

COMPOUND SEMICONDUCTOR

September 2006 Volume 12 Number 8

CONNECTING THE COMPOUND SEMICONDUCTOR COMMUNITY

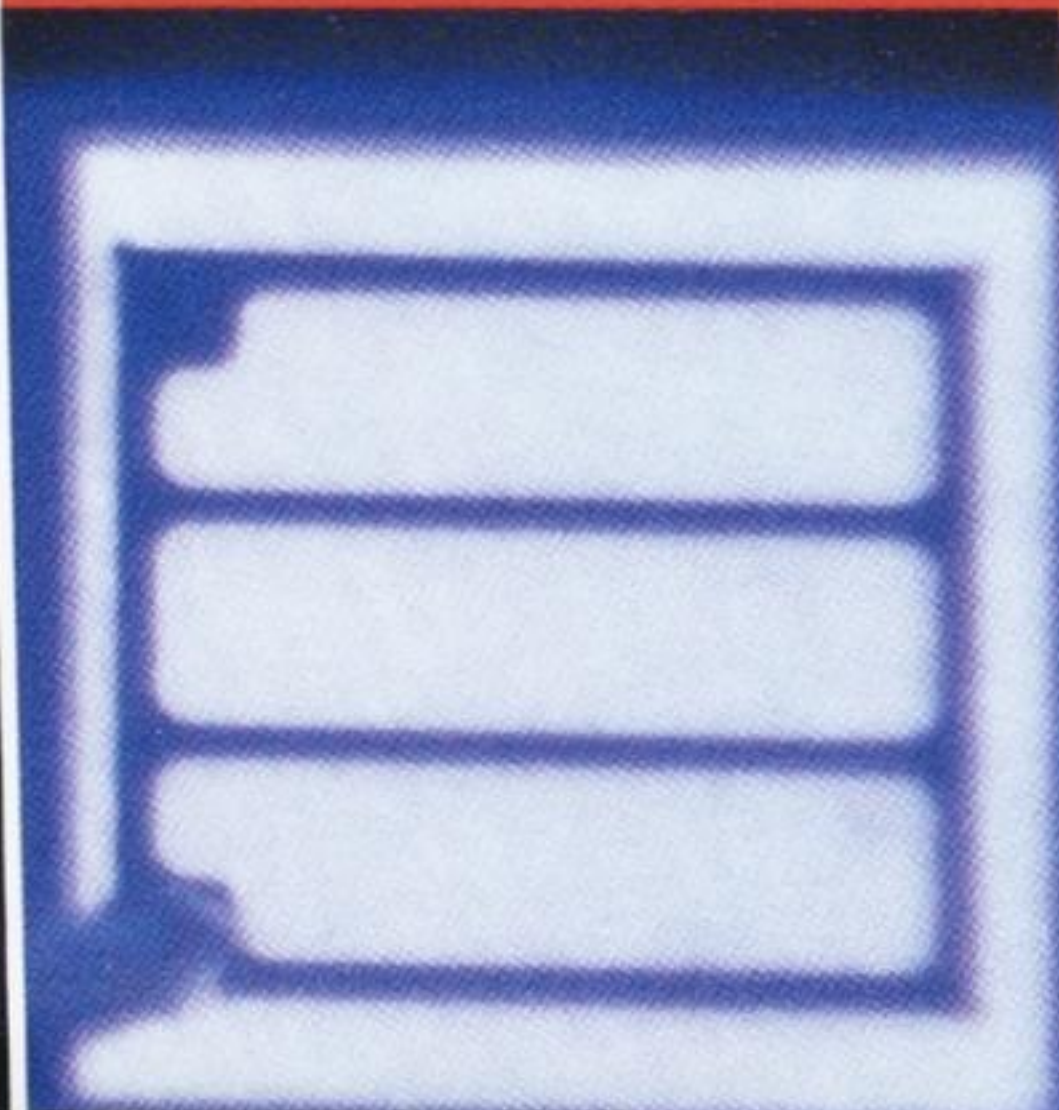
WIDE-BANDGAP DEVICES

**SiC in vogue as
four new fabs
open for business**

SOLAR POWER

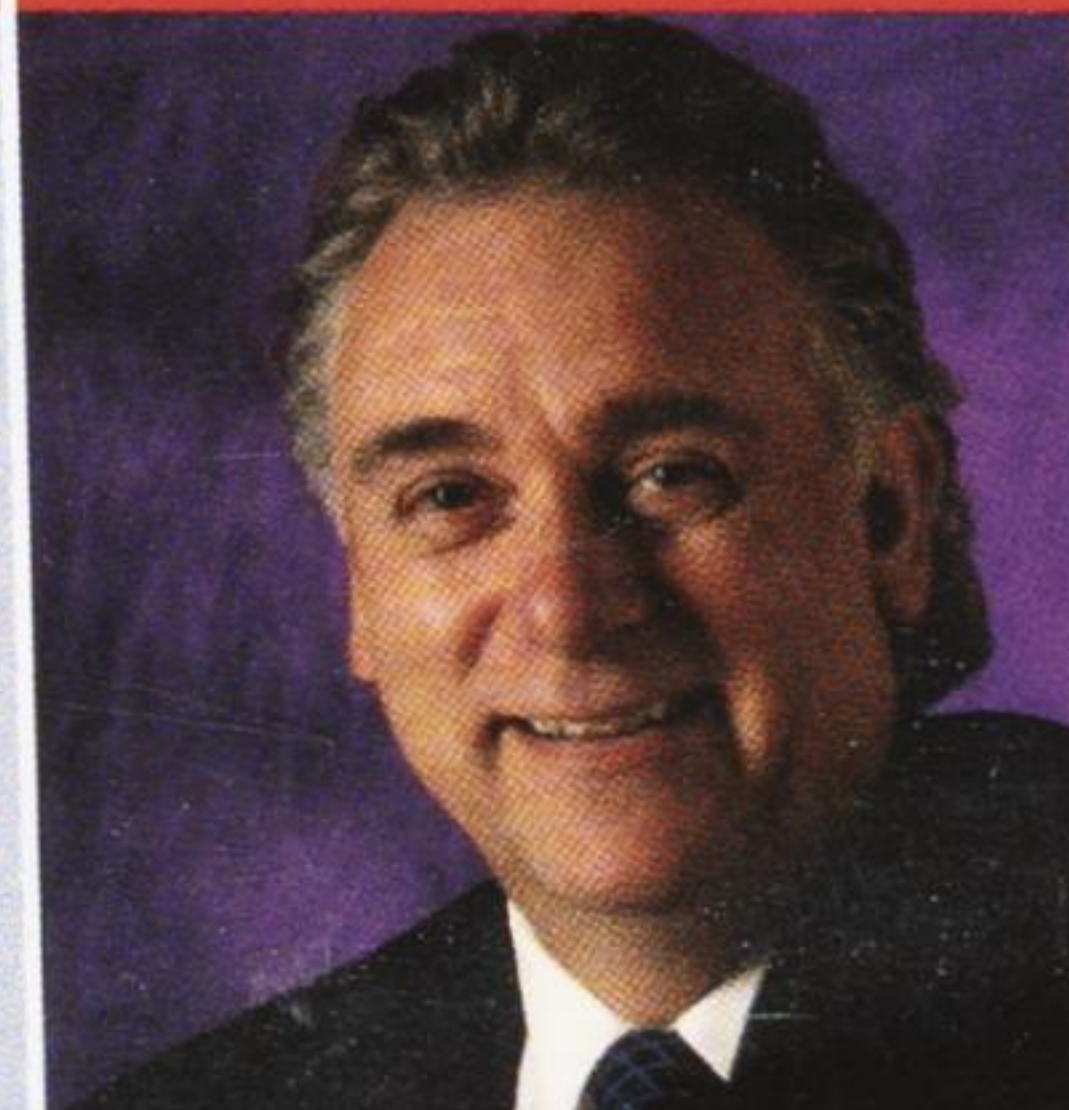
**Australians order
half a million cells
from Spectrolab p10**

TECHNOLOGY

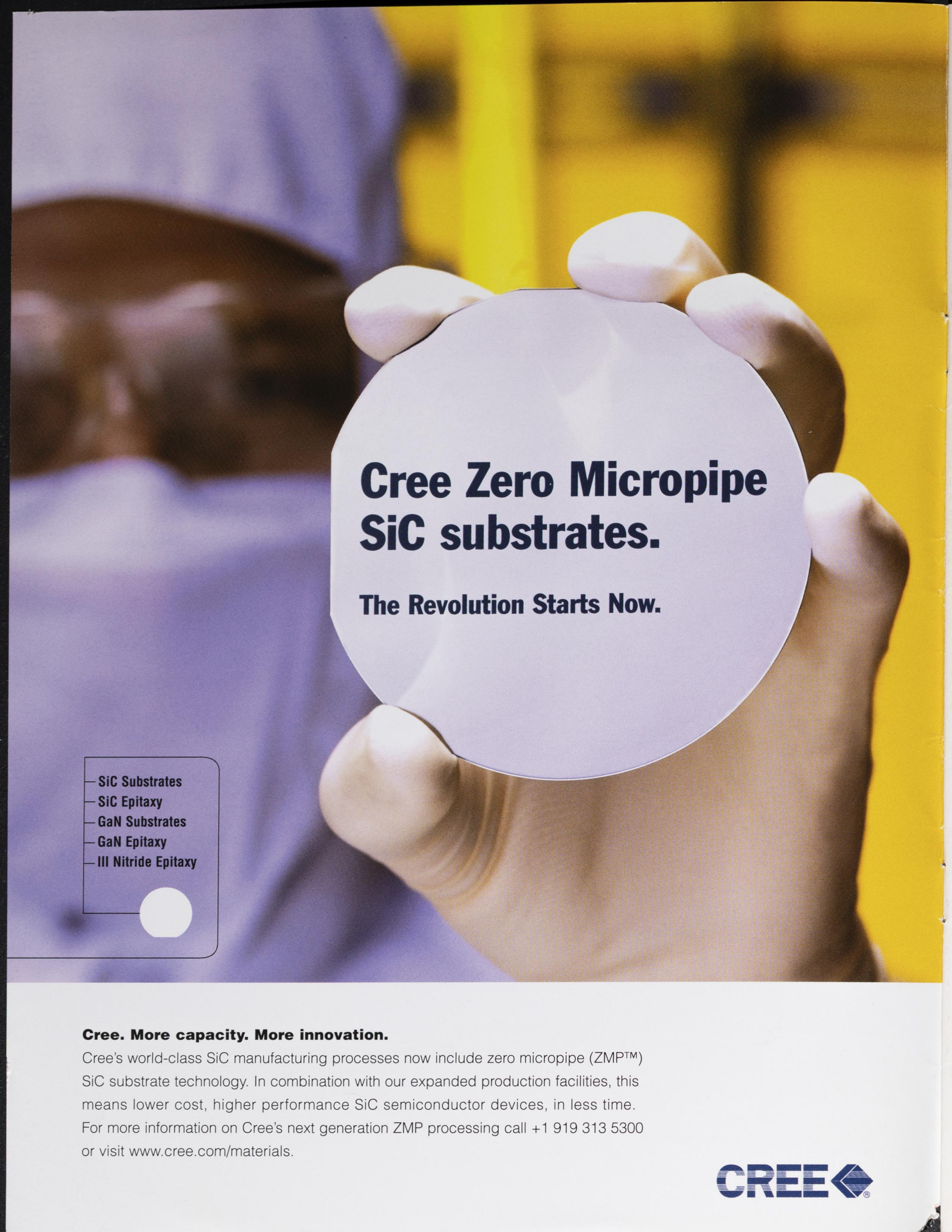


Super-bright
SemiLEDs show how to
boost efficacy with metal
alloy substrates. p16

INTERVIEW



Moving on up
IQE chief Drew Nelson
on the Welsh company's
latest acquisition and
plans for the future. p14



Cree Zero Micropipe SiC substrates.

The Revolution Starts Now.

- SiC Substrates
- SiC Epitaxy
- GaN Substrates
- GaN Epitaxy
- III Nitride Epitaxy

Cree. More capacity. More innovation.

Cree's world-class SiC manufacturing processes now include zero micropipe (ZMP™) SiC substrate technology. In combination with our expanded production facilities, this means lower cost, higher performance SiC semiconductor devices, in less time.

For more information on Cree's next generation ZMP processing call +1 919 313 5300 or visit www.cree.com/materials.



INDUSTRY

- 5** **Headline News:** All eyes on SiC as four new fabs open up...IQE prepared for future profit as revenues rocket.



Fab four

Cree, SemiSouth Laboratories, II-VI and Norstel each cut the ribbon on new fabs during August. **p5**

- 6** **The Month in RFICs:** Usual suspects maintain GaAs device dominance...Filtronic scales back facility plans...GaN developers are 'chasing wrong market'...Sprint gives WiMAX green light...Motorola makes gains as market nears 1 bn.

- 8** **The Month in HB-LEDs:** Optimism returns as Aixtron orders grow...Toyoda Gosei warns firms about patents...Memory company launches LED venture.

- 10** **The Month in Optoelectronics:** III-V cells power outback homes...Solar start-up firm nets \$25 million fund...\$6 million pledged to research silicon lasers.



Solar breakthrough

Remote homes in the Australian outback are becoming the first in the world to use triple-junction solar cells. **p10**

- 12** **Portfolio: Transitional Cree seeks next big thing** Still making the bulk of its revenue from sales of LED chips for cell-phone applications, Cree's finances are taking a hit as the company looks to move into a new growth phase.

