efforts, including: The Japanese Association for Crystal Growth (JACG) Award (1989); an Outstanding Achievement Award by The Japan Society of Applied Physics (2002); and the TMS John Bardeen Award (2006). This year he will receive a \$500,000 prize from Inamori Foundation for Lifetime Achievement in Advanced Technology.

and Industry. This funding for the development of a blue LED based on GaN led to the fabrication of an MIS LED with a world record external efficiency of 0.12 percent in 1978. But these devices were never a commercial success, due to low yields that stemmed from wide variations in the thickness of the intrinsic layer and poor surface uniformity.

Again, Akasaki was not put off by the slow rate of progress, and focused on the positive aspects of the research. Fluorescence microscopy revealed the presence of high-quality microcrystals in tiny parts of the larger crystals, which contained cracks and pits. More encouraging still, even the cluster of needle like crystals, which Akasaki has described as "GaN fungus", produced very efficient light emission.



The publishing activity in the nitride community over the last few decades can be divided into 4 periods. During period A the number of publications increased dramatically, due to intensified research on blue LEDs. Difficulties associated with crystal quality then plagued the field for many years, and period B witnessed a decline in nitride activity. The invention of the GaN LED with a p-n junction sparked renewed interest in this material (period C), and publication are now at an all time high, thanks to research into a wide range of electronic and optoelectronic devices (period D).

These observations led Akasaki to believe that a GaN LED with a p-n junction had great potential for efficient light emission. He thought that it would be possible to produce p-type GaN if epilayers could be grown that exhibited the same crystal quality as the microcrystals. To realize this dream he went back to basics, and focused on crystal growth. In 1979 he made what he has referred to as a "crucial decision" – he switched his growth process from MBE to MOCVD.

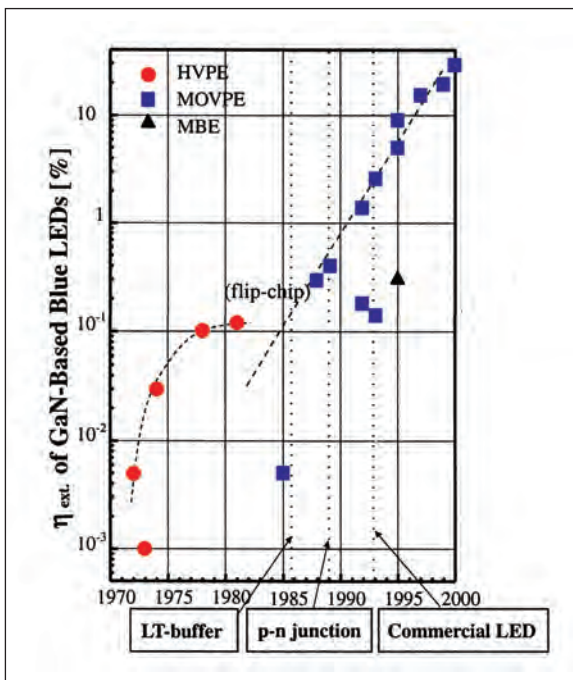
His reason for this switch was a belief that MOCVD was a superior growth technology for depositing nitrides on mismatched substrates, thanks in part to minimal reverse reactions. Typical growth rates were ideal for nitride growth, and adjustments to alloy compositions and dopant concentrations could be made by simply varying the flow rates of the gas sources.

In comparison, HVPE was rejected because film growth by this technique suffered from reversible reactions, and the deposition rates were too fast for films with a thickness of just a few nanometers. MBE, in comparison, had the downsides of producing epilayers with nitrogen deficiencies, and operated at low growth rates.

After Akasaki had selected his growth method, he needed to choose a substrate. He selected sapphire, due to its high stability under the growth conditions for GaN - temperatures above 1000°C and an NH₃ atmosphere. Sapphire also has a crystal symmetry that is similar to that of GaN. Commercial MOCVD reactors were unavailable in the late 1970s, so Akasaki instructed two of his graduate students, Yasuo Koide and Hiroshi Amano, to build the growth tool. By 1981 they were up and running. However, the initial results were disappointing. Crystal quality was poor, due to large thermal and lattice mismatches between GaN and sapphire.

To combat this, the team developed a novel low-temperature buffer layer technology. This involved low-temperature growth of an incredibly thin layer of a material with physical properties similar to both GaN and sapphire that led to a high-quality interface, thanks to elimination of interfacial free energy. Candidates for the buffer included AlN, GaN, ZnO, and SiC, and the first of these was selected, due to Akasaki's familiarity with this material. Success did not follow overnight, but by 1985 this team had grown the world's first high-quality single crystals of GaN.

The characteristics of these films were incredibly encouraging. Near band edge emission dominated the photoluminescence, and the residual electron



The first LEDs were a metal insulator semiconductor design with very low efficiencies. A p-n junction increases the efficiency

concentration was of the order of 10^{17} cm^{-3} , an improvement of more than two orders of magnitude over previous films. Dislocation density had fallen from more than 10^{11} cm^{-2} to $10^8 - 10^9 \text{ cm}^{-2}$, and electron mobility rocketed from $20 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$ to $700 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$. All of these improvements were down to the role played by the low-temperature buffer, which provided a high density of nucleation centers with the same orientation as the substrate, and promoted lateral growth of the subsequent epilayers.

P-type doping in GaN was the next challenge. This problem had already attracted the interest of many research groups that were unable to crack it, but Akasaki's team had the significant advantage of starting with a material containing a far lower residual electron concentration. However, they were unable to realize p-type GaN using a zinc dopant.

An important advance came in 1987, when they discovered that the intensity of zinc-related luminescence

increased substantially after this GaN sample, which has been grown with low-temperature buffer technology, was irradiated with electron beams during cathodoluminescence studies. Although these crystals did not show p-type conduction, they paved the way to success. Akasaki's team switched to developing magnesium-doping in 1988 and the following year they produced high-quality, doped samples with two types of magnesium-based precursors. Irradiating these samples with an electron beam produced low resistivity p-type GaN, and the world's first GaN LED with a p-n junction followed immediately after.

The efficiency of this device, which emitted in the blue/ultra-violet region, was only 0.1 percent. But this shot up to 1.5 percent by 1992, due to improvements in crystal growth quality. The following year Nichia released a commercial device with 2.7 percent efficiency, and the industry has never looked back since then. Revenues have grown to billions of dollars a year, and penetrated a diverse range of markets that include mobile phone displays and backlights, automobile headlamps, torches, streetlights and TV backlights.

Efficiencies continue to rise, and the next goal is general lighting. This market is being targeted with state-of-the-art LEDs that feature sophisticated light extraction technologies, multiple-quantum-well active regions and advanced thermal management packages. However, these devices still tend to share two pieces of DNA with the first GaN LED with a p-n junction – a sapphire substrate; and a low-temperature buffer layer. The advances of Akasaki and his team did not just lead to the making of the first commercially viable LED - they created technologies that have been used to this day for LED manufacture.

Samsung has recently launched a range of LCD TVs with LED backlights. Penetration of LED-backlight technology in LCD-TV panels is predicted to increase to 39 percent in 2013, up from 3 percent in 2009, according to market analyst iSuppli



Credit: Samsung

Further reading

I. Akasaki J. Crystal Growth 300 2 (2007)



SiC looks to shine in the sunlight

Predictions of long-term growth in the photovoltaics market are not just good news for triple-junction solar cell makers. SiC diode and transistor manufacturers are also set to benefit, because these chips can drive up the efficiencies of converters that transform the DC output from cells into the AC form needed for the grid. **Richard Stevenson reports.**

When power electronics manufacturers launched their SiC Schottky barrier diodes onto the market at the beginning of this decade they had one application in mind – switch mode power supplies (SMPS). The existing supplies that converted AC mains into DC outputs for driving computer hardware employed silicon diodes, and higher efficiencies could be realized by switching to SiC equivalents.

These gains in efficiency stem from the very low switching losses associated with SiC. The reverse recovery charges and stored charges are incredibly small, and the forward current and the frequency of the switching speed has very little impact on switching behavior. In short, SiC diodes possess an ideal set of characteristics.

Sales of SiC diodes to builders of SMPS continue to grow. However, SiC power electronic device manufacturers are not complacent – they are looking to new markets to generate additional revenue growth. One opportunity is in the hybrid electric vehicle, which currently employs silicon chips to convert the DC output from the battery into an AC form that is suitable for driving the car. SiC electronics can operate at higher temperatures, eliminating the need for an independent, space-consuming cooling system for the electronics that takes up valuable space. Freeing-up space is a benefit that is highly valued by carmakers, but qualification times of eighteen months to two years mean that it will a while time before SiC can make an impact on the automobile sector.

Where SiC diodes are already making inroads is in solar inverters,

which convert the DC output from solar panels into an AC form that is suitable for connection to the grid. These inverters operate at powers ranging from one kilowatt up to 500 kW, a span that reflects the variations in solar installations, which go from a handful of panels on the roof of a house to massive arrays on a solar farm covering many hectares.

Like SMPS, the first solar inverters employed silicon devices, and again a switch to SiC products could increase efficiency. Although SiC devices are more expensive than their silicon rivals, Brice Le Gouic, a market and technology analyst at Yole Développement that specializes in power electronics, believes that producers of inverters are willing to pay the additional cost. “The return on investment is the first word that people are talking about,” says Le Gouic, and higher costs are acceptable, so long as they are outweighed by increased efficiency. Improving a solar inverter’s efficiency by just 1 percent in a 30 kW system can yield an additional 3000 kWh over ten years, equating to a cost saving of hundreds of dollars.