- 14** **Interview: IQE slots in the final piece of the puzzle** With the electronic materials division formerly belonging to Emcore now under its wing, IQE is the world's biggest independent supplier of III-V epiwafers to the compound semiconductor industry. Michael Hatcher asks Drew Nelson, the CEO at IQE, about the company's latest move.

TECHNOLOGY

- 16** **Sapphire-free vertical design boosts LED performance:** Poor current handling and thermal management are suppressing the performance of LEDs for solid-state lighting applications. These problems can be avoided, however, by switching to a low-cost vertical design and a metal alloy substrate, says Trung Doan from SemiLEDs Corporation.

- 21** **Application Focus: Portable DNA analyzer to use GaN LEDs** Forget about men in white coats. Soon police officers could be using LEDs to analyze and identify DNA evidence at the crime scene, discovers Jon Cartwright.

- 22** **Skyworks favors hybrid BiFET design:** Skyworks believes that its hybrid design for BiFETs, which includes a quicker and lower-cost processing route, outweighs the greater versatility of a monolithic design. Richard Stevenson investigates.



Innovation game

Chipmakers must innovate to remain profitable in today's market. Skyworks has launched a range of BiFET chips with advanced modules that can command a higher price tag. **p21**

- 25** **Etching and regrowth technique increases bipolar diode stability:** The lack of forward voltage stability in SiC bipolar devices is hampering their deployment in electrical power transformers. However, this problem can be overcome with an etching and regrowth process, say Joe Sumakeris, Brett Hull and Dave Grider from US chip manufacturer Cree.

- 29** **TDI cracks AlN template trouble:** GaN HEMT manufacturers and ultraviolet LED developers are using large crack-free AlN-based templates thanks to a new deposition process, say TDI's Vladimir Dmitriev and Alexander Usikov.

31 Product Showcase

- 32** **Research Review:** US Air Force makes diamond advance...Introducing thin SiN layer cuts GaN defects...Photodiodes produce highest optical gain.

Main cover image: A close-up of an SiC wafer with gold metallization manufactured at SemiSouth's new facility in Starkville, Mississippi.

Editor Michael Hatcher
michael.hatcher@iop.org
Tel: +44 117 930 1013. Fax: +44 117 925 1942

Features editor Richard Stevenson
richard.stevenson@iop.org
Tel: +44 117 930 1192

Reporter Jon Cartwright
jon.cartwright@iop.org
Tel: +44 117 930 1014

Consulting editor Tim Whitaker
tim.whitaker@ledsmagazine.com
Tel: +44 117 930 1233

Senior sales executive David Iddon
david.iddon@iop.org
Tel: +44 117 930 1032. Fax: +44 117 920 0977

Business development manager Rosemarie Guardino
Guardino@ioppubusa.com
Tel: +1 215 627 0880. Fax: +1 215 627 0879

Circulation manager Claire Webber
claire.webber@iop.org
Tel: +44 117 930 1252. Fax: +44 117 920 0742

Publisher Sarah Chilcott
sarah.chilcott@iop.org
Tel: +44 117 930 1020

Production editor Ruth Harwood
Ad production Joanne Derrick, Mark Trimnell
Art director Andrew Giaquinto
Technical illustrator Alison Tovey

Subscriptions
Available free of charge to qualifying individuals working at compound semiconductor fabs and foundries. For further information visit compoundsemiconductor.net/subscribe. Subscriptions for individuals not meeting qualifying criteria: individual £86/\$155 US/€125; library £193/\$348 US/€280. Orders to Compound Semiconductor, WDIS, Units 12 & 13, Cranleigh Gardens Industrial Estate, Southall, Middlesex UB1 2DB, UK. Tel: +44 208 606 7518; Fax: +44 208 606 7303. General enquiries: compoundsemi@iop.org.

9314 average total qualified circulation*
*June 2006 BPA audit statement

Editorial board
Mayank Bulsara Atlas Technology (USA);
Andrew Carter Bookham Technology (UK); **Jacob Tarn** OCP/Gigacomm (Taiwan); **Ian Ferguson** Georgia Institute of Technology (USA); **Toby Strite** JDSU (USA); **Mark Wilson** Motorola (USA); **Dwight Streit** Northrop Grumman (USA); **Joseph Smart** Crystal IS (USA); **Colombo Bolognesi** Simon Fraser University (Canada); **Shuji Nakamura** University of California at Santa Barbara (USA)

©2006 IOP Publishing Ltd. All rights reserved.

US mailing information: *Compound Semiconductor* (ISSN 1096-598X) is published 11 times a year for \$148 by Institute of Physics Publishing, Dirac House, Temple Back, Bristol BS1 6BE, UK. Periodicals postage paid at Middlesex, NJ 08846. POSTMASTER: send address corrections to Compound Semiconductor, c/o PO Box 177, Middlesex, NJ 08846. US agent: Pronto Mailers Association Inc, 200 Wood Avenue, PO Box 177, Middlesex, NJ 08846.

Institute of Physics PUBLISHING

Going down under



Australia isn't generally regarded as a hotbed of compound semiconductor action, but some recent developments have shown how the III-V industry is expanding across the globe. Somewhat perversely, it is the outback communities of Australia's Northern Territory and Queensland regions – some of the oldest, most remote human settlements in the world – that have become the first to benefit from cutting-edge solar cell technology.

Developed with military and commercial satellite applications in mind, triple-junction cells represent extreme high-tech. The devices are based on germanium and a variety of GaInAs and GaInP compounds, which convert the sunlight into electricity far more efficiently than any rival approach.

Until earlier this year, however, the very high cost of the semiconductor element meant that it was only satellite applications that had felt the benefit of the technology. But now Hermannsburg, a community of indigenous Australians located 125 km from Alice Springs, has an eight-dish solar power station that provides half of its electricity. Only one of those dishes

“Triple-junction cells represent extreme high-tech.”

features compound semiconductor cells, but Solar Systems, the Australian energy firm pioneering deployment of the technology, has plans to extend that and provide competitively priced solar power on a much larger scale.

With its own band “The Concentrators” helping to spread the word, Solar Systems has also put its money where its mouth is and ordered half a million multijunction cells from Spectrolab. The company is hoping to build a 154 MW solar power station in its home state of Victoria, an installation that would represent the largest photovoltaic project in the world by an order of magnitude.

Nor is Australia likely to be simply a consumer of III-V chips. Epitactix and BluGlass are two companies in the Sydney area developing novel semiconductors, and the latter is working on a potentially game-changing type of LED that uses a low-cost glass substrate and low-temperature deposition method. BluGlass recently issued a public share offering to support its development and, if successful, it could become a key part of the nascent compounds industry in Australia.

Michael Hatcher *Editor*

Advertisers' Index

Air Products and Chemicals	6	KLA-Tencor	13
Bandwidth Semiconductor	8	Materials Research Society	20
BOC Edwards	24	Nitronex Inc	11
Cree Inc	IFC	NuSil	9
Dowa International Corporation	27	ORS Ltd	27
Freescall Semiconductor Inc	19	Raboutet	10
Honeywell Electronic Materials CA	IBC	Riber	3
III/V Reclaim	15	Seoul Semiconductor Co Ltd	20
Indium Corporation of America	27	Shiva Technologies	24
Instrument Systems GmbH	24	Veeco Instruments Inc	OBC

Compact 21 System

Versatile MBE

Twelve source ports / Modular and expandable
Suitable for III-V's, II-VI's, MCT, oxides, spintronics, etc.
Very high performance
Small footprint / Low cost of operation



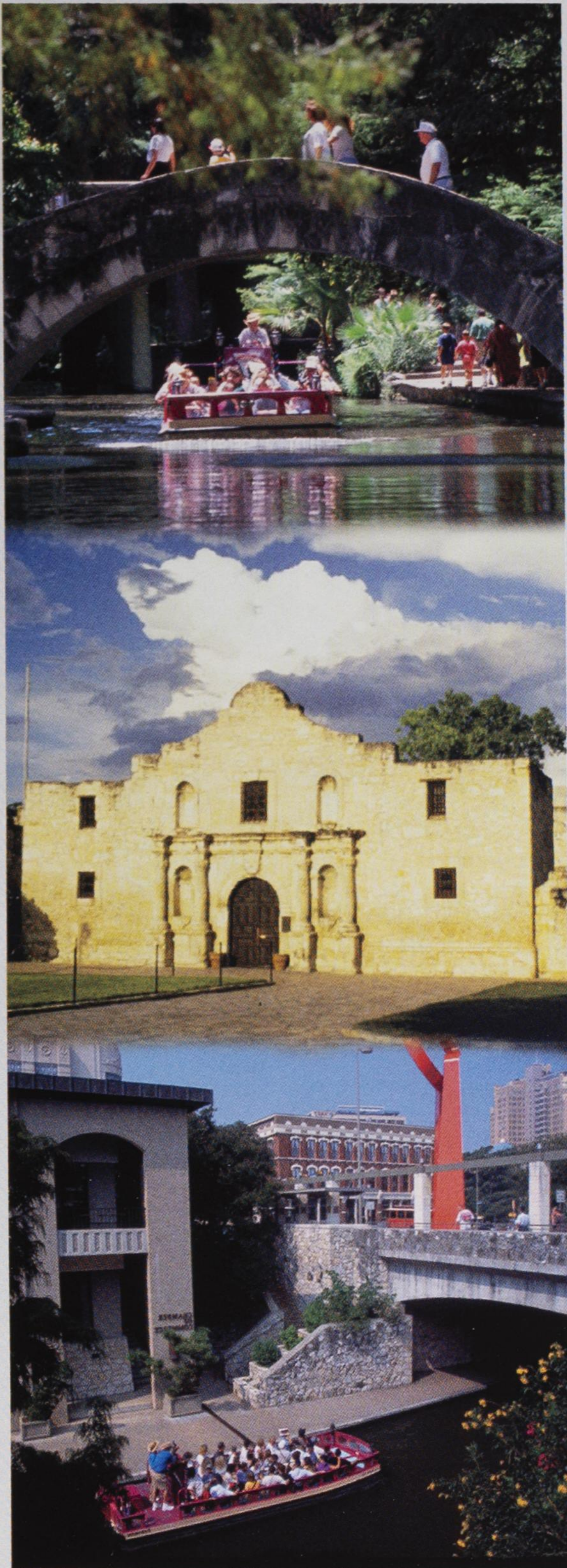
RIBER

Products and Services for the Compound Semiconductor Industry

To find out more, call +33 (0)1 47 08 84 35, e-mail at info@riber.com or visit our web site www.riber.com

COMPOUND SEMICONDUCTOR WEEK 2006

**November
12-15, 2006**
**San Antonio,
Texas, USA**



THE KEY CONFERENCE NOVEMBER 13-14, 2006 PART OF COMPOUND SEMICONDUCTOR WEEK 2006



This two-day conference will be packed with top invitation-only speakers from the key players in the compound semiconductor industry, respected market analysts and cutting-edge start-ups, and it will focus on the following key areas:

- GaAs-silicon convergence;
- silicon carbide power devices;
- alternative III-nitride technologies and applications;
- multi-junction solar cells;
- new laser application markets.

Confirmed speakers include senior representatives from:

IBM • Sony • JDSU • Cree • Freescale • Massachusetts Institute of Technology • Telesoft Ventures • Infineon Technologies • SemiSouth • Yole Developement • Kyma Technologies • Group4 Laboratories • SEMATECH • IMEC • GA Tech • Sensor ET • NRL • Spectrolab • APT • Emcore • OSU • Cermet • Infinera

If you need to know about the materials, technologies and applications that will drive the compound semiconductor market of the future, make sure you don't miss this event.

Sign up to receive regular program updates online

compoundsemiconductor.net/csweek

GOLD SPONSORS

RFMD



KLA Tencor

Event organized by



IEEE

Institute of **Physics** PUBLISHING

**COMPOUND
SEMICONDUCTOR**

WIDE-BANDGAP SEMICONDUCTORS

All eyes on SiC as four new fabs open up

With no less than four new facilities opening for business during the past few weeks, August 2006 could go down in history as the month when SiC power electronics came of age.

US firms Cree, SemiSouth Laboratories and II-VI each cut the ribbon on new fabs, while in Sweden, Norstel did likewise. MicroSemi's advanced power division is also in the process of finalizing its new plant.

Cree's 230,000 ft² production facility in Research Triangle Park was the first to be inaugurated officially. John Palmour, the Durham, NC, company's vice-president of advanced devices, said: "The new Cree site houses one of the first commercial SiC and GaN production facilities in the world devoted to the power and wireless infrastructure markets."

GaN and SiC electronic devices are expected to find use as higher-efficiency replacements for silicon technology in applications such as high-end power supplies, motor drives and wireless communications.

Next to open was SemiSouth Laboratories, a spin-off company from Mississippi State University (MSU) that specializes in SiC power devices. According to SemiSouth, its fab in Starkville, Mississippi, does not just represent the dawn of the firm as a volume manufacturer, it also marks the emergence of the semiconductor industry in this area of the US.

"The celebration signifies the beginning of high-tech economic development in the heart of Mississippi," said SemiSouth. As well as the device fab, SemiSouth's new building houses a cleanroom dedicated to wafer processing that is operated by SiC substrate supplier II-VI. The materials company recently received an order worth \$1 million for 3 inch SiC substrates from a large US customer.

Aptly named US Congressman Chip Pickering was among the dignitaries taking part in the opening ceremony, along with SemiSouth CEO Jeff Casady and II-VI coun-



Swedish success: Norstel's state-of-the-art SiC wafer facility was one of four SiC fabs to be inaugurated in August. US companies Cree, II-VI and SemiSouth also held grand openings during the month with MicroSemi to follow suit.

terpart Carl Johnson. Spun out from MSU back in 2001, SemiSouth now boasts 45 employees and is actively hiring. It expects the semiconductor fab to provide jobs for more than 250 people within five years as the market for energy-efficient high-power electronic components gathers pace.

SemiSouth is aiming to generate annual revenue in excess of \$100 million from the production of more than 50 million SiC-based components in the same time-frame. "We anticipate production will begin in the fourth quarter of 2006," said the company. "[We are] developing proprietary products and have secured contracts with both governmental and commercial customers."

Norstel, the spin-off from Finland-based silicon materials specialist Okmetic Oyj, opened its new SiC wafer manufacturing facil-

ity near Norrköping, Sweden, on August 29, with Sweden's Minister for Industry and Trade Thomas Östros cutting the ribbon.

Construction of the fab began in February 2005, and, according to the company, it is kitted out with the very latest in process tools and characterization equipment. Norstel uses a technique called high-temperature chemical vapor deposition (HTCVD) to produce its material, a manufacturing method that was pioneered at nearby Linköping University.

"We are now taking a major step towards establishing Norstel as a significant supplier of SiC materials," said Asko Vehanen, Norstel's CEO. "Making HTCVD truly industrial will enable Norstel to produce high-quality, large-diameter SiC crystals and wafers cost-efficiently, thereby opening new markets and applications."

EPIWAFERS

IQE prepared for future profit as revenues rocket

Boosted by strengthening markets across all applications, independent epiwafer supplier IQE reported a 51% increase in sales revenue in the opening half of 2006.

In the six months up to June 30, IQE posted sales of £14.6 million (\$27.8 million), compared with £11.2 million in the opening half of 2005. That upwards trend is set to continue after shareholders approved a £12 million share issue and the \$16 million acquisition of

Emcore's electronic materials division (EMD) at an extraordinary general meeting in August.

The Cardiff, UK, company reported an operating loss of £1.5 million in the latest financial period, but is on track to post a profit next year. Under Emcore's ownership, the EMD business – now known as IQE RF – was running close to profitability, and synergies between it and the rest of the IQE group companies, such as enhanced materials buying

power, ought to help improve the financial picture considerably.

IQE has also negotiated a two-year extension of its "effective exclusivity" deal relating to the firm's largest outsource contract, and says that all areas of the business are growing, with wireless products showing real strength.

● See interview with IQE's CEO Drew Nelson on page 14.

Ask the Expert



Rajiv K. Agarwal, Ph.D.
Lead Research Engineer

Q

I am experiencing high n type background doping levels in my MOCVD process when I grow GaAs and AlGaAs devices. I think the problem is in the arsine I use. I'm buying the best grade available. What can I do?

A

Higher background levels of n type dopants in GaAs and AlGaAs structures are caused by trace levels of germanium, silicon and sulfur species present in the arsine. As customer applications evolve, the purity requirements for arsine must as well. Until recently, background doping levels of $10^{15}/\text{cm}^3$ were considered acceptable in most applications. In general, most currently available high-purity grades of arsine can satisfy these requirements. However, process changes and demand for more sophisticated devices have resulted in the need for lower background doping levels. To address these more stringent requirements, Air Products is introducing Megabit™ III arsine, our purest grade available. Our new Megabit III arsine has significantly reduced the amounts of germanium, silicon and sulfur species. Testing done at an independent laboratory proved the effectiveness of Megabit III on thick gallium arsenide films, with excellent results. In all cases, the background doping level was $<<10^{14}/\text{cm}^3$. Our research has shown that Air Products' Megabit III arsine will perform more consistently and produce fewer defects in our customers' finished products.

For more information or to submit a question for "Ask the Expert," visit us at www.airproducts.com/AsktheExpert or call us at (800) 654-4567 or (610) 706-4730 and mention code #144.

tell me more
www.airproducts.com/AsktheExpert

DEVICE MANUFACTURING

Usual suspects maintain GaAs device dominance

Strong growth at fabless RF component supplier Hittite Microwave has propelled the Chelmsford, MA, firm into the world's top-ten GaAs device manufacturers for the first time. Hittite just scraped into 10th place in Strategy Analytics' new list, and is the only fabless company to be represented in the top ten.

According to the survey of the industry's biggest hitters in 2005, there have also been major changes among the rankings of Japanese GaAs chipmakers. Eudyna Devices, Sony and NEC all fell out of the top ten, while Mitsubishi Electric and Toshiba gained market share.

Eudyna's fall is perhaps the most surprising. The firm, created in early 2004 by merging Fujitsu Quantum Devices and Sumitomo Electric Industries' electronic devices division, had been tipped by Strategy Analytics to break into the top five shortly after it formed.

Reasons for the failure to challenge the top tier of US suppliers are unclear, but it is possible that Eudyna has failed to capitalize on the trend towards multimode handsets, while the

likes of RFMD have concentrated on transceiver modules and amplifier-switch integration. Mitsubishi has gained ground thanks to strong growth in its GaAs MMIC business. "It led supply of GaAs power amplifiers to the Japanese 3G cellular handset market," said Strategy Analytics.

The US trio of RF Micro Devices, Skyworks Solutions and TriQuint Semiconductor continue to dominate the industry, accounting for 52% of the merchant market. "We believe the North American players will continue to cement their dominance," concluded the report.

While no European companies made it into the top ten for 2005, Asif Anwar from Strategy Analytics reckons that UK-based Filtronic will feature in 2006. Foundries in the Asia-Pacific region are also set for continued growth as many of the major GaAs device companies look to outsource excess production requirements rather than invest in their own expensive upgrades.

FAB EXPANSION

Filtronic scales back facility plans

Filtronic, the chipmaker with a GaAs fab in Newton Aycliffe, UK, has cut the projected spend on its capacity expansion program from £45 million (\$83 million) to £15 million.

In June, Filtronic announced plans to sell its wireless infrastructure division, which accounts for nearly 80% of its current revenue, along with details of a huge investment in the fab.

However, after analyzing the requirements of its customers in detail, Filtronic has now concluded that the average die size of many of the GaAs-based products needed in the future will be smaller than previously envisaged. As a result, the manufacturing demands will not be so great. Following the £15 million cash investment in the fab, the division should become self-financing, however.

Filtronic finance director Charles Hindson confirmed that the company's compound semiconductor division should be "at or near" its break-even point during fiscal 2007. In fiscal 2006, which ended on 31 May, the division posted an operating loss of £5.1 million after sales rose sharply to £20.8 million, more than double the 2005 revenue figure.

Hindson added that Filtronic is now sup-

plying a second customer with PHEMT die, and that a third would begin receiving shipments around the end of this calendar year.

North Carolina-based component supplier RF Micro Devices, which remains Filtronic Compound Semiconductor's primary customer, is in the process of expanding its own facility to make GaAs PHEMT switches, although with demand for its products growing fast, it may still use supplies from Filtronic.

Hindson added that it is mostly back-end fab equipment that is required for the £15 million expansion, with the majority of the required epitaxy capacity already in place. Filtronic will continue to use a mixture of in-house and external supplies of epitaxial material in the future.

Expecting to see market adoption of PHEMT switches in 80% of mobile handsets over the next three years, the company now forecasts sequential revenue growth of more than 25% in the coming six months. Aside from the PHEMT market, Filtronic believes that there will be strong growth in non-switch GaAs-based products for filter and back-haul radio applications.

MARKET REPORT

GaN developers are 'chasing wrong market'

Developers of high-power RF semiconductors based on GaN and SiC materials will have little success if they continue to focus on the cellular infrastructure market.

That's according to a new study carried out by analysts at ABI Research that focuses on the six key markets for RF semiconductors operating at above 5 W and below 3.8 GHz.

It suggests that the overall market for these devices should grow to almost \$1 billion in 2011, driven by applications in cellular infrastructure, defense, broadcasting, commercial avionics, non-cellular communications and science, medicine and industry.

ABI research director Lance Wilson, a 30-year veteran of the wireless communications business who previously worked at Motorola, said: "Everybody gets seduced by wireless infrastructure, but getting into [this market] is extremely difficult. To get products qualified can be more difficult than getting into the military [market]."

While GaN and SiC-based RF transistors do show some impressive performance, he firmly believes that silicon LDMOS will continue to be "the elephant in the room" as far as cellular infrastructure applications are concerned. "In my opinion, the chase for [cellular] infrastructure has retarded the growth of the GaN business," said Wilson. "They have gone after the wrong market."

Instead, he says, the key RF application areas for wide-bandgap materials are the ones that need higher powers and, crucially, that operate at high frequencies. This means that military and satellite communications offer the best chances for the high-performance semiconductors in the sub-3.8 GHz range.

However, the area where GaN could really come into play is at frequencies of more than 3.8 GHz, claims Wilson. "Here, the big elephant has gone," explained the analyst, pointing out that silicon LDMOS does not work at these high frequencies and that GaAs-based solutions tend to struggle to deliver the high powers that will be necessary for some emerging applications.

Aside from further military uses in this range, the medical world could also offer a sizable future market for these devices, Wilson added. The magnetrons and traveling-wave tubes that are now used as microwave generators could eventually be replaced by solid-state digital technologies.

WIRELESS NETWORKS

Sprint gives WiMAX green light

Sprint Nextel is to build the first fourth-generation (4G) network for broadband wireless Internet connectivity across the US. The network will be based on the mobile Wireless Interoperability for Microwave Access (WiMAX) technology standard, also known as IEEE 802.16e-2005, and will operate in the 2.5 GHz frequency band.

Makers of semiconductor chips and components such as RF amplifiers are looking to the new communications protocol as a key driver for devices based on GaAs, GaN and SiC.

Sprint, which has also pioneered the deployment of digital optical and CDMA cellular networks in the US, says that it will spend up to \$3 billion over the next two years as it deploys the network in rapid fashion.

Long-time WiMAX supporters Intel, Motorola and Samsung are all involved in the

project. Sprint is aiming to launch the wireless broadband service in trial markets by the end of 2007, and plans a full roll-out to as many as 100 million people in 2008.

GaAs component specialist Anadigics could be one of many III-V companies set to benefit from the network build, as it already has a strong relationship with Intel through its Centrino Wi-Fi chipset. The linearity demands of mobile WiMAX on the power amplifier are even more demanding than for Wi-Fi and cellular applications, suggesting a key role for GaAs when the technology is rolled out.

Cree, which has developed wide-bandgap transistors for WiMAX infrastructure applications, has also welcomed Sprint's move. Jim Milligan from the company said: "It is probably the firmest commitment to WiMAX that I've seen, at least in North America."

HANDSETS

Motorola makes gains as market nears 1 bn

Worldwide sales of mobile phones totalled 229 million in the second quarter of 2006, according to market researchers at Gartner.

Although that represents rapid year-on-year growth of more than 18% in terms of unit sales, it does mean that the rate of increase in handset shipments has slowed since the first quarter of 2006, when the figure was almost 24%.

Gartner is keeping faith with its prediction that 960 million units will sell in 2006 as a

whole. If it proves to be an accurate forecast, that would mean an 18% annual rise in unit sales from last year's figure of 816.6 million.

Nokia and Motorola, the two market-leading handset brands, are continuing to tighten their grip on the sector, and now account for more than half of global sales.

"Motorola is the big winner this quarter," said Gartner analyst Carolina Milanese. The US company's market share has risen by more than 4% year-on-year to reach 21.9%.

Nokia, whose phones primarily feature RF components made by RF Micro Devices, remains at the top with more than 33% of the market, while Samsung remains in third place with 11.1%.



From our Web pages...

visit compoundsemiconductor.net for daily news updates

AXT adds to 6 inch GaAs

Substrate vendor AXT has seen a sharp upturn in sales revenue thanks to the buoyant cellphone handset market and returning customers. With strong market conditions and order visibility from its returning customer base, AXT now plans to add an extra 40% to its existing 6 inch semi-insulating GaAs substrate capacity within the next nine months.

NEC touts GaN amplifier

Japanese electronics giant NEC electronics claims to have developed the world's most powerful transistor amplifier. The 400 W single-transistor package, which operates at 45 V and 2.14 GHz, has been developed through a nine-

company partnership that includes Toyoda Gosei. Toyoda made the GaN epiwafer on which the transistor was fabricated, and NEC says that after more development work it will aim to commercialize the amplifier for 3G base-station applications by the end of 2008.

Mitsubishi ramp

From October, Japan's leading GaAs device manufacturer Mitsubishi Electric will ramp fabrication of its new GaAs HEMTs to high-volume production. The high-gain transistors are said to be ideal for low-noise amplifiers operating at 18–20 GHz, and have been ordered for use in satellite broadcast receivers and very small aperture terminal systems.

COMPOUND SEMICONDUCTOR FOUNDRY SERVICES



Bandwidth Semiconductor

Bandwidth has an innovative and cohesive team of professionals that enable continuing growth in today's marketplace. Bandwidth operates in a compound semiconductor growth & device fabrication line housed in 14,000 ft.² class 100/1000 clean room.

EPITAXIAL SERVICES

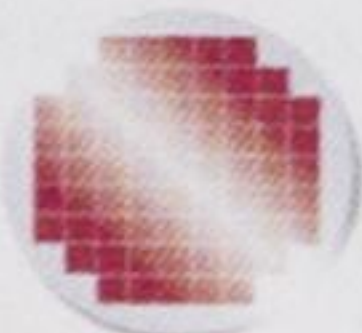
Bandwidth's extensive MOCVD experience and capacity enable the production of a wide range of GaAs and InP epitaxial structures to meet general or custom designs.