Le Gouic says that the SiC market for solar is still in its infancy but will grow to tens of millions dollars over the next decade. However, sales to SMPS builders will continue to dominate this SiC market and increase at a compound annual growth rate of 60 percent between 2010 and 2015. But the rocketing growth of shipments of SiC products to solar manufacturers will gnaw away at this sector, with sales to SMPS makers declining from 88 percent of the market in 2010 to 55 percent in 2015.

Emerging markets, such as solar inverters and HEVs, also offer new product opportunities for SiC. “SMPS manufacturers are mainly interested in SiC diodes,” says Le Gouic “but all the other markets will be driven by the inverter application

and have two SiC devices in each of the systems – transistors and diodes.” Single-phase inverters employ four transistors and four diodes, while three-phase variants use six transistors and six diodes.

Inverters take the DC input from solar cells, possibly boost it, and then chop it at very high frequencies, before the signal is filtered to produce a rectified sine wave. The higher the frequency, the cleaner the output. However, higher frequencies mean higher switching losses, primarily through higher switching losses in the power transistors, which are far lower for SiC devices than their silicon equivalents.

Another major benefit of switching to SiC transistors is that it can lead to a reduction in the inverter’s bill of materials. Today’s silicon inverters typically operate at 16-18 kHz and include large inductors and capacitors. Replacing the silicon power electronics with SiC chips allows a transition to even higher operating frequencies, without sacrificing efficiency, and also cuts the costs of the inverter thanks to smaller inductors and capacitors that can be used at these higher frequencies.

Infineon unveiled its third generation of SiC Schottky barrier diodes this February. The portfolio includes 600 V diodes operating at 3A, 4A, 5A, 6A, 8A, 9A, 10A and 12A



CREDIT: Infineon

Left: Infineon manufacturers its third generation SiC Schottky barrier diodes at its fab in Villach, Austria. CREDIT: Infineon

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**Jazz Semiconductor to
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SiC looks to shine
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SiC transistors can also operate at higher temperatures, cutting the cooling requirements for the power electronics in the inverter.

Opportunities for savings are greatest in the high-power, water-cooled inverters used in solar farms, and far smaller in the air-cooled versions used for small roof-top installations.

A handful of SiC device makers have been developing various forms of SiC transistor over the last few years, and these products are winning the attraction of solar inverter manufacturers. For example, ISET (Institut für Solare Energieversorgungstechnik, Kassel, Germany), has built a unit with a SiC MOSFET that has an efficiency of 99.08 percent, according to Le Gouic.

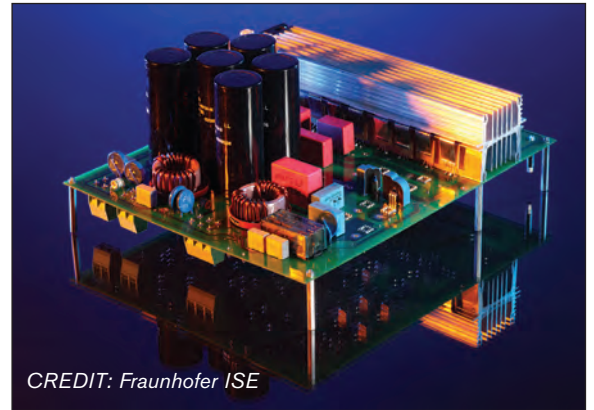
Developers of SiC transistors include Infineon Technologies, which is working on a JFET that will complement its well-established range of SiC diodes. Interest in these established products continues to grow, thanks to the emergence of voluntary energy efficiency standards for power supplies, according to Jan-Willem Reynaerts, who combines the role of Business Segment Manager for high-voltage metal-oxide semiconductors with worldwide responsibility for SiC Schottky

diodes. "On top of that, the solar industry is also extremely interested in SiC, whether it is high voltage diodes or switches." He is also seeing interest in SiC diodes for HEV, and in lighting applications.

Infineon launched the world's first SiC diode to market in 2001, and it came out with a second-generation product in 2005. "The biggest change from generation one to generation two was the added surge explains to current capability, explains Reynaerts." This addressed the thermal runaway issue that plagued the initial product - a cycle of rising temperatures leading to an increase in resistance, a higher forward voltage, and greater power dissipation that drove up the device's temperature once more.

Early this year, Infineon launched a third generation of SiC diodes to address three issues: the customer's desire for a less expensive product; better switching performance at higher frequencies; and improved efficiency when the inverter operates at a relatively light load, such as 20 percent of its maximum. "The third generation is an answer to all those points," says Reynaerts.

Development focused on improvements to device performance at high current densities. This held the key to cutting chip sizes, which

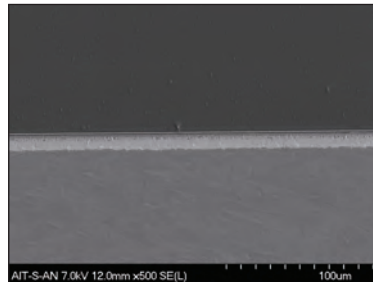
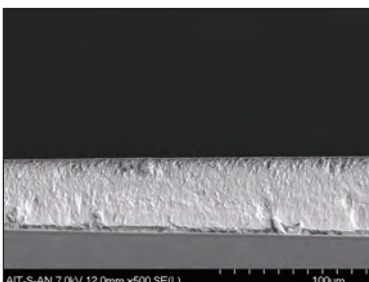


CREDIT: Fraunhofer ISE

would reduce capacitance and improve high-frequency performance, while simultaneously lowering production costs. "What we did was find a way to get the heat out of the package," explains Reynaerts. Engineers developed a "diffusion soldering" process that almost eliminates the solder layer between the chip and the lead frame, and produces a very good thermal connection for cooling.

The new approach gives third generation diodes about a 20 percent cost advantage over second-generation equivalents, if products are ordered in similar volumes. "We are not talking small beer," says Reynaerts. "This is really important for our customers. We are the leading supplier in power semiconductors, and it is for us to lead in developing the SiC market."

This summer Fraunhofer ISE raised the efficiency of its solar inverter to 99.03 percent. The key behind its success was incorporation of SiC JFETs made by SemiSouth Laboratories



Infineon's third generation of SiC Schottky barrier diodes have better thermal characteristics than their second generation equivalents. Improvement was driven by a switch from a solder-based join between the chip and the package (left) to a diffusion solder attach (right).

CREDIT: Infineon

These SiC products are still much more expensive than their silicon equivalents, but the gap is closing fast, partly due to the reduction in the cost of 4 inch substrates at higher volumes. "There used to be a time when SiC diodes were nearly an order of magnitude more expensive, but this is coming down to roughly a factor of three, product for product," says Reynaerts. Closing this gap is encouraging the SMPS and inverter manufacturers to think seriously about SiC. "This message is starting to sink in that at the system cost

“JFET behaves in many ways like a MOSFET would, with some differences in the drive. It has a very familiar feel to circuit designers” Jeffrey Casady, SemiSouth Laboratories

level, in a lot of applications where energy efficiency is important, the added cost of SiC over silicon is more than paid back.”

Infineon faces competition from a handful of other SiC diode manufacturers, including SemiSouth Laboratories, which released its product to the market in 2008. Jeffrey Casady, the company’s chief technical officer and vice-president of business development, says that its diode is similar to Infineon’s. However, the company’s primary focus is on the promotion of its JFET. “We made the first normally-off JFET in the summer of 2007, we started ramping in 2008, and now in 2009 we have got reliability and qualification data that looks really good,” says Casady.

SemiSouth’s normally-off JFETs have recently been deployed in inverters for photovoltaic systems that were built by Fraunhofer Institute for Solar Energy Systems in Freiberg, Germany. A conversion efficiency of 99.03 percent was announced this July, with the German team stating that the SiC JFETs were the key behind their latest efficiency improvements. More recently, they have shown that a SiC-based inverter operating at 48 kHz with SiC products can outperform a silicon-based equivalent running at 16 kHz.

This means that it is possible for SiC-based inverters to not only deliver higher efficiencies than their silicon-based rivals, but also realize this while using smaller, lower-cost inductors and capacitors.



When SemiSouth began its SiC transistor development, it could have decided to invest in a MOSFET, JFET, or a bipolar device. “Every device has its pros and cons,” says Casady, but SemiSouth selected the JFET because of its ruggedness, low cost, and avoidance of an oxide that can lead to reliability issues. “It behaves in many ways like a MOSFET would, with some differences in the drive. It has a very familiar feel to circuit designers.”

Casady says that the JFET is now in low-volume production – SemiSouth produces hundreds of these wafers every month. Production is currently performed on 3-inch material, but the company plans to convert to 4-inch in the next year or two, when the higher volumes justify this move.

By then the current blip in the solar market will be in the the past, and Semisouth, along with other SiC transistor and diode makers, will be battling it out for substantial contracts with the builders of solar inverters.