- GaAs and InP-based materials
- 2", 3", 4" custom Epi-Wafer capability
- Excellent uniformity & reproducibility
- Production & Development Quantities

FOUNDRY SERVICES

Bandwidth designs the process steps and conditions to meet the desired device characteristics and then implements the process in our fab, using the following process equipment:

- PECVD
- Metallization
- Wet & Dry Etch
- Photolithography
- Dielectric & Optical Thin Film Deposition
- Wafer Polishing, Lapping, Dicing & Cleaving



BANDWIDTH
SEMICONDUCTOR
EPITAXY & FOUNDRY SERVICES



Bandwidth Semiconductor, LLC
A Wholly Owned Subsidiary of Spire Corporation
25 Sagamore Park Road, Hudson, NH 03051
T 603-595-8900 F 603-595-0975
Email sale inquiries to: sales@bandwidthsemi.com

EQUIPMENT ORDERS

Optimism returns as Aixtron orders grow

MOCVD equipment vendor Aixtron says that new applications for high-brightness LEDs are the reason behind a big increase in orders during the firm's most recent financial quarter.

Although the market for GaN-based blue lasers and LEDs used in cell-phone camera flash applications have yet to take off as predicted, orders of compound semiconductor equipment were up 62%, driven largely by rising demand for liquid-crystal display backlights featuring LEDs.

"At the end of the [previous] quarter we said that the cautious growth in industry confidence first witnessed in the latter half of 2005 had continued into the first quarter of 2006," explained Aixtron CEO Paul Hyland. "I am very pleased to say that this improvement in sentiment has continued and perhaps even strengthened in the second quarter."

Aixtron's total order backlog as of June 30 stood at €81.2 million (\$103.9 million), up 55% year-on-year. While that figure includes a strong performance from the group's silicon division, new MOCVD equipment has also been ordered

by a raft of LED makers recently, including Philips Lumileds, Taiwan-based Epitech, Epivalley in Korea and the Chinese firm Dalian Meiming Epitaxy Technology Company.

The Aachen-based equipment supplier has also noted an upturn in demand from customers making components for telecommunications applications. Although it is unlikely that existing capacity for telecommunications devices will be used up in the near term, Aixtron is in general very positive about the end markets that it serves.

It cites an early-generation build-up in capacity for blue lasers, LEDs in backlighting and automotive applications, and SiC devices for hybrid car engines as three key areas that promise to push MOCVD equipment orders.

However, because of the much weaker order book one year ago, Aixtron's sales in the three months up until June 30 were only €35.7 million, down from €44.4 million in the same period last year. Full-year revenue is still expected to reach €150 million and Hyland said that the firm should break even on that basis.



From our Web pages...

visit compoundsemiconductor.net for daily news updates

...GaN-on-glass firm goes for IPO

BluGlass, a newly formed Australian company, has launched an initial public offering (IPO) of shares in a bid to commercialize a low-cost (non-MOCVD) method for manufacturing GaN-based light emitters.

The BluGlass management, led by CEO David Jordan, a veteran of the semiconductor and solar cell industries, is looking to raise at least AUS\$6 million (\$4.6 million) through the sale of 30 million shares. If successful, it plans to build a pilot manufacturing facility for its low-temperature deposition technology, which is claimed to be compatible with glass substrates up to 8 inch in diameter.

In the company's new prospectus, chairman Michael Taverner said: "Macquarie University researchers have successfully demonstrated a GaN LED grown at below 700 °C."

...Evans Analytical gets SIMS expertise

Independent materials characterization service provider Evans Analytical has increased the scope of its III-V offering through the purchase of Applied Microanalysis Labs (AML). AML, which was founded in 1998 by Yumin Gao and is based in Santa Clara, CA, specializes in secondary ion mass spectrometry (SIMS).

Gao still runs AML and is regarded by Evans's

VP of operations Mike Edgell as a world leader in III-V material characterization, specifically GaN-based LED structures. SIMS provides a way of characterizing semiconductor materials through depth profiling analysis.

...Synova bags expansion cash

Armed with new debt financing, the Swiss laser wafer-dicing equipment vendor Synova plans to open up micromachining application centers around the world in key high-tech locations. The company believes that it will now be able to penetrate the semiconductor wafer dicing market further and make inroads into new applications by providing its services in closer proximity to its potential customer base.

One Swiss bank and one mezzanine fund (a financial combination comprising debt and equity options) have loaned the company a total of SwFr10 million (\$8.1 million).

...New TV uses LED backlight

Arizona-based high-end television manufacturer NuVision will begin shipping a new model with an LED backlight this month. The company's illumination system is based on the PhlatLight LED-based light source developed by US firm Luminus Devices and uses individual red, green and blue LEDs to replace conventional lamps.

GAN LEDs

Toyoda Gosei warns firms about patents

Japanese GaN LED giant Toyoda Gosei has taken a leaf out of Nichia's book by warning companies about the patents that protect its light-emitting semiconductors. The company

says that it has received information that firms other than licensees have been making and selling white LEDs using silicate phosphors.

The phosphor detail relates to the new yellow materials developed by Toyoda and three European collaborators, which form white emissions when pumped with a blue LED. Toyoda has now signed cross-licensing agreements with Philips Lumileds and Nichia, allowing the three parties to use each other's LED-related patents.

In a related development, lawyers for

Columbia University academic Gertrude Neumark have claimed victory in a patent dispute with the Japanese firm. Declining to give details of the settlement, Neumark said: "I am pleased that Toyoda Gosei has acknowledged the relevance and importance of my patents. I believe that my patents claim a manufacturing process for GaN LEDs that is relevant to the LED industry as a whole." Neumark's legal team added that similar claims against Cree, Lumileds and Osram remain unresolved.

TAIWAN

Memory company launches LED venture

In a bid to make a play in the LED market, two Taiwanese companies from the mainstream silicon semiconductor business have set up a new joint venture company called EpiLED.

ProMOS Technologies, a manufacturer of dynamic random access memory chips and equipment vendor Hermes-Epitek have raised NT\$550 million (\$16.8 million) to get the chip manufacturing company up and running.

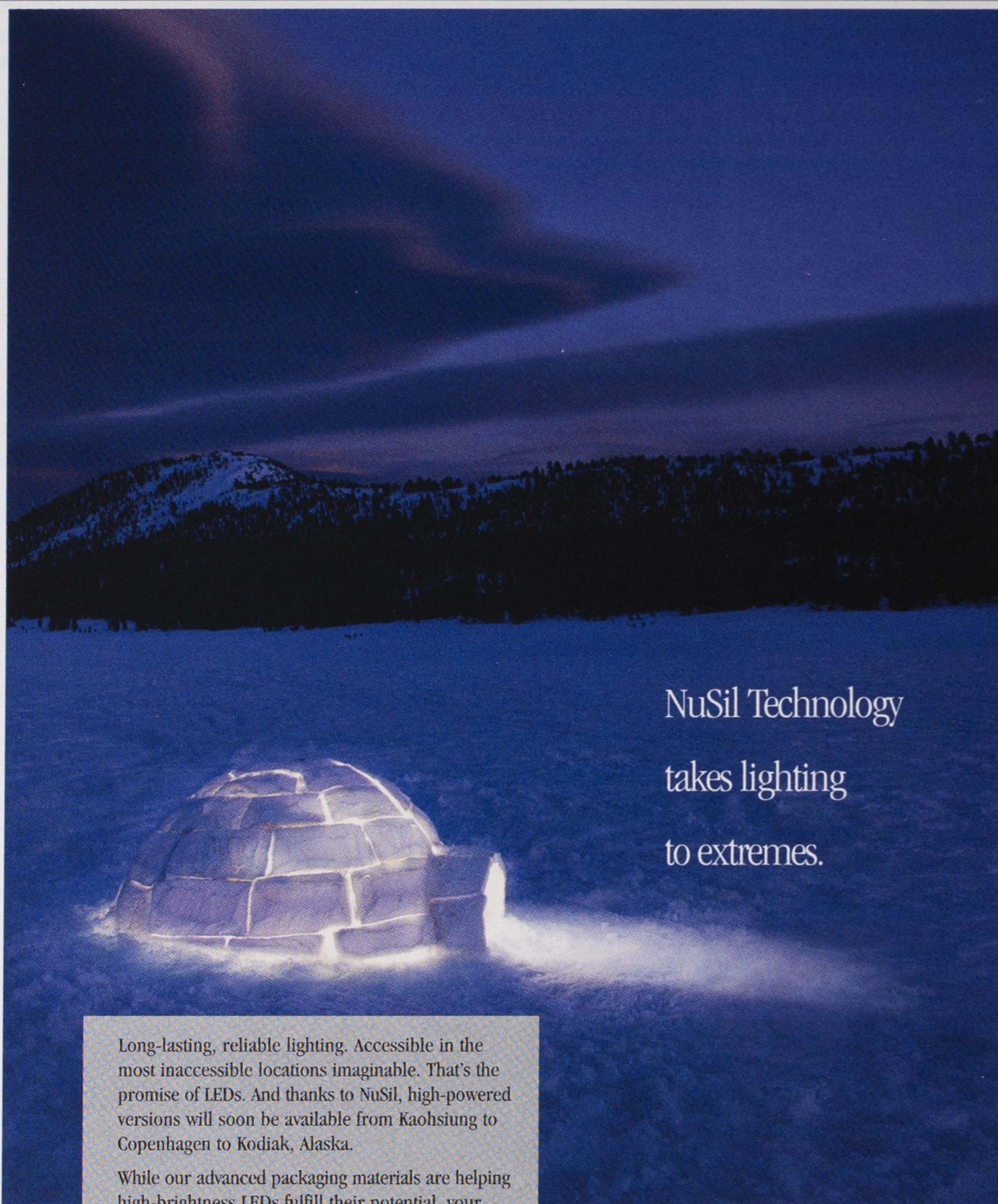
ProMOS chairman M L Chen will oversee the running of the EpiLED, with a trial manufacturing run planned for the second quarter of 2007 and volume production set to follow soon after that. The company told *Compound Semiconductor* that it will focus on manufacturing unpackaged blue LED chip die.

ProMOS has invested NT\$160 million of its own money into the venture and is expected to provide the MOCVD equipment needed for volume wafer manufacturing at the joint venture's fab in the Tainan Science Park. The memory firm hopes to employ its mainstream semiconductor know-how and help to open up new applications like large-scale LCD backlights, automotive lamps and indoor lighting. Hermes-Epitek sells a range of chip processing equipment, including ion implantation, wafer probe, etching and inspection kit.

Already a big semiconductor company, with recent quarterly revenue at NT\$11.7 billion, ProMOS will have sizable resources and experience with which to support the venture.

However, the market entry of the joint venture could be viewed as a late one. Taiwan's LED industry has undergone huge restructuring in the past couple of years, with much consolidation among major manufacturers.

For example, the merger between Epistar and United Epitaxy Company last year created the world's largest LED maker in terms of wafer volumes. However, following two years of similar retrenchment, Taiwan's LED makers have begun to order more MOCVD reactors as demand continues to grow. Both Veeco Instruments and Aixtron have witnessed a significant boost in orders for such equipment.



NuSil Technology
takes lighting
to extremes.

Long-lasting, reliable lighting. Accessible in the most inaccessible locations imaginable. That's the promise of LEDs. And thanks to NuSil, high-powered versions will soon be available from Kaohsiung to Copenhagen to Kodiak, Alaska.

While our advanced packaging materials are helping high-brightness LEDs fulfill their potential, your needs might be very different. From LEDs to fiber optics, large batches to small, our Lightspan brand of products deliver precise, custom formulations and the most complete line of high-refractive index matching adhesives, encapsulants and thermosets available. All backed by more than 25 years of engineering materials expertise.

What? When? Where? If it's NuSil, it's no problem.

NuSil SILICONE TECHNOLOGY

What's your challenge?
www.nusil.com
Europe +33 (0)4 92 96 93 31
USA +1-805-684-8780

©2006 NuSil Technology LLC. All rights reserved. CS0406-PH

SOLAR CELLS

III-V cells power outback homes

Remote homes lying deep in the Australian outback are becoming the first in the world to use an electricity supply generated by triple-junction solar cells.

In a multi-million pound deal to support the deployment of new solar power stations, Spectrolab, the Boeing subsidiary that specializes in multi-junction cells based on compound semiconductors and germanium, is set to deliver half a million solar cell assemblies to the Australian firm Solar Systems, which will manufacture modules, receivers and optics for the concentrator systems.

The power stations being built by Solar Systems are expected to generate more than 11 MW of electricity in total – enough to meet the demands of 3500 homes.

The two companies have been partners for some time and in April this year they developed a 35 kW solar generator. One of its concentrator systems soon began operating in Hermannsburg – deep in Australia's Northern Territory and 120 km from Alice Springs, the closest town of any size. Solar Systems project consultant Julia Birch said: "This installation has been successfully operating since April 2006 and has demonstrated a world record for commercial photovoltaics."

Both Solar Systems and Spectrolab are excited about the potential of the technology. According to Solar Systems managing director Dave Holland, the latest supply deal could be just the start of what may become a more extensive agreement, partly because the Australian government is supporting the development of alternative technologies to diesel to supply power to remote communities. It recently released an extra AUS\$123 million



The concentrator dish at Hermannsburg featuring Spectrolab cells has been operating since April. Inset: the element that houses the triple-junction cells.