The cells that generate electricity are made of triple-junction III-V devices grown on germanium substrates, and if DC-to-AC inverters are going to operate at their highest efficiencies, then they need to employ SiC diodes and transistors. CREDIT: SolFocus

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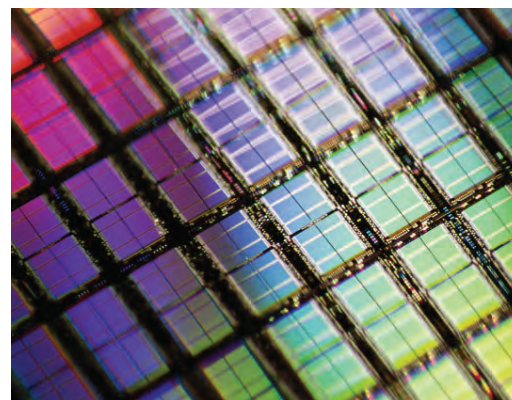


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Chair's Message

On behalf of the organizing committee and the IEEE Electron Devices Society, the Microwave Theory and Techniques Society, and the Solid State Circuits Society, I invite you to be a part of the 2009 IEEE Compound Semiconductor IC Symposium (CSICS).

This year's symposium will be held October 11th – October 14th in Greensboro, NC.

CSICS has been going strong for 31 years. This year we chose to locate in what has become a hub of Compound Semiconductor research and manufacturing. I don't think that anyone at the 1979 meeting of the GaAs IC Symposium (the first) would have imagined that the largest manufacturer of GaAs in the year 2000 would be in the cellular (or in late 70's parlance... "portable") telephone business. Yet by 1990 it was clear that this was one of the most promising applications of this fledgling technology.

Through the years, the GaAs IC Symposium grew in size and breadth as GaAs integrated circuits spread into defense and commercial products. Corporate and academic programs

in GaAs research led to exciting advances in materials growth, device physics, higher integration levels and commercial applications. As GaAs technology matured, other III-V materials systems came into the mix. In 2004 in Monterey, CA, the Symposium changed its name to IEEE Compound Semiconductor IC Symposium (CSICS) to reflect the evolution of the III-V industry and the interests of its participants.

The CSIC Symposium is the preeminent international forum on developments in integrated circuits using compound semiconductors such as GaAs, InP, GaN, SiGe and other materials. Coverage embraces all aspects of the technology, from materials issues and device fabrication, through IC design and testing, high volume manufacturing, and system applications.

Several social events are planned that allow our attendees to interact in a relaxed setting. Events include the Sunday Evening Opening Reception, the Monday evening Technology Exhibition Opening Reception, the Tuesday

Technology Exhibition Luncheon, and the Tuesday Theme Party. This year's Theme Party has a distinct Southern flavor that I'm sure you will enjoy. We also offer daily breakfast and AM/PM coffee breaks Monday through Wednesday.

The IEEE CSICS is also offering a short course entitled "PA Design Fundamentals, Advanced Techniques and Technologies" on Sunda Oct. 11th, 2009. This course offers the student detailed instruction on circuit design techniques for various technologies as well as design examples by leaders in the compound semiconductor industry. In addition, we offer our "Primer Course" which is an excellent tutorial presented within the context of our Symposium technical program.

The Primer Course is offered on Sunday Oct. 11th, 2009.

We hope you will join us again this year as we're goin' to Carolina!

Marko Sokolich, Chair

Questions or Concerns

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Tightly wrapped

Tube heaters are applied any time where liquid or gaseous media are being delivered through tubes. These tube heaters do have a critical impact on process results when used with thermal sensitive media or processes and contribute to the extension of maintenance cycles in the facility. Pump and gas line heaters, were developed especially for those kinds of applications. **By Matthias Müller of Watlow.**

The well tempered process heating and tempering of media plays an important role in modern process engineering as many processes only proceed within a specific temperature range. Since raw material is generally delivered to the process chamber through tubing systems and reaction products are removed through tubing systems as well, it is necessary to hold delivery and exhaust lines at a certain temperature.

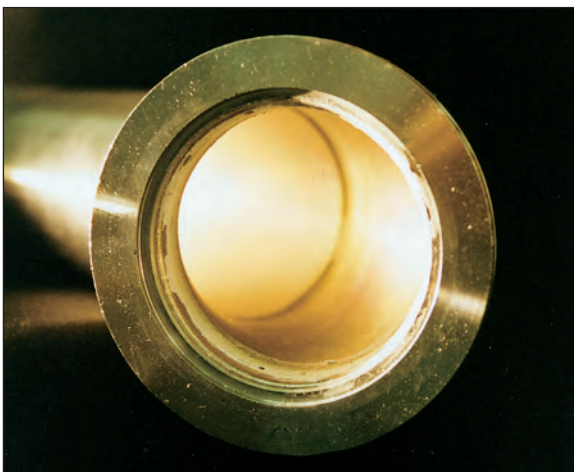
The smaller the temperature window in which the processes take place, the more important becomes the right tempering of the tubing. Precise temperature control along

the tubing is, in such cases essential for good process results. The following example emphasizes the importance of tube heating for thermally critical processes:

The pictures below show exhaust lines of an aluminium etching tool as it is used in semiconductor fabrication. On the left picture a tube with insufficient heating of the tubing is shown, whereas the right picture shows a fully heated tube. In this process, formation of aluminium chloride, which precipitates along the walls of the tubing, is critical. These precipitations lead to a successive reduction of the cross section of the tube and are sources for particles

which negatively affect the results of the process which is run under clean room conditions. Moreover, these precipitations cause unscheduled maintenance cycles which generate significant cost due to equipment downtime. Use of conventional heated cable may not prevent precipitation because a full coverage of the tube and thus uniform tempering cannot be achieved.

Therefore, for this kind of application a heating system was developed which ensures a full coverage of the tubing and also uniform tempering. The heating elements are applicable at temperatures up to 200°C and are available for different nominal



Left: Fig. 1: Illustrates the reduction in tube cross section due to aluminum chloride build up in an insufficiently heated tube

Far left: Fig. 2: Fully heated tube shows no build up of precipitate

In most tubing systems, additional components like pumps, valves or other equipment are integrated which create particular challenges for uniform tempering. These components create the biggest heat losses, and their geometry is in most cases considerably unsymmetrical which makes efficient heating extremely difficult

voltages. Core of this so called Pump / Gas Line heating system is a heater jacket made from fibreglass enforced silicone material with backside insulation and snap fasteners or velcro for easy assembly and disassembly. With this design, time-consuming wrapping of heat trace around the tubing and subsequent insulation becomes redundant. Moreover, each heating jacket is equipped with plugs that ensure easy connection between the individual heating jackets and to the control unit. For temperature measurement, thermocouples or RTDs can be attached to the heating elements.

The system is completed by a control unit, equipped with a PID

temperature controller and semiconductor power switch. Optionally, the control units can be connected to a PC. This allows configuration and data logging with a HMI software package. Pump/ Gas Line heaters are available in different diameters, lengths and geometries as a standard. Also elbows, flanges and T-sections can be covered and heated with standard jackets. By choosing suitable heater jackets, a full covered heating of the complete tubing will be achieved.

In most tubing systems, additional components like pumps, valves or other equipment are integrated which create particular challenges for uniform tempering. These

components create the biggest heat losses, and their geometry is in most cases considerably unsymmetrical which makes efficient heating extremely difficult. Sufficient heating of these particular components however, is of great importance, because condensation and precipitation take preferentially place in these areas. This is due to the significantly different thermal properties of these components compared to common tube sections. In these cases simple wrapping with heat trace does not lead to the desired results, so that a specific adjustment of the heating element to the component becomes necessary. Such an adjustment is not only limited to the geometry of the heater jacket, but also must consider heat losses in these locations. This requires an adaption of power and power density of the heater jacket to the specific thermal conditions.

Especially at valves, much higher heat losses occur compared to common tube sections which make a higher power input per surface unit necessary. In some cases it is required to equip the heating jacket with an additional temperature sensor and to operate it in a separate control loop. This becomes particularly necessary when the thermal properties of the valve are significantly different than the rest of the tubing system. It ensures desired temperatures and prevention of condensation even in tubing systems with sections of highly different thermal properties.

Another feature of these heating systems is the accurate distribution of heating power. This can be achieved on one hand by adapting watt density to the specific requirement, on the other hand by temperature control of the heaters. This, together with the insulation of the heating jacket, leads to energy savings because only the amount of actually required power is brought into the thermal system.





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Tel 303-735-5336
kristi.anseth@colorado.edu

Li-Chyong Chen
National Taiwan University
Tel 886-2-33665249
chenlc@ntu.edu.tw

Peter Gumbsch
University of Karlsruhe (TH)
Tel 49-72-1608-4363
peter.gumbsch@izbs.uni-karlsruhe.de
--and--
Fraunhofer-Institut fuer Werkstoffmechanik IWM
Tel 49-761-5142-100
peter.gumbsch@iwf.fraunhofer.de

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The Ohio State University
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GENERAL INTEREST

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Moore and more: the increasing importance of materials

Throughout the history of mankind, materials have been a defining factor in terms of tools and technologies. From the Stone Age, through the Bronze and Iron ages, materials have played a key role in human advancement. **IQE's Richard Hammond and Rob Harper** take a look at the way modern day materials continue to define technological progress.

Had there been an electronics technology roadmap at the start of the 1940s, it may well have foreseen the coming of the "silicon age" with the evolution from the thermionic valve to the semiconductor transistor.

Such a roadmap may even have forecast the transition from Bardeen, Brattain and Shockley's first germanium based transistor to the thousands of integrated silicon based transistors from which the earliest microprocessor chips were formed. It was in 1965 that Gordon Moore of Intel observed that the complexity of integrated circuits increased exponentially over time, roughly "doubling" every two years.