(\$93.9 million) for this effort.

"The breakthrough shows the potential for concentrating photovoltaics to change the economics of solar power," said Holland. "We expect this to be the first commercial phase of a very large and valuable relationship."

The concentrator dishes developed by Solar Systems use a set of curved mirrors that direct a concentrated beam of sunlight onto the triple-junction material. A tracker system follows the path of the Sun throughout the day, maximizing the collection of direct sunlight.

In the remote areas that Solar Systems is targeting, the solar power stations provide energy during the day before diesel generators take over at night.



From our Web pages...

visit compoundsemiconductor.net for daily news updates

...Emcore on the up

For the quarter that ended 30 June, Emcore posted total sales of \$42 million, up 26% on the same period last year and slightly up sequentially. Orders for triple-junction solar cells in both terrestrial and satellite applications could drive annual revenue to more than \$200 million next year, say analysts.

...Bookham gets a loan

Bookham, the San Jose, US, company with an optoelectronic wafer fab in Caswell, UK, registered a net loss of \$27 million in its latest financial quarter. Bookham's managers have

arranged a new three-year revolving \$25 million credit facility with the Wells Fargo bank, as well as a \$23.5 million share issue to bolster its balance sheet.

...Whispering lasers

Mid-infrared lasers based on the InSb material system are to be developed by an eight-partner consortium in the UK, thanks to £1 million (\$1.9 million) of funding from the UK Department of Trade and Industry. The QinetiQ-led effort will employ strained-layer engineering to develop new types of lasers that will operate in the 3–5 µm atmospheric window.

Manufacturer
of Molybdenum
Components for MBE.

Specialized Cleaning
& Degassing available



RABOUTET S.A.

250, av. Louis-Armand - Z.I. des Grands-Prés
B.P. 31 - F 74301 CLUSES Cedex - FRANCE
Tel. : 33 (0)4 50 98 15 18 - Fax 33 (0)4 50 98 92 57
e-mail : info@raboutet.fr - <http://www.raboutet.fr>

VENTURE CAPITAL

Solar start-up firm nets \$25 million fund

SolFocus, a start-up company based at the Palo Alto Research Center near San Francisco, has agreed a \$25 million equity deal that will secure a supply of 600,000 multi-junction solar cells from fellow Californian firm Spectrolab.

SolFocus says that its triple-junction supply deal is the "largest to date" in the concentrator photovoltaics industry. It will support a series of field tests and the company's first phase of active deployments through 2007.

The deal with New Enterprise Associates (NEA) and seed investors NGEN Partners and Yellowstone Capital forms part of a series A financing round that SolFocus is aiming to close at \$32 million.

"The strong financial support and world-class team at NEA will allow us to rapidly grow our 10 MW pilot production line," explained

SolFocus CEO Gary Conley. Conley's technology is based on mirrors that concentrate sunlight onto tiny triple-junction solar cells that are based on compound materials.

As well as guaranteeing a long-term supply of the high-efficiency cells, which employ GaAs alloys and germanium substrates, the cash will be used to expand the SolFocus team, accelerate reliability testing and enable pilot production to begin.

That team will include technical expertise from Bell Laboratories legend and Nobel laureate Arno Penzias, who joins as part of the company's technical advisory board.

Penzias was a key member of the research team that discovered the cosmic microwave background – a hugely significant breakthrough that confirmed the Big Bang theory.



Scientists at Cascade Technologies in Stirling, Scotland, say that within the next two years they could develop a sensor based on quantum cascade lasers (QCLs) that would be able to "sniff out" explosives as routinely as existing X-

ray scanners in airports check for metal objects. The alleged plot to detonate improvised liquid explosives on transatlantic flights, uncovered by UK police last month, highlighted the inability of current airport security scanners to check for these types of explosives.

The QCL-based sensor would work by identifying the tell-tale gases given off by substances that could be used as part of a liquid explosive. "You could also implement the technology into existing X-ray screeners," claimed Cascade's chief scientific officer Erwand Normand. "Everything and everyone could be checked." He added that the technology has proved its potential in recent experiments where it spectroscopically fingerprinted two explosive compounds in only 10 ms.

RESEARCH

\$6 million pledged to research silicon lasers

The Microphotonics Center at the Massachusetts Institute of Technology (MIT) has launched a \$3.6 million research project into silicon-based lasers and nanophotonics.

Funded by the US government's Department of Defense under the multi-university research initiative program, the project, called Electrically Pumped Silicon Based Lasers for Chip-Scale Nanophotonic Systems, is headed by Lionel Kimerling, who is director of MIT's Materials Processing Center and Microphotonics Center.

Although optically pumped silicon lasers have been produced by Intel among others, electrical pumping has so far proved elusive – largely because of silicon's indirect bandgap. However, if silicon can be made to lase in this manner, it could have a significant effect on

III-V optoelectronics.

The research partners are considering two approaches. The first aims to use nanocrystalline silicon in combination with erbium to produce a 1550 nm source. This will be based in a dielectric matrix such as SiO₂ or Si₃N₄.

The second approach is to use a germanium layer deposited on silicon as the active laser material. In this case, the germanium is modified to act as a direct bandgap semiconductor, which could create a high-power light source in the milliwatt range.

"Either way, these devices will be integrated into a CMOS process. We want to integrate these optical devices on a microchip; we want to be able to make millions of them," said principal investigator Jürgen Michel.

Introducing...



SIGANTIC[®] RF
...it's watts in the package

GaN-on-Si

WiMAX RF Power Transistors

3.3GHz to 3.8GHz, 50W & 15W, 28 Volt
GaN HEMT available now for production

- Typical OFDM performance for $V = 28V$, $I = 750mA$, center frequency = 3.5GHz. Single carrier OFDM waveform 64 QAM 3/4, 8 burst, 3.5MHz channel bandwidth. PAR= 10dB, 20ms frame & 75% filled
- At 6W Average Output Power, EVM = 2.5%, Efficiency = 18%, and Gain = 11dB.
- At 1.5W Average Output Power, EVM=2% Efficiency = 18%, and Gain = 11dB
- Plastic overmold package for 1.5W device
- Fully Qualified 100mm GaN on Si process
- 15W & 50W at 2.5GHz sampling now

WiMAX Sample Kits Now Available
Ask for Part #: **NPT35050** and **NPT35015** Kit

\$950 for NPT35050 Kit
(Kit includes 2 devices and an application board)

\$650 for NPT35015 Kit
(Kit includes 1 device and an application board)



NITRONEX
CORPORATION

Contact us today for datasheets, application notes, samples and more information

Visit us online at
www.nitronex.com/contact
to find your sales representative
info@nitronex.com
919.807.9100



STOCKS AND SHARES

Transitional Cree seeks next big thing

Still making the bulk of its revenue from sales of LED chips for cell-phone applications, **Cree's** finances are taking a hit as the company looks to move into a new growth phase.

When Cree warned in mid-July that its fourth-quarter profit would not meet initial expectations, investors were spooked and its stock price closed down 25% on the previous day's valuation at just under \$18.

This is not what we've been accustomed to hearing from the Durham, NC, company – since 2002 almost every quarter has brought record-highs in revenue and solid profits as its fortunes followed in the massive upswing of the cell-phone handset business.

That upswing is still in full force, with almost a billion phones expected to sell this year – all of which will feature GaN-based LEDs in the keypad and display backlight modules. The problem for Cree is that, unlike in the RF space, where GaAs chipmakers have benefited from the need for more complex, higher-value components, LED backlighting is now largely commoditized.

Greater competition has been accompanied by protective measures from rival chip manufacturers and the resulting drop in average selling prices is now outweighing any increase in unit sales – and hitting Cree's margins. In the company's most recent investor conference call, CEO Chuck Swoboda said that he expected this market to remain relatively flat.

But there are other factors that are squeezing Cree – some apparently fleeting, but others are longer-term trends. The first is production. A quiet period of relatively low fab utilization in early summer was followed by a sharp spike that the company failed to predict and had difficulty coping with. Demand has since tailed off again and these sudden variations in manufacturing volumes make efficient management of a chip fab harder.

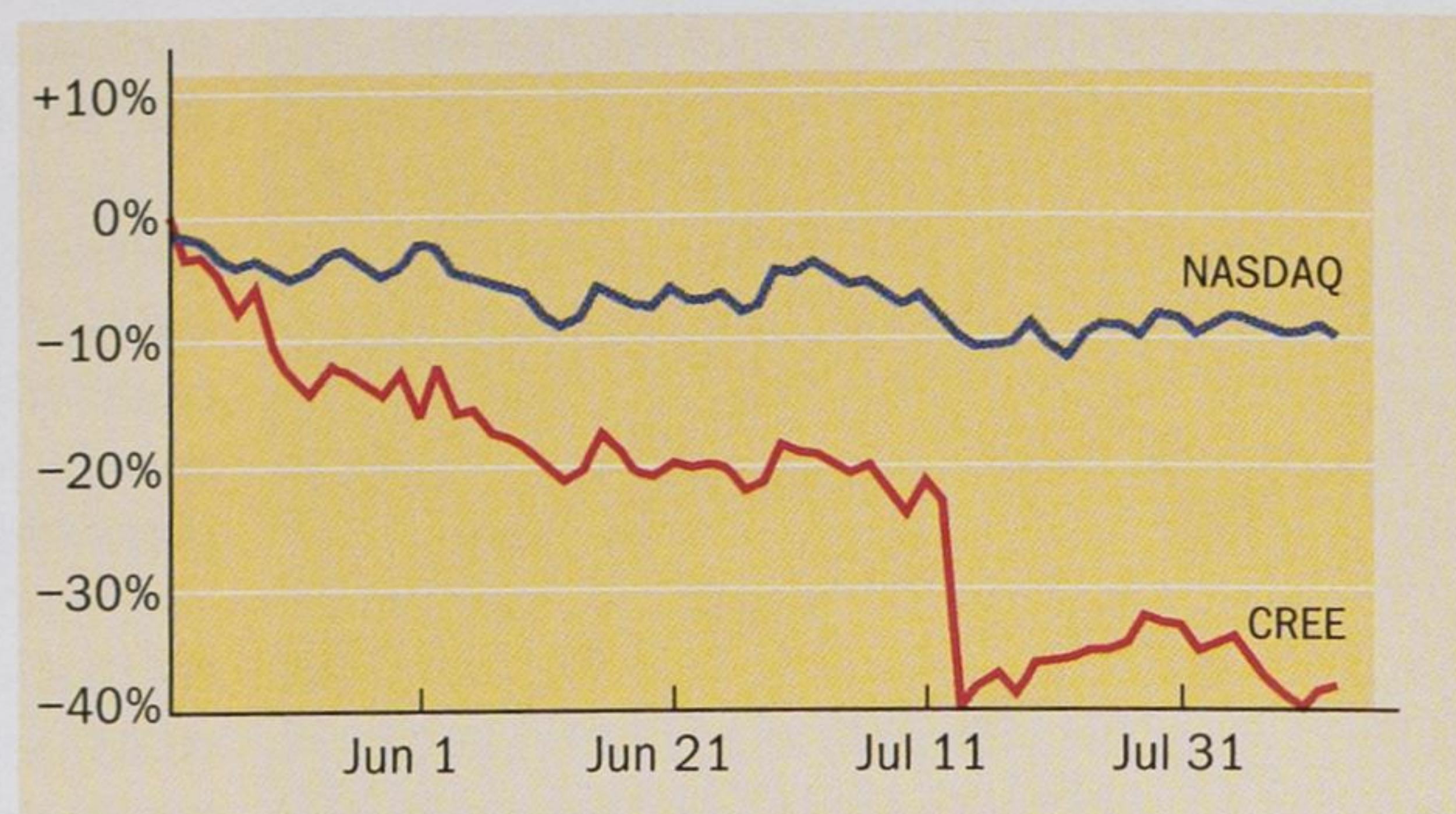
Bottom line squeezed

The second squeeze to Cree's bottom line is intentional and has come from its rising research and development spending. Even after some considerable stock compensation expenses are taken into account, this has grown by 25% in only 12 months, coming in at nearly \$51 million or 12% of total fiscal 2006 revenue.

Now in the middle of a strategic transition, this is all part of Cree's push to reinvigorate its business and reproduce the record-busting performance that has been wooing investors over the last few years. At the moment, that means absorbing the costs of ramping up the production of Schottky diodes for applications in power switches, as well as the XLamp packaged LED components.

The power device market is going to be an important one for Cree. Having now officially opened its new production facility in Research Triangle Park, NC, where it will manufacture these chips, the foundations are in place to exploit the global drive to reduce energy waste by replacing relatively inefficient components with those based on GaN and SiC.

In the latest quarter, sales of high-power electronic devices were just under \$5 million, representing a 29% sequential rise and up from just \$1.8 million in the equivalent quarter of 2005. Swoboda says that it will take time to build both the Schottky diode product line-up and the



While most technology stocks have been hammered since peaking in early summer, Cree's have underperformed the Nasdaq index and are yet to recover from the 25% drop it suffered in mid-July when it warned of lower-than-expected profits. Source: Yahoo Finance.

associated power device "brand". He estimates that, in terms of their commercial maturity, the power products are about one year behind the XLamp.

Also fitting into this future investment category are Cree's "Colorwave" lighting modules for large-scale liquid-crystal displays. Although some rival products have been commercialized, this is, for now, a long way from being the volume market for HB-LEDs that has been envisaged. Cree's own experience probably explains why. Although the backlight development team has met every technical target that it has been set, there is still a problem: cost.

Cree's LCD-making customer needs the LED backlight at a lower cost than the US company is able to provide it for at the moment and this could hamper its commercialization. The expected date for initial deployment of Colorwave modules in production LCD TVs has now slipped back into 2007.

In the short term, Cree's shareholders may have to put up with lower margins, squeezed profits and flat sales figures (guidance for the current quarter is \$106–110 million compared with \$106.7 m in the period that ended on June 25). The company even admits that forecasting the next two quarters is tricky. But if Swoboda and the gang can bring the right products to market at the right prices, then investors playing the long game will reap the benefits. "We are in the middle of an exciting transition," said Swoboda. "We are trying to build a much larger business and to deliver real energy savings."

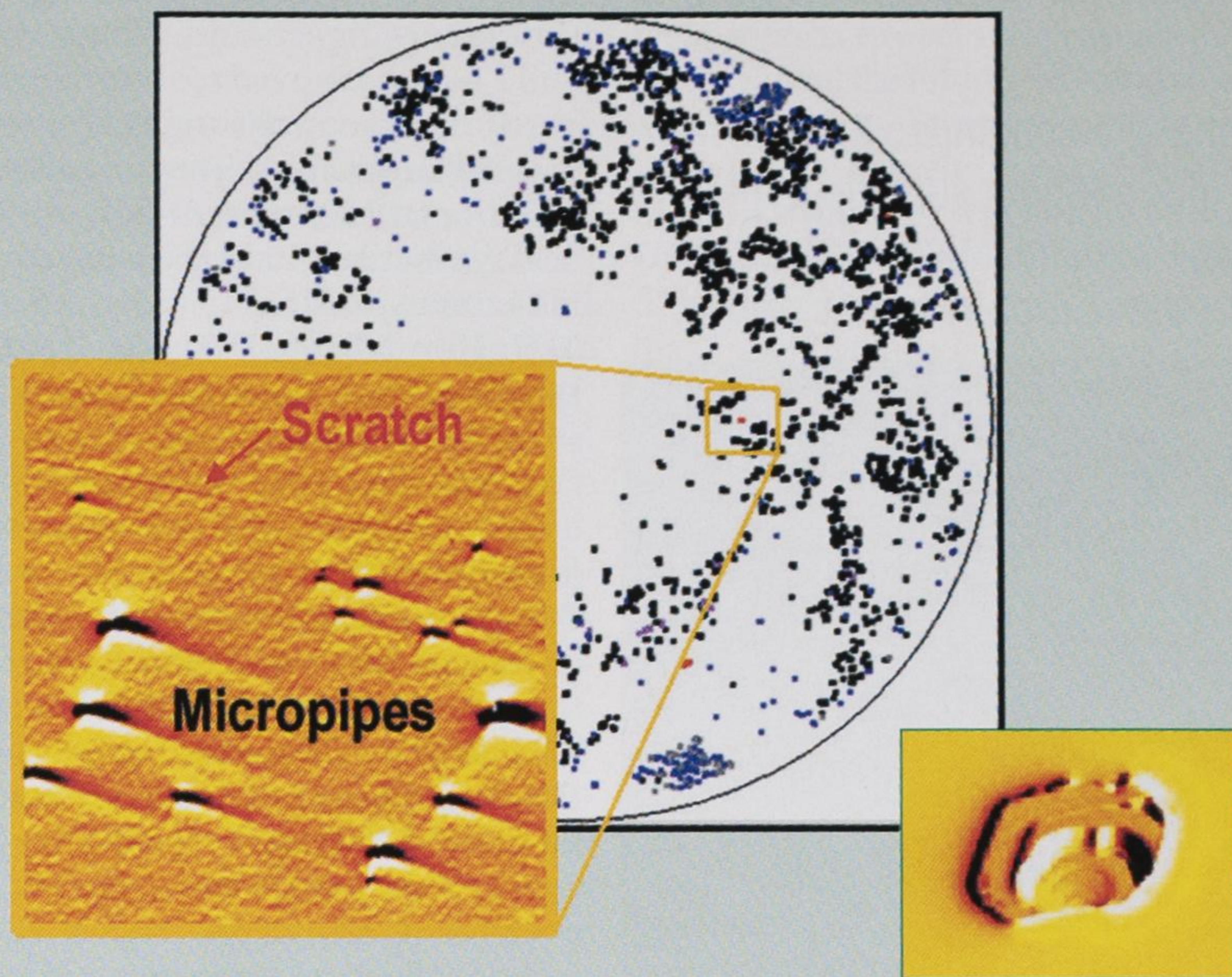
Quite how large Cree becomes will depend on many factors aside from its own execution. Sticking his neck out a little, Swoboda says that the goal is to increase revenue by 60–70% over three years. That would mean an annual revenue of \$700 million in fiscal 2009 and would be great news for the wider industry.

Not that all of that increase in revenue is likely to be a result of organic growth. Cree now has \$376 million burning a hole in its deep pockets and its acquisition of zero-micropipe SiC substrate developer Intrinsic this summer seems likely to be followed by similar deals that will broaden its net.

"We are trying to build a much larger business."

Chuck Swoboda
Cree CEO

Detects SiC micropipes, then maps their locations



OSA images offer
built-in defect review



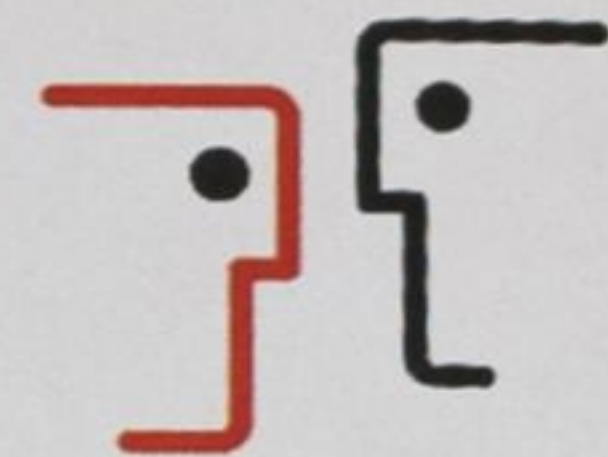
We count micropipes where it counts.

High-resolution surface inspection for silicon carbide substrates.

For silicon carbide devices, monitoring micropipe defect densities is critical to achieving yield targets. Visual inspection methods are slow, operator dependent and can be destructive. Our Candela™ optical surface analyzers use multiple measurement methods simultaneously to detect and classify particles, surface defects and subsurface crystal defects like micropipes. These high-resolution images offer a rapid way to review wafer quality as well as individual defects. Which means you can nondestructively measure micropipe density where it matters most— on your product substrates.

- Surface inspection systems for transparent materials such as SiC, GaN and sapphire
- Detect and classify surface and subsurface crystal defects like micropipes
- Accommodates wafer sizes from 50 to 300 mm
- Manual or automated cassette-to-cassette operation
- For more product information, go to

www.kla-tencor.com/candela



IQE

IQE slots in the final piece of the puzzle

With the electronic materials division formerly belonging to Emcore now under its wing, IQE is the world's biggest independent supplier of III-V epiwafers to the compound semiconductor industry. Michael Hatcher asks **Drew Nelson**, the CEO at IQE, about the company's latest move.



Drew Nelson : the CV

1981: Leads MOVPE group at British Telecom Research Labs.

1988: Co-founds Epitaxial Products International (EPI).

1992: Becomes CEO and chairman of EPI.

1999: Merges EPI with (QED) to form IQE.

2000: Awarded silver medal by Royal Academy of Engineering.

2001: Receives OBE in the Queen's Birthday Honours List.

2004: Elected fellow of the Royal Academy of Engineering.

MH: How does this acquisition fit the IQE strategy?

DN: We merged with Quantum Epitaxial Devices (QED) in 1999 principally to give ourselves a position in the wireless market place with MBE technology. That business is focused on PHEMTs and has been very successful. It has established strong positions with a number of key players, but what was obviously missing was an MOCVD electronic position, principally for HBTs and upcoming materials like BiFETs, BiHEMTs and GaN. The electronics materials division (EMD) acquisition fits perfectly into that strategy.

It was a good time for both IQE and Emcore to make the transaction. As a company Emcore is focusing more on systems so the EMD was becoming significantly non-core to their main business. They were keen to find a good home for it and IQE fits that bill perfectly.

MH: How will your customers benefit?

DN: It allows our customers to deal with a single company for their complete range of current and future products. Consolidation of supply chains is a key trend in the industry and we can offer more cost-effective products, a complete route to future product roadmaps, and large-capacity. Capacity is an important issue. Companies are faced with the prospect of either having to install internal epi if they don't have it – which is obviously very

costly and time consuming – or risk expanding their existing capabilities. They can also recall the problems of 2001 and 2002 quite vividly. At IQE, the entire business is about outsourcing epi effectively and we're committed to expansion.

MH: How is MOCVD capacity affected?

DN: EMD was coming up against some capacity constraints. For some of their customers there were some concerns about future investment in capacity. IQE does have some spare MOCVD capacity, as a result of the investments that we made two or three years ago. In Europe, our main focus is optoelectronics, but we have developed HBT capability here and we can use some of the spare capacity [in Cardiff, UK] to help EMD.

MH: Will we see more acquisitions by IQE?

DN: From a technological point of view we've got all the pieces of the puzzle. We'd never rule out more acquisitions if they made sense, but it's not something that we're going all-out for. In general, I think that further consolidation is probably inevitable. As the largest independent epiwafer supplier, we're in a position to command keener prices [for materials] than a smaller supplier. We should therefore be able to offer our customers better, more secure, deals than some of our rivals.

Small epi companies will have to come up with something that's specific and very attractive to the supply chain to overcome the disadvantages in terms of security of supply, economies of scale and future roadmaps.

MH: How does EMD fit into the overall business?

DN: The new IQE-RF site has a solid managerial and operational team, who have built the business strongly. We don't envisage making any fundamental changes and it'll be run as a stand-alone entity. The big benefit is that there can be lots of cross-fertilization of ideas and we can obviously purchase things like raw materials in bulk.

MH: Do Asia-Pacific suppliers pose a threat to IQE?

DN: There is MOCVD capability supplying HBTs into the market place from Taiwan. Through the EMD acquisition, we have an answer for that. I think that the Far East companies are starting from a very low base, even if they are increasing very rapidly. The scale of our operation will mitigate the competition.

MH: How are current business conditions?

DN: We're pretty excited by wireless because there are a number of drivers in the market place – from Wi-Fi to WiMAX to 3G. The EMD division has a strong BiFET technology, which is really beginning to get a lot of interest. It also has GaN capability for base station applications, as well as the existing InGaP HBT business for CDMA and W-CDMA protocols. Add to that the products from IQE and we can cover the entire wireless space. Market growth is forecast to continue and more GaAs will be used [in handsets] because of multiple radios and faster communications, so I think we're in a very strong position and we're very bullish about the future.

In optoelectronics, there are lots of new applications that require VCSELs in very large quantities – and that's

exciting for us as we are one of only a few suppliers of VCSEL wafers in the world. For example, the new laser [computer] mouse uses VCSELs instead of red LEDs. Other applications include laser printers, photocopiers and short-distance communications.

Revenue from the Cardiff business is growing at about 25–30% per year. Selling prices have decreased a little bit, but not that much. That growth rate illustrates the buoyancy of the market although, undoubtedly, wireless is growing more rapidly than optoelectronics.

MH: Where is the market for GaN technology?

DN: It is driven by the needs of 3G base stations and although right now it is difficult to predict when base stations featuring GaN will appear, we're certainly getting quite a lot of interest in the technology and EMD is selling the wafers on a commercial basis.

MH: How much revenue will EMD add?

DN: We expect revenues to continue to rise, particularly as we increase production capacity. Next year, analysts expect the increase to be around \$24 million on an annual basis. With synergies, we will try to improve on that.

MH: Is IQE close to becoming profitable again?

DN: [As part of Emcore], EMD was already approaching profitability. By utilizing existing spare MOCVD capacity within the IQE group of companies, the scale of the operation will increase. Our purchasing power in the supply chain will also be greater than Emcore's would have been as a stand-alone business. Additionally, there are a number of operational technologies and

implementations that we can exchange with EMD. Two heads are always better than one and if we get the best of both worlds then we should be able to improve production efficiency across the business.

As a group, IQE is approaching profitability and analysts' reports expect full profitability next year. We're excited about the future and being able to supply customers with a full range in the wireless market and the other angles of the optoelectronics and silicon businesses.

MH: In what way will you be adding capacity?

DN: In the short term, we will be getting more wafers through [existing] reactors, but very quickly following that up with additional capacity at both EMD and full utilization of IQE's MOCVD capabilities in Cardiff.

Eventually, that will mean more reactors, but not now. We expect to begin filling up our unused capacity very quickly now and that will stimulate the need for additional tools. The other advantage of having MOCVD operating out of both Cardiff and New Jersey is that we will have two independent sites for MOCVD. So for any customer who is using IQE, they have the security of knowing that two completely different sites are able to supply the same product.