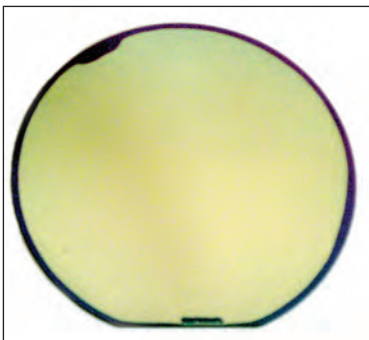
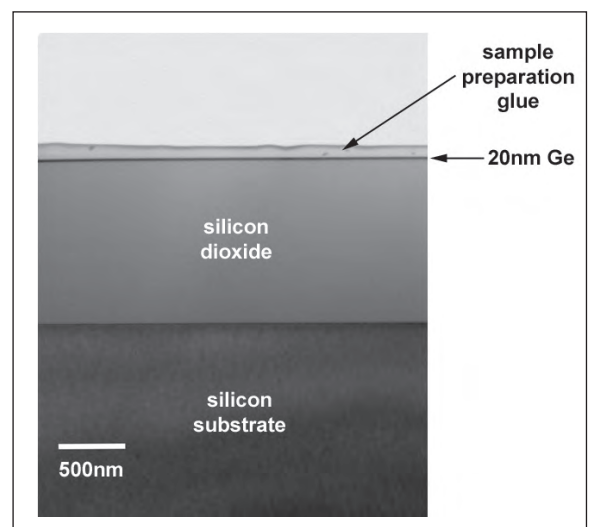


Image of a 150mm diameter Germanium-on-Insulator (GeOI) wafer, with a Ge film thickness of 20nm

"Moore's Law" has continued to hold true for the last four decades, during which time the Semiconductor Industry Association (SIA) has established a formal industry roadmap to predict and forecast technology trends aimed at ensuring continued development in the field of semiconductors. This roadmap is known as the International Technology Roadmap for Semiconductors (ITRS).

For most of the interceding years since the ITRS was established, the focus of attention has been on device scaling, with ever decreasing feature dimensions being the key to achieving greater levels of integration and improved transistor performance.

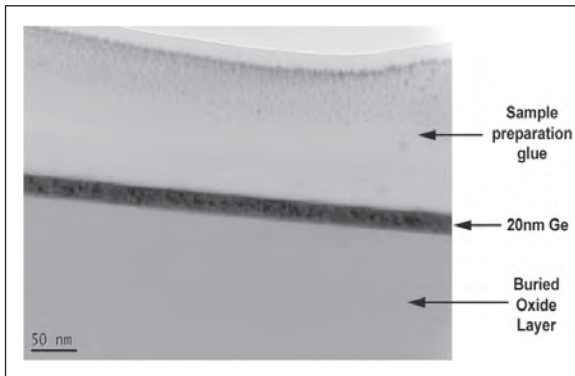
In recent years, it has become apparent that physical limitations and spiraling fab costs means that continued reductions in feature size cannot continue indefinitely. The ITRS fully recognizes the limitations of continued scalability and recent roadmap updates clearly indicate that the way forward for future technological evolution is expected to be based on the development of novel materials based technologies which are compatible with the pre-existing manufacturing infrastructure. The increasing demand for radio frequency (RF) wireless connectivity,



high processing speeds and portability with its associated requirement for low power consumption, has already led to the widespread adoption of materials based solutions in the form of gallium arsenide (GaAs) devices. Similarly, the adoption of materials manipulation techniques such as high-k dielectrics, strained silicon and silicon on insulator signal a trend towards the industry entering a new materials era.

In addition to high speed and low power consumption, next generation applications are likely to demand integration of photonic and CMOS functionality within a single chip, a

Low magnification cross sectional electron microscopy (XTEM) image of the GeOI substrate, depicting a 20nm Ge film transferred to an insulating silicon dioxide layer



High magnification electron microscopy (XTEM) image of a 20nm GeOI substrate

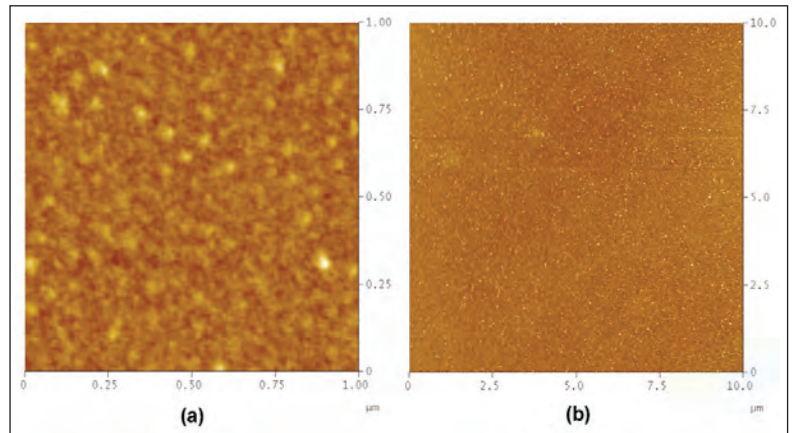
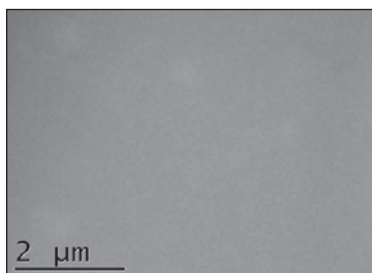
challenge that can only be addressed from a materials perspective. Although silicon has long been established as the de-facto standard semiconductor material, germanium, the material from which the first transistor was made, offers substantially higher electron and hole mobility and consequently can achieve far higher operating speeds, for a given device dimension.

Traditionally, silicon has become the material of choice because of its relative abundance and lower cost as well as its mechanical strength and its excellent native oxide SiO₂ that forms an ideal insulating interface with silicon.

Germanium by contrast is a brittle material with poor native oxide properties and, being a less common commodity is comparatively expensive. However, the recent introduction of deposited high-k gate dielectrics to replace the traditional silicon dioxide, now affords the superior electronic properties of Germanium a new lease of life within mainstream CMOS manufacturing.

Beyond the 22nm device node, the ITRS roadmap has predicted the development of 'new materials to replace silicon as a alternate device

Plan view electron micrograph (PV-TEM) of the GeOI substrate. No defects are observable within the measurement detection limits (< 10⁶cm⁻²)



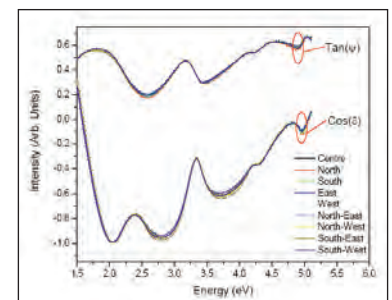
Atomic force micrographs of the GeOI surface. (a) depicts a 1x1μm scan and (b) depicts the corresponding 10x10μm scan. The root mean square (RMS) surface roughness values are 0.55nm and 0.5nm respectively.

channel to increase the saturation velocity and maximize drain currents in MOSFETs, while minimizing leakage currents and power dissipation for technologies scaled to 16nm and beyond'

In order to address such stringent requirements, engineers at IQE's manufacturing plant in Cardiff, UK have developed a new range of engineered substrates including germanium on insulator (GeOI). Engineered GeOI substrates are produced using a unique layer transfer process from a 'proprietary lattice matched substrate' to produce a material with extremely low defectivity levels and excellent across wafer thickness uniformity. The GeOI substrate is manufactured using conventional epitaxial growth techniques, which eliminates the use of bulk Germanium wafers, and offers a cost effective solution to future CMOS requirements. Removal of co-transferred material is achieved using highly selective etch methods resulting in smooth Germanium layers with excellent across wafer thickness uniformity and extremely high crystal quality. Typical Germanium layer thicknesses are of the order 10-100nm, with an across wafer thickness uniformity of ~3% and a surface roughness of 0.5nm. The thickness of both the final Ge device layer, and the buried oxide layer, can be tailored to suit the specific application.

The hybrid approach provides a virtual germanium substrate on top of a silicon substrate which means that the enhanced mobility performance that can be achieved in partially or fully depleted germanium devices can be produced using established, "CMOS safe" production processes and can employ the same range of dopants used in standard silicon processes. The engineered substrates therefore allow device designers to look beyond the performance constraints imposed by existing silicon technologies to push the boundaries of future CMOS devices for generations to come.

Additionally, the inherent photonic properties of GeOI also provides a potential platform for advanced, multi-junction photovoltaic devices for high efficiency solar cells.



Nine point spectroscopic ellipsometry (SE) map of the GeOI substrate, indicating a Ge thickness uniformity of 2.8%

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13th International Conference on Silicon Carbide and Related Materials (ICSRM)
October 11 to October 16
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The aim of the conference is to present and discuss recent progress in crystal growth, characterization and control of material properties, as well as other basic research issues concerning silicon carbide (SiC) and other wide-band gap semiconductors involving III-nitrides and diamond. The scope should cover but is not limited to theoretical and experimental investigations.

PHOTONEX 2009
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PHOTONEX is the UK's premier photonics event and takes place at Stoneleigh Park, Coventry. It is the most important opportunity in 2009 to learn of innovations and latest technology developments in photonics and optical technologies for science and industry. Attending Photonex 09 is vital if you wish to 'get down to business', meet all the UK's major suppliers and network with colleagues.

Light Emitting Diodes 2009
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SSL design Summit
November 3 to November 4, 2009
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The Summit will consist of two full days,

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December 2009**SSL Design Summit**
December 1 to December 2
Los Angeles California, USA

The Summit will consist of two full days, including networking breaks and lunches, along with a "hands-on" evening Summit Showcase, in which attendees can see first hand some of the current technologies, luminaries and application solutions that will have been discussed during the day. Poor quality design and manufacturing is a substantial problem facing the SSL decision makers, and the SSL Design Summit is here to provide quality answers.

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Development of single-step and high-resolution ICP dry etching for a wide range of InP-based materials

Mode-locked lasers (MLLs) are effective sources of periodic trains of coherent optical pulses and are fundamental components in a range of optical communications and spectroscopy applications. Especially, integrated semiconductor lasers have advantages over other forms of laser since their waveguide structure concentrates the optical intensity into the active medium, and the short cavity lengths typically lead to repetition rates in the range 40 GHz to 2 THz. **By Rafal Dylewicz, Lianping Hou, Gábor Mezősi and Catrina Bryce, Optoelectronics Research Group, Department of Electronics & Electrical Engineering, University of Glasgow.**

The Optoelectronics Research Group in the Department of Electronics and Electrical Engineering at the University of Glasgow, UK has been engaged in research to develop techniques that integrate the three desirable properties of semiconductor lasers in a single mode-locked laser diode: high output power, high repetition rate and ultrashort pulses. All these aims of the project may be achieved with the implementation of properly designed photonic-band gap mirrors (intra-cavity reflectors) into laser gain sections [1] and/or periodic structures into ridge waveguide lasers [2, 3] in order to compress the pulses. Both intra- and extra-cavity structures in 1.55- μm emitting MLLs based upon InGaAs/InGaAsP/InP and InGaAs/AlGaInAs/InP quantum well systems are of the special interest. Appropriately designed and fabricated air-slots and grating structures will provide controlled degrees of reflectivity, optical dispersion and compression of the laser pulse. The key to fabricate these fine-pitch patterns is the development of precise and reliable dry etching process to provide highly

anisotropic transfer of both micron- and nanometer-scale features with minimized scattering loss. Furthermore, to ensure strong overlap between waveguided mode and periodic structure deep fabrication process is required to etch the structures sufficiently below laser active region, preferably into lower cladding layer.

Therefore high-resolution, deep (> 3.0 μm) dry etching is a fundamental demand for the fabrication of submicron-sized gratings, photonic crystals and low-loss ridge waveguides in InP-based materials. For the purposes of the project, optimization of the dry etching process was carried out in an STS Multiplex ICP etch tool [4, 5], courtesy of the Institute of Photonics (IoP), Glasgow, UK. All experiments were performed on three different types of wafer: bare p-type InP substrates, MOCVD grown InP/InGaAsP passive waveguides and a commercial AlGaInAs-based 1550 nm laser diode (LD) wafer, supplied by the IQE company. An optimized ICP dry etching process based on a $\text{Cl}_2/\text{Ar}/\text{N}_2$ gas mixture

was used in the experiment, with hydrogen silsesquioxane (HSQ) as the electron-beam lithography (EBL) resist/etch-mask. The highly anisotropic process resulted in near-vertical sidewalls on deeply etched structures, as presented in Fig. 1. Properly balanced process conditions were set to produce a strong passivation effect on the sidewalls while still maintaining a useful InP etch rate (560-730 nm/min).

The low roughness of the etched sidewalls and surfaces was further confirmed using both optical waveguide propagation with Fabry-Pérot resonances (fringe contrast) and the roundtrip attenuation method. The scattering loss was measured for ridge waveguides with widths varying from 10 μm down to 3 μm and for different etch depths (between 1.5 μm and 3.2 μm). In all these cases, for both TE and TM polarized optical signals at $\lambda = 1.55$ μm , low waveguide propagation loss was observed, estimated to be less than < 0.3 dB/mm. For the process conditions given, transfer of small-feature-size patterns was

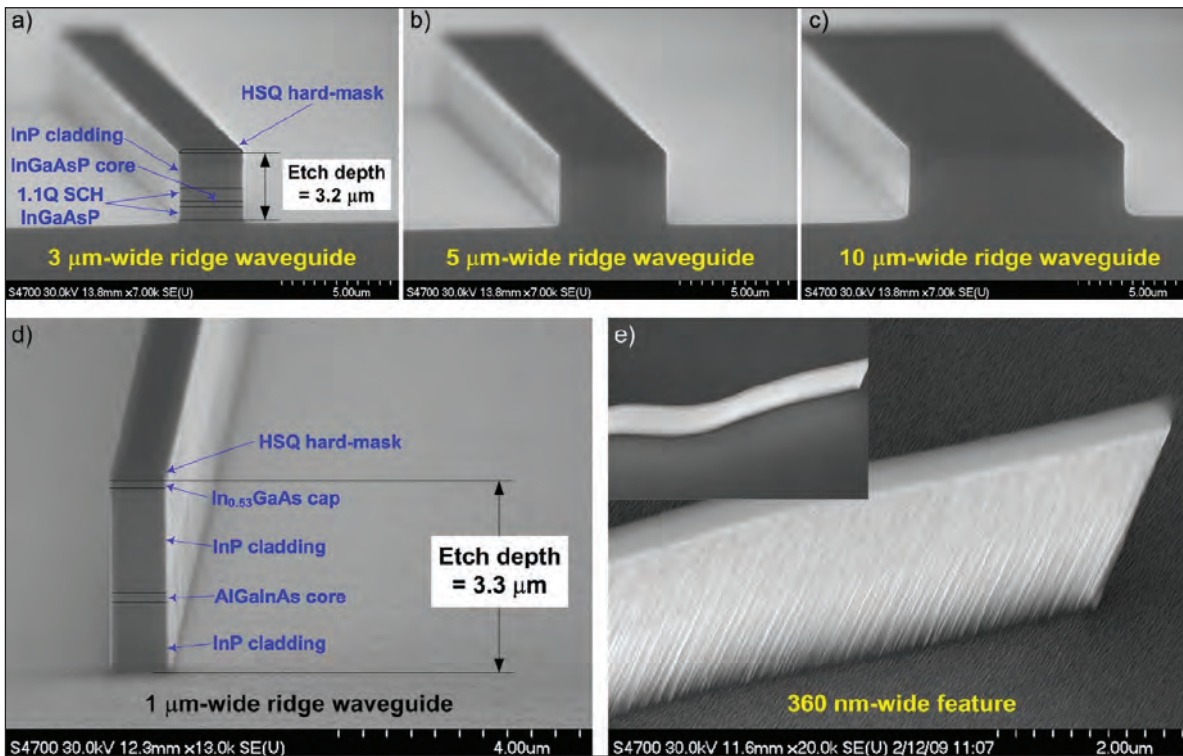


Figure 1: Highly vertical sidewalls obtained for an optimized ICP dry etching: a), b), c) SEM cross-sections of 3 μm -, 5 μm - and 10 μm -wide ridge waveguides fabricated in InP/InGaAsP wafer; d) deeply etched 1 μm -wide optical waveguide in InP/AlGaInAs material; e) 45° side-view on the 3.2 μm -deep sub-nanosized feature with the evidence of different layer compositions in InGaAsP-based wafer

accomplished at a very high aspect ratio, as shown in Fig. 2. A deeply etched first-order grating with a period of 236 nm was fabricated in a 3 mm-wide InP/InGaAsP ridge waveguide (Fig. 2a). The grating is etched directly into the sidewall of the ridge since, with this geometry, it is relatively easy to control the grating strength/ reflectivity. Fabrication of such distributed Bragg reflectors (DBR) is less critical than

for surface gratings etched deeply into the central part of the laser ridge. Fig 2b presents an angled-view SEM micrograph of deeply etched 86 nm-wide features in InP/InGaAsP, where aspect ratios as high as 30 have been obtained.

An additional outcome of the balanced process was equal-rate etching of all the materials investigated. Smooth transitions

between the layers in InP/InGaAsP/InGaAs/AlGaInAs structure with different compositions for constant etching conditions are shown both in Fig. 1 and Fig. 2.