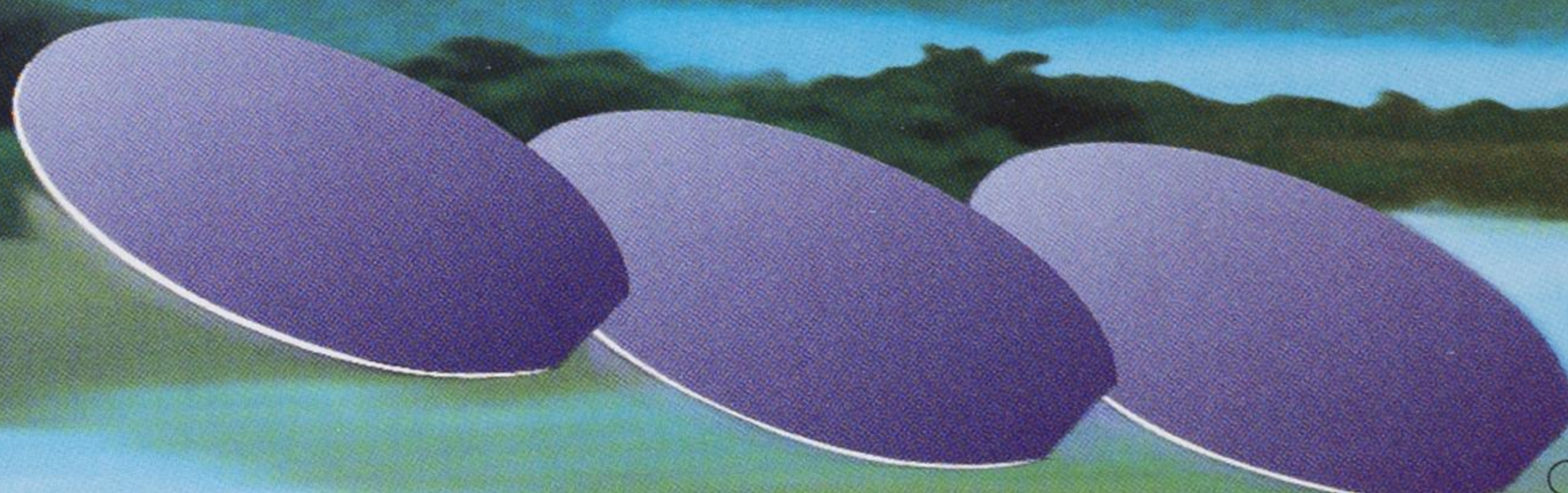
MH: What else will the capital raised in the £12 million share issue be spent on?

DN: With a rapidly expanding business, working capital has to be funded. We operate a number of supply-managed inventory agreements with customers, which gives them a buffer stock, and that also has to be funded.

Bavarian High Tech

III/V-Reclaim GaAs InP

The Cheapest Way to Excellent Quality.



III/V-Reclaim

Werkstraße 13

84513 Töging / Germany

Telefon: +(49) 8631-394777

Telefax: +(49) 8631-394778

E-Mail: Reclaim@t-online.de

Internet: www.35reclaim.de

○ We recycle your GaAs and InP wafers (all formats and sizes)

○ One and double side polished wafers

○ Best surface quality for direct use in Epitaxy

○ Backside thinning of fully structured wafers

○ Thin wafers (100 µm)

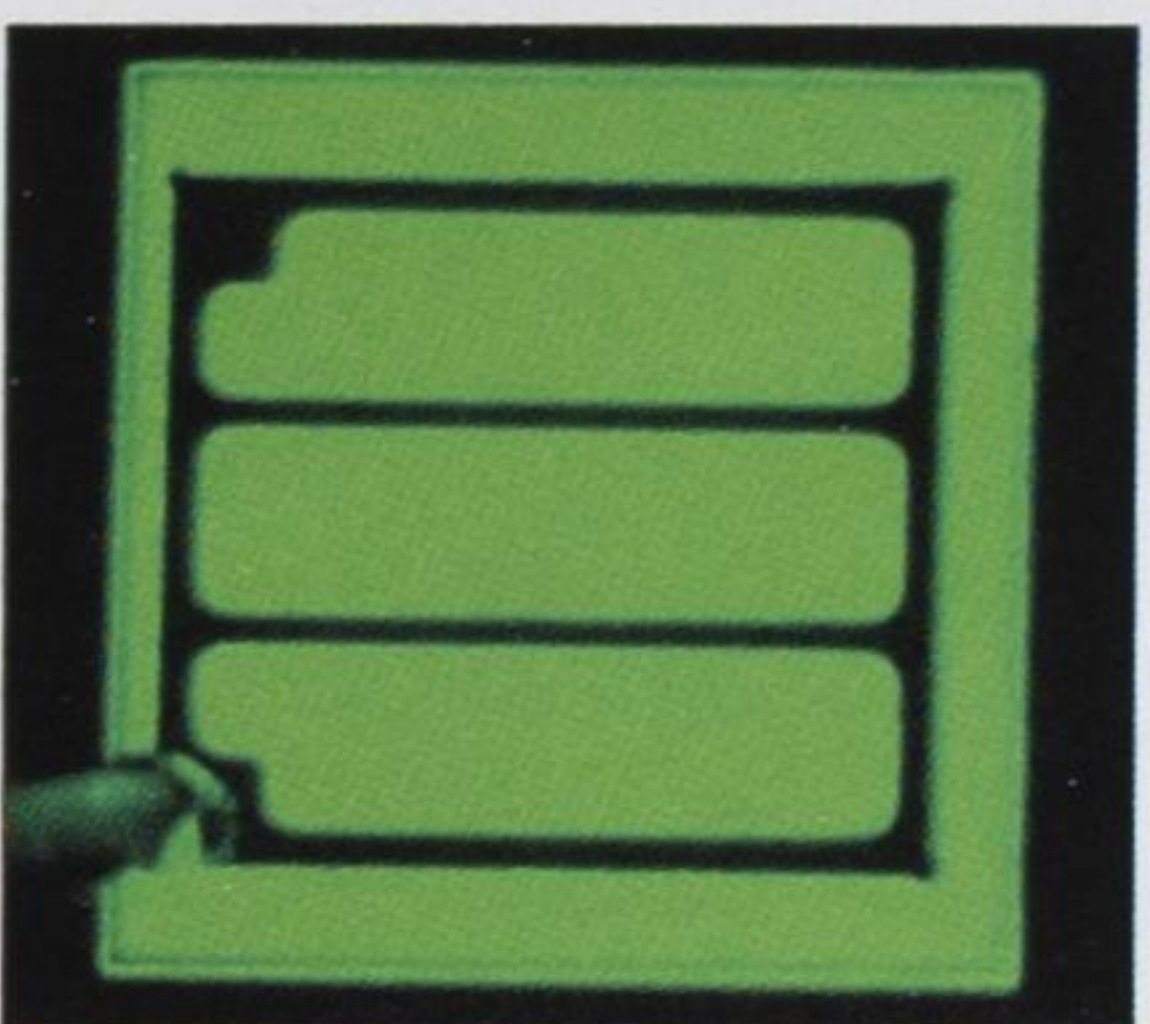
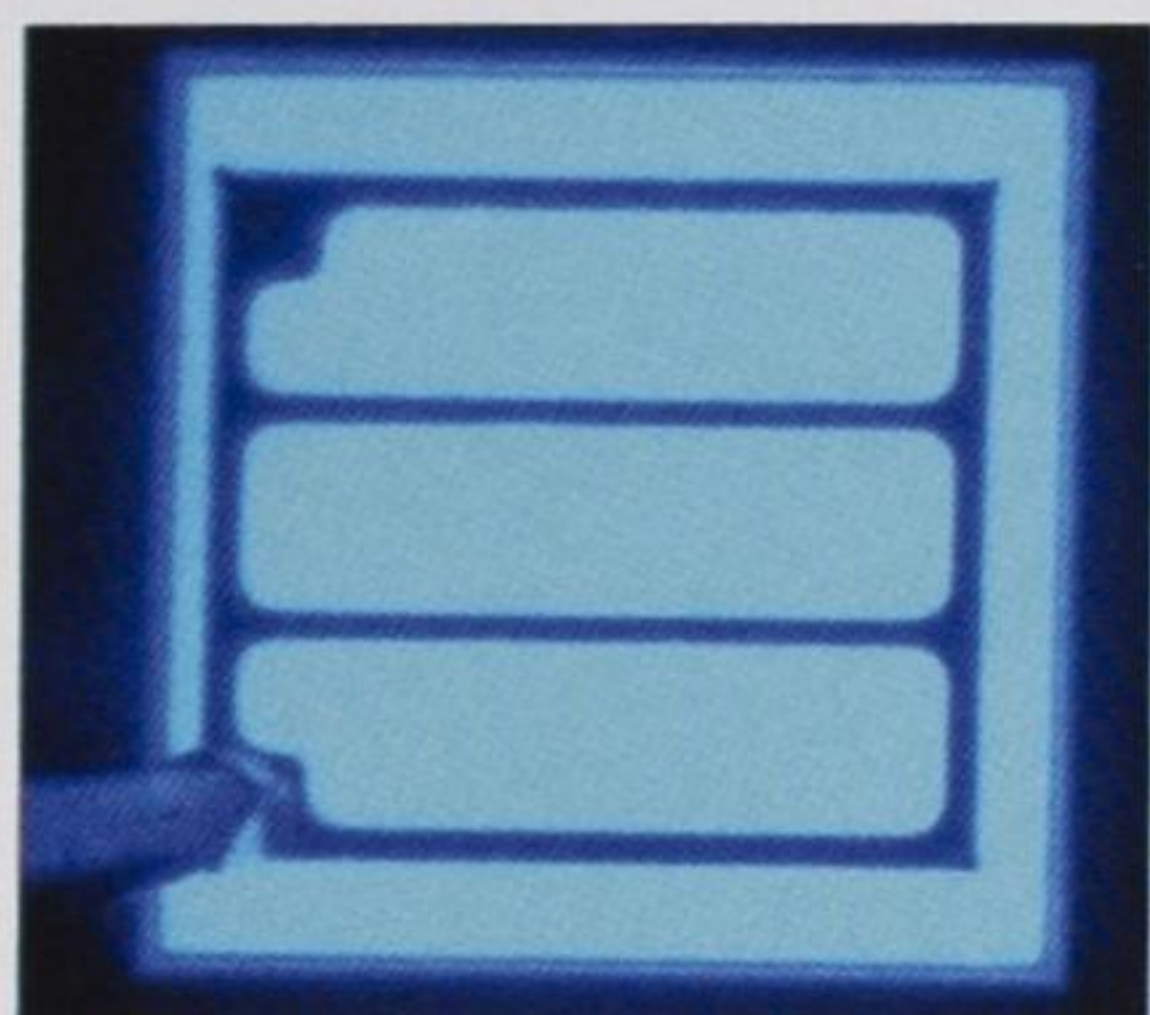
○ Single wafer processing possible

○ We buy used wafers and sell recycled wafers

Sapphire-free vertical design

Poor current handling and thermal management are suppressing the performance of LEDs for solid-state lighting applications. These problems can be avoided, however, by switching to a low-cost vertical design and a metal alloy substrate, says **Trung Doan** from SemiLEDs Corporation.

GaN LEDs are widely used in handset keypads, back-lighting units, camera flashes and full-color outdoor displays, but their output is, as yet, insufficient for significant penetration into the solid-state lighting market. This is primarily because the LEDs have relatively poor thermal management characteristics and cannot operate at the high injection currents required for super-bright emission. However, these issues can be overcome by producing GaN LEDs on electrically and thermally conducting substrates, and this is an approach that we have pioneered at SemiLEDs. Our vertical LEDs on metal substrates (VLEDMS), which are built using low-cost mass-production processes, use a novel vertical design and feature a metal alloy substrate. These emitters deliver many benefits over conventional and flip-chip LED designs (see figure 1, p17) and can deliver 75 lm/W at 350 mA drive current, which is among the highest output efficacies achieved to date.



SemiLEDs can produce 80 lm/W 1 mm² GaN-based LEDs in a variety of colors using its proprietary metal alloy substrate technology. The light emission pattern is highly uniform, thanks to the improved current spreading in the n-GaN layer.

Sapphire's drawbacks

The issues affecting conventional GaN LEDs stem from the poor thermal and electrical properties of the sapphire substrates that they are grown on. Sapphire has a thermal conductivity of only 35 W/mK (see figure 2, p17), which restricts the LEDs' operating current. The material is also an insulator and so the n-contact cannot be attached to the back of the substrate, but has to be formed on top of the n-type layer. This means that the active material has to be removed from the chip, which decreases the emission intensity by 20–30%. Having both contacts on the top side of the LED also results in current transport through the n-GaN layer, which produces current crowding and a higher dynamic resistance that increases the device's temperature.

Conventional GaN LEDs also suffer from non-uniform light emission due to low current spreading in the p-GaN layer. This can be overcome with either semi-transparent contact layers or interdigitated electrode arrays that spread the current across the device. However, semi-transparent layers also absorb some of the chip emission and can reduce the output power.

These are issues that have caused leading LED manufacturers such as Lumileds to turn to designs that use a flip-chip geometry. However, this approach also requires material from p-GaN and active layers to be



SemiLEDs Corporation designs, develops, manufactures and sells high brightness LED company is headquartered in Milpitas, in Silicon Valley, CA, and has operations in, Msir

removed in order to form the n-type contact, which again reduces the emitting area. Current transport from anode to cathode is still routed along the n-GaN layer, which means that the current crowding and higher dynamic resistance problems remain.

One advantage of flip-chip LEDs is an improvement in the heat dissipation over conventional structures. Flip-chips also produce higher extraction efficiency than the conventional LEDs, partly because of the patterned or textured sapphire surface, but these structures are quite complicated to produce.