High-aspect ratio ICP dry etching is a crucial technological step to properly fabricate intra-cavity reflectors in Al-quaternary based material [1]. Before the fabrication of photonic band-gap mirrors the

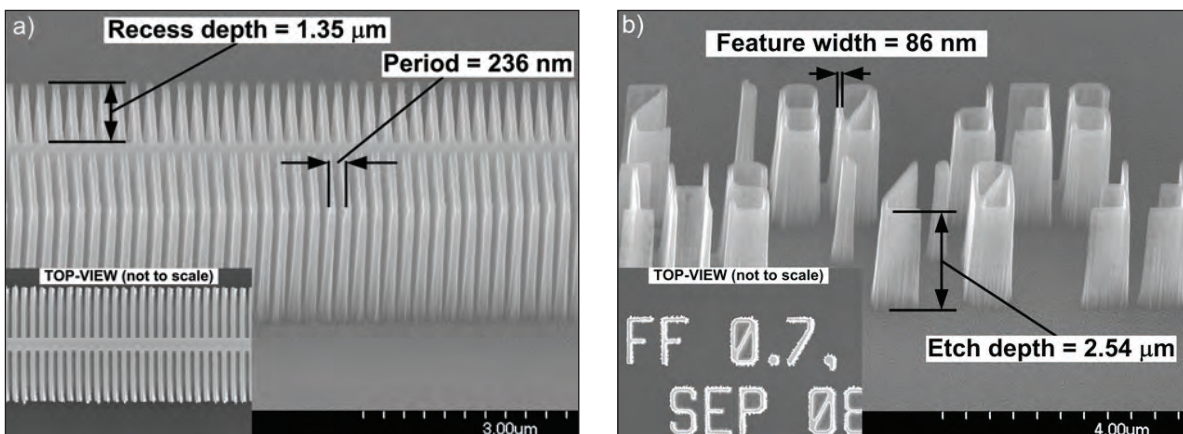


Figure 2: Results of ICP dry etching of InP/InGaAsP-based nano-sized features: a) deeply etched (3.2 μm) and highly recessed first-order sidewall grating fabricated in a ridge waveguide; b) SEM micrograph of high aspect ratio (~ 30) etching of InP/InGaAsP material

theoretical response of device in terms of reflection (R), transmission (T) and loss (L) was calculated using two-dimensional (2-D) simulations. Cross-section approach was employed with CAvity Modelling Framework (CAMFR) simulation tool. Numerical results for 363 nm-wide air-slot for a fundamental TE₀ optical mode at the constant wavelength of $\lambda = 1.55 \mu\text{m}$ are presented in Fig. 3. The single air-slot efficiency is highly dependent on total structure depth, as presented in Fig. 3c. For non-optimum etch depth conditions (1.96 μm -deep air-slot) both low reflectivity R of ~17% and high feature loss L (~78%) are observed.

The reason for such a behaviour is that a vast amount of power carried by TE₀ optical mode, propagating from the left to the right where the mirror is located, is coupled into the substrate. The substrate coupling loss effect is indicated by a logarithmic plot of electric field distribution within the structure. In contrary, high reflectivity and low loss case may be observed for a deeper 2.95- μm -deep mirror, which provides reflectivity of R ~ 67% and negligible structure loss (~7%). Therefore, fabrication process for the experimental purposes involves deep anisotropic etching of 363-nm-wide features with use of optimized Cl₂/Ar/N₂ inductively coupled plasma etching. An optimized dry etching

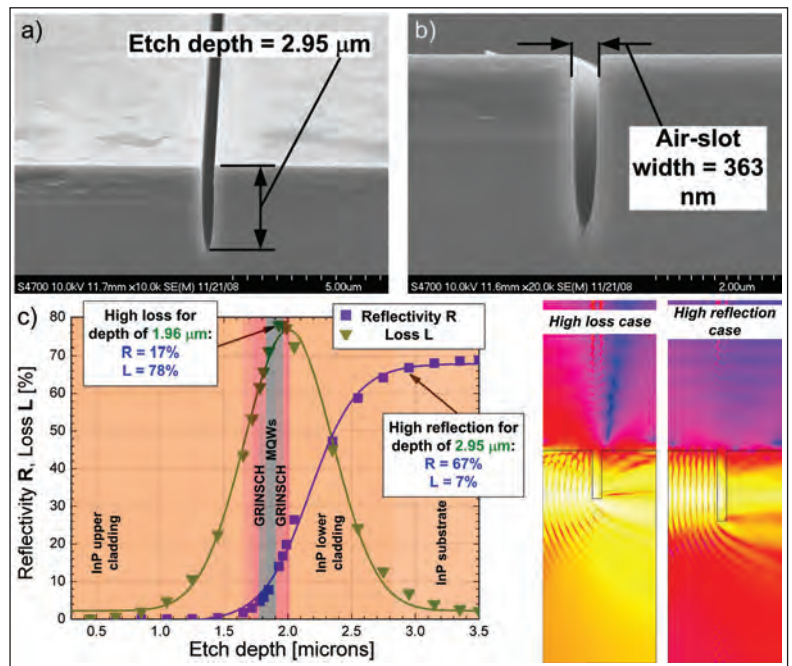


Fig. 3. Air-slot reflectors fabricated with Cl₂/Ar/N₂ ICP dry etching and the computed device behavior: a), b) SEM micrographs of deeply etched, highly vertical features; c) 2-D simulation results (reflection and loss) in the function of total etch depth, where two distinct cases are presented on the right (log plot of electric field distribution for TE₀ optical mode within the structure).

with minimal damage has been demonstrated for a wide range of InP-based materials. Highly anisotropic process produces transfer of both micron- and nanometer-scale features in a single etch step. Intermediate etching stages (i.e. PMMA pattern transfer to underlying SiO₂/Si₃N₄ layer) could be

avoided due to the usage of HSQ as both electron-beam lithography resist and dry etching hard-mask. The high-aspect ratio ICP dry etching technique will be used for the fabrication of intra-cavity reflectors and DBR grating structures used in InP-based mode-locked (M-L) lasers.

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Corporate Partnership

T: + 44 (0) 1923 690 200
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GaN: better with defects?

It is taken for granted that lowering the defect density in GaN-based light emitters improves their performance. But photoluminescence studies on GaN powders suggests that defects might actually be a good thing, says **Birgit Schwenzer from the University of California, Santa Barbara.**

There is no doubt that GaN-based light emitting devices are a great success. Blue, green and white LEDs made with this material now backlight the keypads and screens of billions of mobile phones, and provide light sources in bill-board displays, torches and traffic lights. Meanwhile, GaN ultra-violet lasers are powering Blu-ray players and some of the latest games consoles.

However, if sales of these devices are to continue to grow, then their manufacturers will have to target new

markets. These include car headlamps, projectors, and the most lucrative sector of them all, general illumination. But success in these markets will only come if the cost-per-lumen of the devices falls substantially.

Researchers throughout the world are embarking on this quest by increasing the efficiency of GaN devices, particularly at the high drive currents needed to generate the required lighting levels demanded by the emerging applications. Many believe that brighter devices can be realized by reducing the defect density in these structures. Although nitrides are incredibly resilient to high defect densities - which would kill luminescence in other compound semiconductor light emitters - several theoretical and experimental studies are claiming that defect-free nitrides would be far more efficient.

I decided to take a different path to cutting the cost-per-lumen of nitride devices, which focused on reducing expenditure on the growth tools used for manufacture. However, through these efforts at developing a lower cost synthesis method, I have turned one of the core pieces of perceived wisdom about GaN on its head - I've discovered that increasing the defect density in this material can actually enhance its photoluminescence intensity in the case of GaN nanoparticles.

Back in 2002 - under the guidance of Umesh Mishra and Steven DenBaars at the University of California, Santa Barbara (UCSB) - I started looking at methods to grow nitride materials that could offer a more affordable alternative to the widely used MOCVD approach that employs multi-wafer reactors with million dollar price tags. My work focused on a growth method known as ammonolysis, which is also described as ammonothermal synthesis. This process aimed to create highly crystalline, chemically pure material by heating a gallium containing starting material in an ammonia atmosphere. Wet-chemical approaches to GaN synthesis were avoided, because they can lead to the addition of impurities such as carbon, oxygen or hydrogen, which diminish the intensity of the band edge photoluminescence in GaN. These impurities

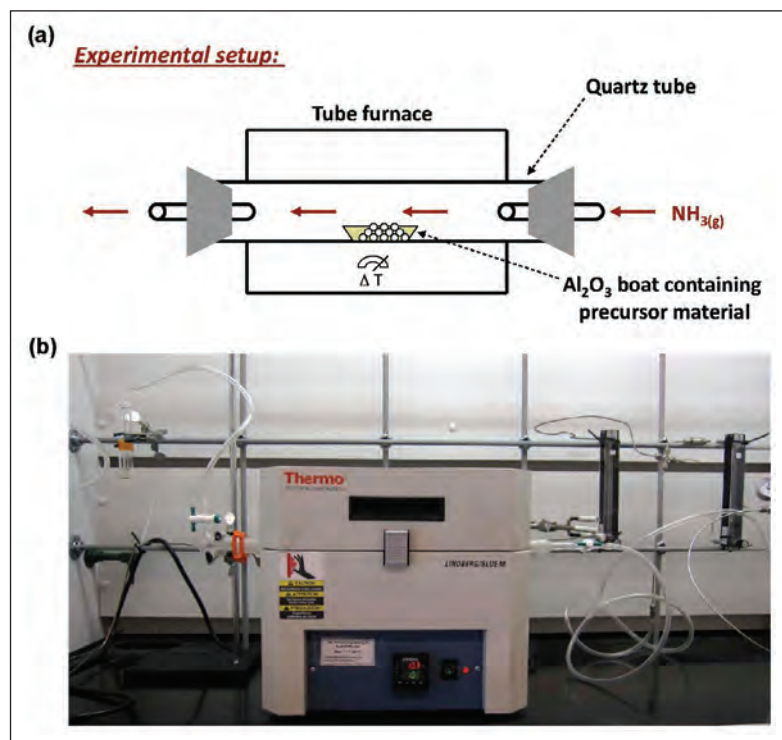


Figure 1. Ammonolysis is a relatively simple technique for producing group III-nitrides in a tube furnace. GaN powders were prepared at UCSB by heating either metallic gallium or gallium oxide-based precursors under ammonia at temperatures of 900-1100°C

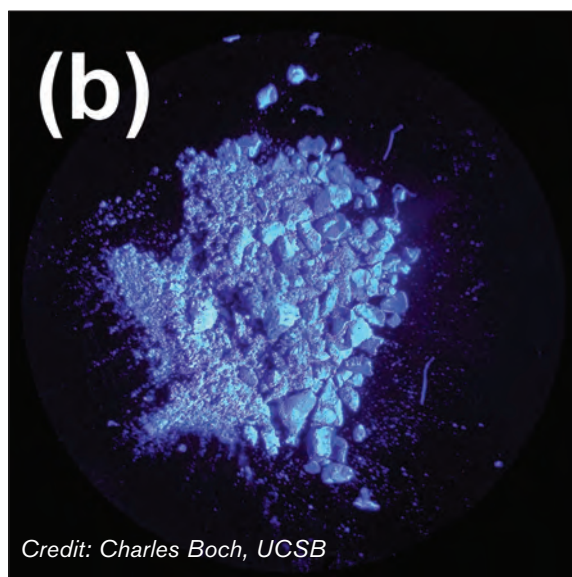
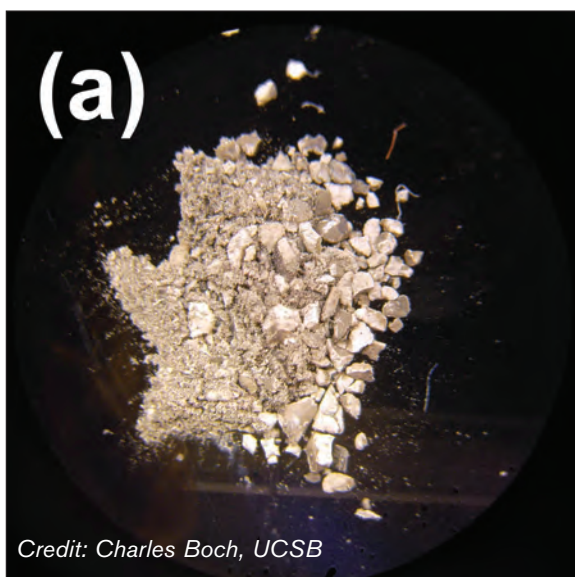


Figure 2. This GaN powder was grown at a temperature above 1100°C. Its grey color stems from the decomposition of this material into metallic gallium and nitrogen gas (a). However, under excitation from a ultraviolet lamp, this sample is still capable of intense PL (b)

would therefore hamper the efficiency of any form of optoelectronic device. One of the strengths of ammonolysis is its versatility for preparing GaN nanostructures - it is possible to use a wide range of gallium-containing compounds as a starting material. However, I avoided gallium alkoxides and other organo-gallium compounds because of the threat of carbon contamination, and selected metallic gallium and gallium oxide-based precursors instead.

The equipment that I used for producing GaN by ammonolysis is incredibly simple. A single-zone tube furnace that features a quartz tube that can be connected to tubing at either end fulfills the requirement for a continuous gas flow (see figure 1). Gas supplies feed ammonia and nitrogen into this reactor, and precursor materials placed in an alumina crucible provide the source for group III metals, such as gallium and indium. As the minimum temperature for the conversion of gallium oxides to GaN under ammonia flow is at least 800°C, I decided to prepare a series of GaN powders using various different reaction temperatures within the 900°-1100°C range. These nanostructured samples, which were produced with a range of precursors, are composed of the hexagonal form of GaN, according to X-ray diffraction measurements.

The photoluminescence results produced by these samples gave me a tremendous shock. They directly opposed the widely held view in the nitride community that better quality material produces brighter emission. In my case I found that the very opposite was true - better quality material produced far weaker emission than its poorer quality counterpart.

The more defective GaN powders were produced at 1100°C, a growth temperature that drives the decomposition of GaN into metallic gallium and nitrogen gas. These samples were grey in color and produced far

stronger photoluminescence than those grown at lower temperatures, which were powders that displayed a light yellow color. This surprised me because I expected the lightly colored materials to have similar properties to the transparent/yellow, high-quality, epitaxially grown films.

My next goal was to try and make sense of these seemingly contradictory results. Any additional phases of gallium oxide, or any other possible contamination source for that matter, could be eliminated in all the samples by X-ray diffraction results. But what about forms of contamination that don't have a crystalline phase? They would not be exposed by diffraction, because this technique only probes the long-range order in materials. Hydrogen, for example, which has been claimed to quench band edge related photoluminescence, would be difficult to pick up by X-ray diffraction and most other analysis methods. Fortunately there is a technique that doesn't just detect hydrogen, but also determines how it is bound to its nearest neighboring atoms - nuclear magnetic resonance (NMR). I then started an ongoing study of my samples using this technique in collaboration with Jerry Hu, the Spectroscopy Facility manager and NMR expert at UCSB's Materials Research Laboratory. This was the first ever study of hydrogen contamination in GaN by ^1H NMR.

During these studies I discovered that NMR is, in general, incredibly well suited to studying atomic level binding in GaN powders. In addition to revealing hydrogen impurities, it is possible to investigate the type of coordination of gallium within the material, thanks to the ^{71}Ga isotope being NMR active.

Hu and I recorded ^{71}Ga NMR spectra of different GaN samples, and discovered striking differences between different materials on the atomic level. To our big surprise, we found a strong correlation between the ^{71}Ga NMR spectral features and photoluminescence (see figures 2

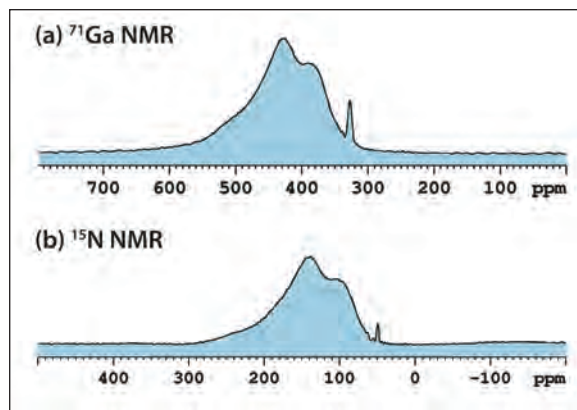


Figure 3. Researchers at UCSB investigated the ^{71}Ga NMR spectrum of a GaN sample with good photoluminescence properties (a) The sharp peak on the right can be attributed to stoichiometric GaN with a gallium-to-nitrogen ratio of 1:1. Increases in band-edge-related photoluminescence are correlated with increases in the area underneath a broad peak to the left of the sharp signal at 324 ppm. This peak is caused by nitrogen deficiencies in the material, the chemical structure being GaN_{1-x} . (b) NMR spectra were also recorded for ^{15}N . The similarity in lineshape between the two spectra is quite striking. This data was first presented in *Solid State Sciences*, **8**, 1193 (2006).

and 3 for details). These results indicated that the observed intense photoluminescence could be caused by nitrogen deficiencies. What's more, they also contradicted the assumption that stoichiometrically balanced GaN is needed to produce the strongest luminescence.

The next step, which we reported in 2006, involved the NMR study of isotopically labelled GaN nanostructures that were produced using similar conditions. By labelling ammonia with the ^{15}N isotope, we could identify gallium, nitrogen and hydrogen isotopes in our samples. What we discovered was a striking similarity between the NMR data for the ^{71}Ga and ^{15}N isotopes in the samples grown at high temperatures (see figure 3). We were also able to assign the broad feature in the NMR spectra to crystal structure defects at the nearest-neighbor atomic level. This implies that it is very unlikely that chemical shift distributions are due to electronic effects, a cause that has been suggested by other researchers in this community.

We continue to believe that these shifts are instead caused by nitrogen-deficiencies, which is a conclusion that we had drawn in 2004. The addition of ^{15}N NMR data has also enabled us to determine gallium-to-nitrogen ratios, while the ^1H NMR measurements have offered us an insight into hydrogen contamination within the material. As expected, higher growth temperatures

lead to an increase in nitrogen-deficiency and a reduction in hydrogen contamination. A closer investigation of the X-ray diffraction results reveals that the samples that produce more intense photoluminescence contain several crystalline phases. Each of these is hexagonal GaN, but these phases contain slight variations in lattice spacing that can be attributed to the increase in nitrogen vacancies. After completing this work, I went in search of new challenges in Dan Morse's group at UCSB's Institute for Collaborative Biotechnologies. But it wasn't long before I found myself hankering for an even better understanding of the interplay between the structure and the properties of GaN, and wondering about the answers to a series of nagging questions: How does the chosen precursor influence photoluminescence? What extent of nitrogen-deficiency is needed to increase the emission intensity? Is the band edge related luminescence in GaN powders directly or only indirectly (no oxygen contamination, no structural protons) linked to the observation of nitrogen-deficient phases in the ^{71}Ga NMR spectrum?

Today I'm devoting some of my time to answering these questions in a team that now includes Brad Chmelka's group in the Department of Chemical Engineering. Our understanding of the relationship between band edge related photoluminescence and the levels of nitrogen deficiency in GaN nanostructures is still based on experimental evidence, but we now are trying to tie these results to underlying physical principles. For example, we have confirmed our hypothesis that nitrogen-deficiencies are responsible for the increase in photoluminescence by converting non-luminescing GaN - which was prepared from gallium oxide under nitrogen gas at 1100 °C - into luminescing GaN. Again, the results of NMR spectroscopy revealed changes at the atomic level.

Since my efforts of ammonolysis began, several groups have independently reported increased photoluminescence after re-annealing their GaN LED epistructures. However, none of these groups appears to have established a connection between potential decomposition of GaN and an increase in emission, which stems from the introduction of nitrogen-deficiencies. Although it would be fascinating to compare the chemical composition of the GaN layers in these devices before and after annealing, one of the drawbacks of NMR is that it is that it cannot readily be used to investigate assembled device structures, due to the relatively large dimensions of an LED and the small amount of GaN that it contains. However, it might be possible to simulate the heat treatment techniques used for GaN LEDs, and then study the chemical composition of the active layers in these structures. It should be possible to carry out this analysis using several of the techniques that we employ to determine the characteristics of our bulk samples. These studies would not only be very interesting from a scientific perspective - they could also help to spur the performance of LEDs, and enable them to enjoy success in emerging markets such as solid-state lighting.

Further reading

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Sumitomo snatches the green laser crown

Japanese substrate manufacturer Sumitomo has won the race for the first truly green nitride laser with a 531 nm semi-polar device that it announced on 17 July, 2009.

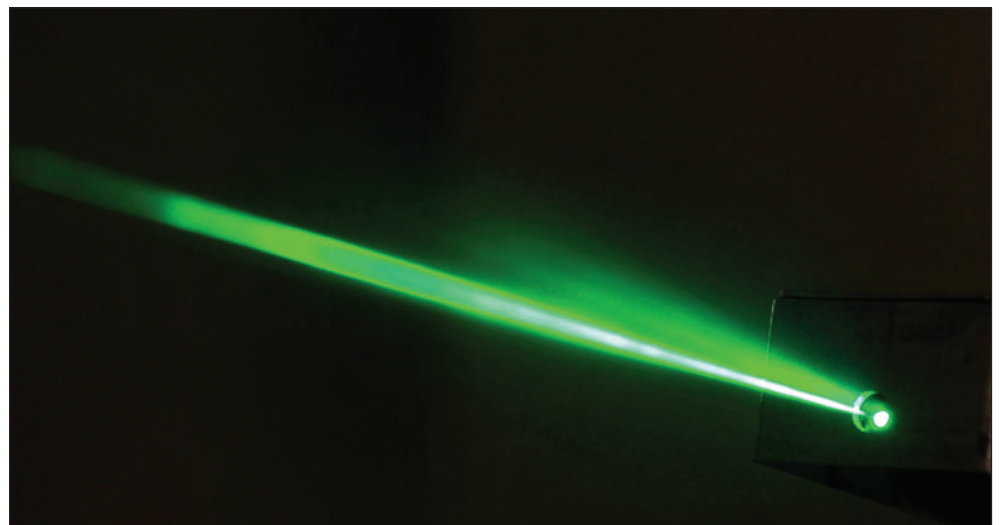
Although this device's performance characteristics are not good enough for commercialization, if they were improved this laser could then provide the green laser source for laser TV and tiny color projectors. These displays currently use cumbersome, expensive green lasers that combine an infra-red source with crystals that convert 1064 nm emission to 532 nm.

Sumitomo's engineers grew their laser structures on the $\{20\bar{2}1\}$ plane of free-standing GaN substrates that were fabricated in-house.

The researchers say that the selection of this plane is the key to their success – it enables the fabrication of indium-rich InGaN quantum wells with a high degree of compositional uniformity.

A series of gain-guided lasers with 10 μm stripes were fabricated by conventional deposition and lift-off techniques. The 531 nm variant was driven in pulsed mode with a 0.5 percent duty cycle, and had a threshold current density of 15.4 kA cm^{-2} .

Devices emitting at 520 nm had a lower threshold current density of 8.2 kA cm^{-2} , a threshold voltage of



Credit: Sumitomo

17.7 V, and produced a maximum output power of 28 mW.

More recently, Sumitomo's engineers have improved the 520 nm laser performance by adding a lattice-matched InAlGaIn cladding layer, and switching to a ridge-stripe geometry. These refinements created a device that delivers 2.5 mW in continuous-wave mode, and has a threshold voltage and current density of 9.4 V and 7.9 kA cm^{-2} , respectively.

Y. Enya et. al. *Appl. Phys. Express* 2 082101 (2009)

Y. Yoshizumi et. al. *Appl. Phys. Express* 2 092101 (09)

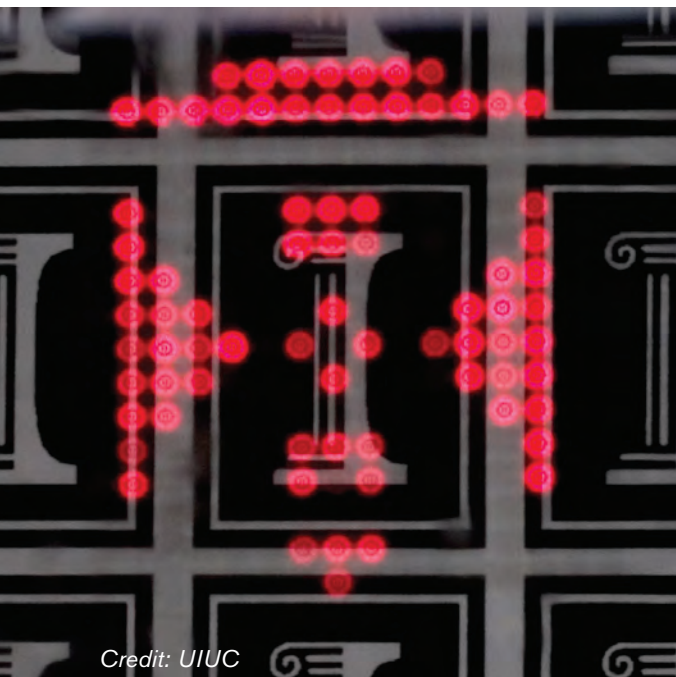
Printing LED displays

Researchers at the University of Illinois at Urbana Champaign (UIUC) have led the development of a series of novel processes that can produce small and medium-sized displays featuring an array of LED pixels.

Conventional processes are unable to make LED displays of this size, because they cannot produce chips that are small enough. And even if this issue were overcome, this approach would not be attractive due to the large quantities of wiring needed to interconnect pixels.

Sumitomo's semi-polar substrates were a key factor in the fabrication of the first nitride-based green laser

Progressing to color displays will require the addition of blue and green LEDs. The team has already had success in this area, according to corresponding author John Rogers from UIUC, and a paper is now being written on that topic



Credit: UIUC

Displays based on an array of red LED pixels have been built by a partnership led by the University of Illinois at Urbana-Champaign and Semprius

Desktop monitors, home theatre systems and instrument gauges could all be produced with the US team's technology. Wearable health monitors offer another opportunity, which would require the mounting of LED chips on a flexible platform.

The researchers built a range of small, red displays by first growing sacrificial 1.5 μm -thick AlAs layers and GaInP-based LED structures on GaAs substrates. Square islands containing the LED epistructure and having a length of just 50 μm were defined on the wafer by a combination of photolithography and inductively-coupled plasma, reactive-ion etching.

Immersion of the processed wafer in

hydrofluoric acid etched away the vast majority of the AlAs layer. An automated printing tool with elastomeric stamp then pulled arrays of these tiny LED chips from the substrate, thanks to a sufficiently strong Van der Waals interaction, and printed them onto another surface. Fabrication of red displays was completed by adding electrical interconnects with planar processing methods.

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If this technology is to be transferred to the manufacturing arena it will have to demonstrate acceptable yields. "The yield of printed, working devices is very close to 100%," says Rogers, "and the yield for interconnected arrays interfaced to computer control systems is in the 85% range." Most of these failures are associated with external connections to ribbon cables.

Similar etching and printing methods are also being employed by a partner in this research, Semprius, which is making small GaAs solar cells coupled to concentrating optics. "They have built working modules, and are on the verge of sending out research demos at the 1-10 kW level for customer evaluation," says Rogers.

Lighting systems could also be

produced with the processes developed by Rogers and his co-workers. "Options to licenses to the necessary IP have been obtained from Semprius by a separate startup, CoolEdge, that will pursue lighting exclusively, starting with systems for general illumination."

S.-I. Park et al. *Science* 325 977 (09)

HVPE ups GaN resistivity

Scientists from Nanjing University, China, have used HVPE to produce undoped GaN epilayers with a room-temperature resistivity of $10^9 \Omega \text{ cm}$.

Such high resistivities in GaN films - which are needed to provide the necessary isolation from the substrate during the production of powerful, high-frequency III-nitride transistors - are normally realized with iron or carbon doping. However, additional impurities can lead to leaky devices, inferior transport properties, and possibly reduced reliability. The Chinese team grew their high resistivity GaN epilayers on a commercial, free-standing GaN substrate, which was also produced by HVPE.

Cathodoluminescence measurements revealed a dislocation density for the film of $6 \times 10^6 \text{ cm}^{-2}$. Resistivity was evaluated by fabricating a Schottky diode, and taking current-voltage measurements.

Treating the GaN substrate and epilayer as two resistors connected in series led the researchers to deduce a resistivity for the undoped film of $3.6 \times 10^9 \Omega \text{ cm}$.

H. Shi. *Electron. Lett.* 45 910 (09)

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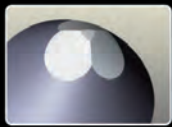
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