SemiLEDs' VLEDMS overcome many issues that restrict the performance of conventional and flip-chip LEDs. For example, there is no need to remove any material to form the n-type electrode pad, which boosts emission compared with equivalently-sized GaN-on-

gn boosts LED performance



brightness LEDs using proprietary technologies that are protected with over 20 patents. The facilities are located in Hsinchu Science Park, Taiwan.

sapphire LEDs. Current crowding is avoided because the current passes through the device in a vertical direction, while dynamic resistance is cut significantly.

Sapphire-free benefits

Our chip geometry also improves the current spreading in the device. This allows the chips to be scaled to larger sizes without any loss in performance and circumvents the need for semi-transparent conductive layers that reduce the output efficiency.

In addition, our VLEDMS dissipate heat more effectively than conventional and flip-chip LEDs, thanks to the higher thermal conductivity of a copper alloy substrate. This increases their maximum operating current and output power and makes them more suitable for solid-state lighting applications.

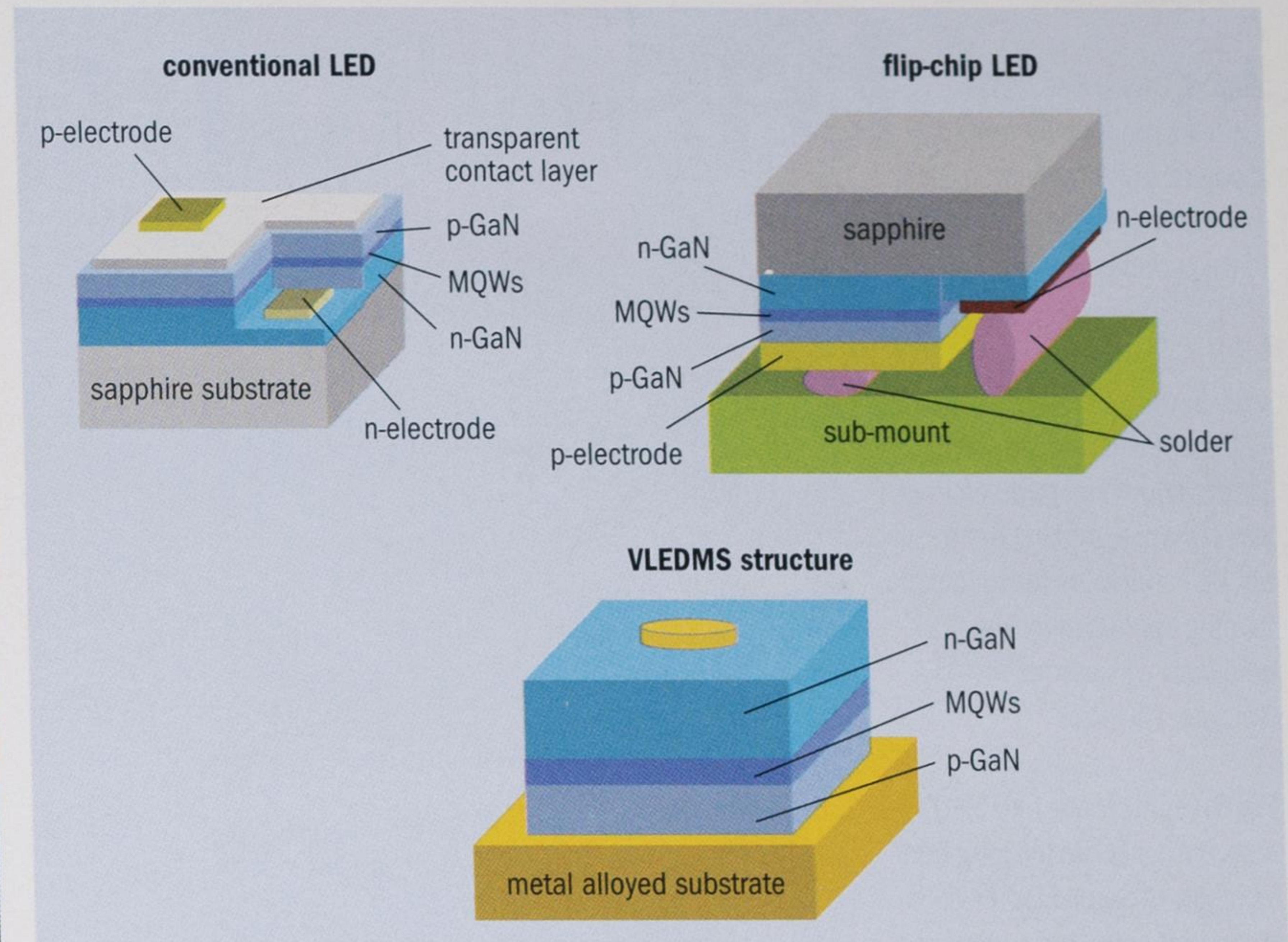


Fig. 1. SemiLEDs has tackled several of the problems that limit the performance of conventional (a) and flip-chip (b) LEDs, such as current crowding and device heating, by employing a vertical structure and a metal alloy substrate (c) with n- and p-electrodes on opposite sides of the device.

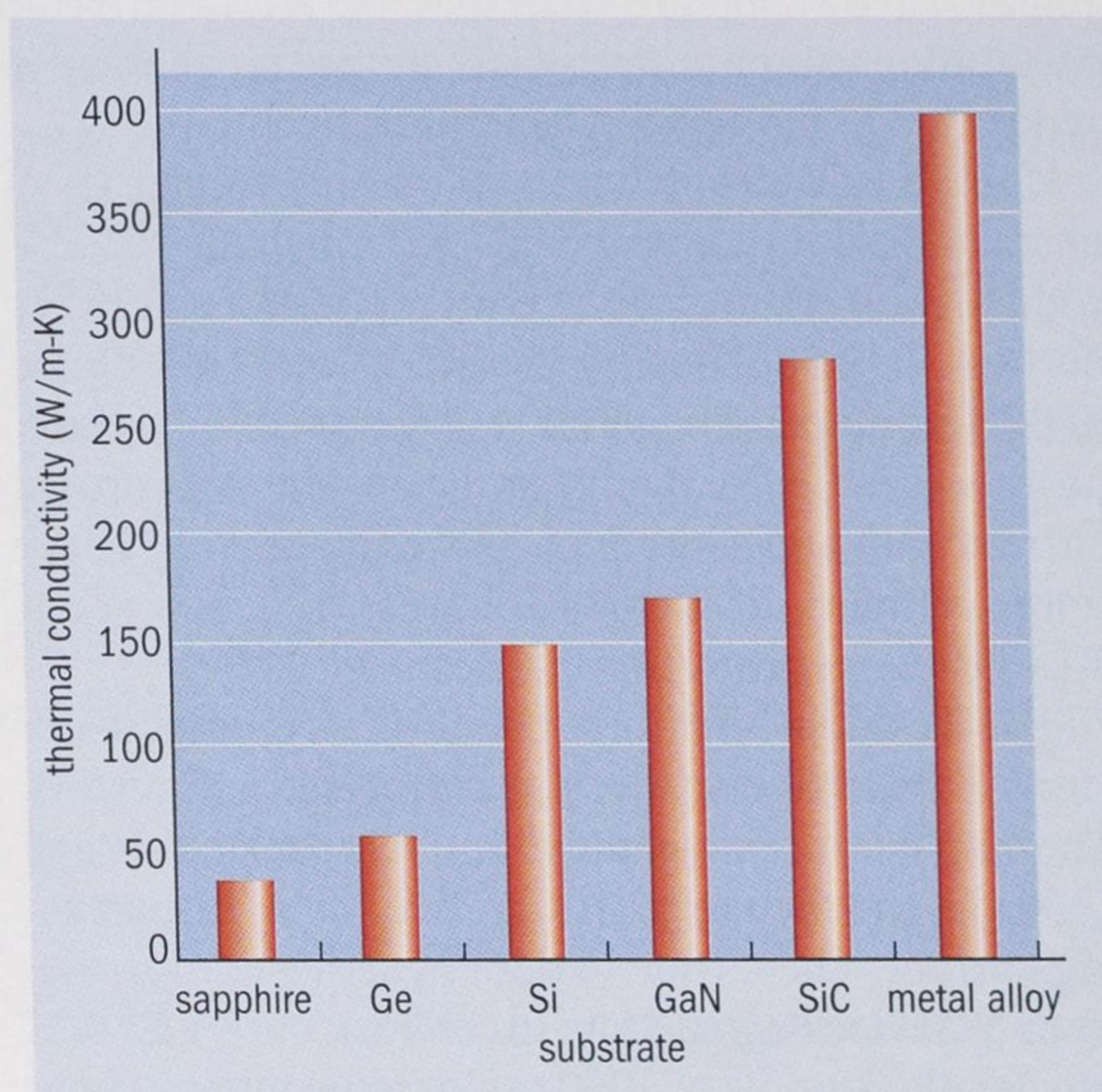


Fig. 2. Sapphire has the lowest thermal conductivity of all the common substrates used to manufacture GaN LEDs. SiC, which is used by Cree, offers a significant improvement, but better still is a metal alloy employed by SemiLEDs.

The structure of our VLEDMS, which we have manufactured as blue, green and ultraviolet 1 mm² LED chips, is shown in figure 3 (p18). Using our patent-pending epitaxial deposition technology, these LEDs are grown on sapphire along with an additional structure that enables

Fig. 3. (left) SemiLEDs' vertical LEDs comprise a mirror directly deposited on metal alloy substrate, a 0.2 μm thick p-GaN/p-AlGaIn layer, an InGaIn/GaN multiple quantum well active region and a 4 μm thick n-GaN layer.

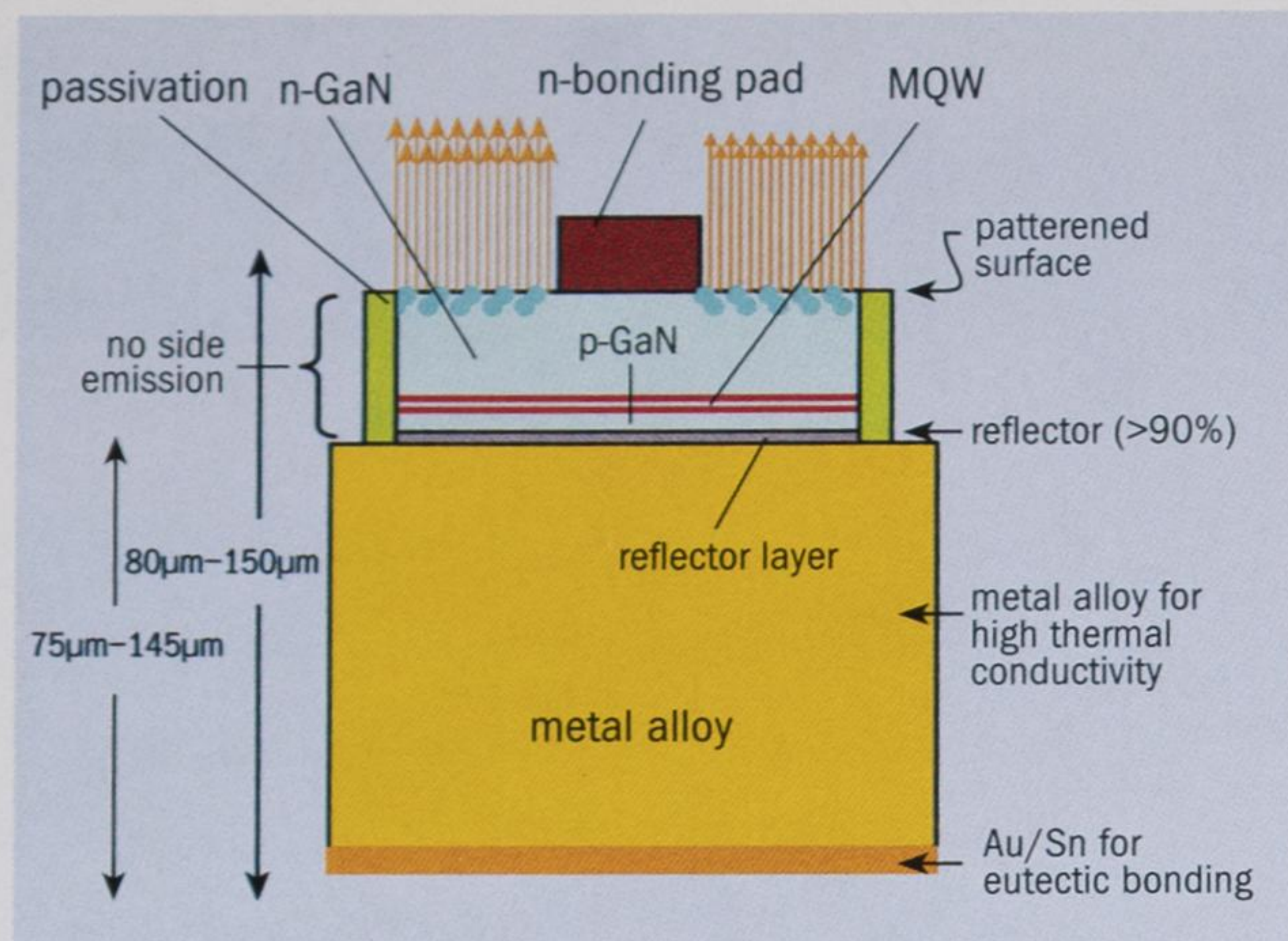


Fig. 4. (right) SemiLEDs' devices produce an output power that is higher than GaN-on-sapphire LEDs, particularly at drive currents of over 1000 mA.

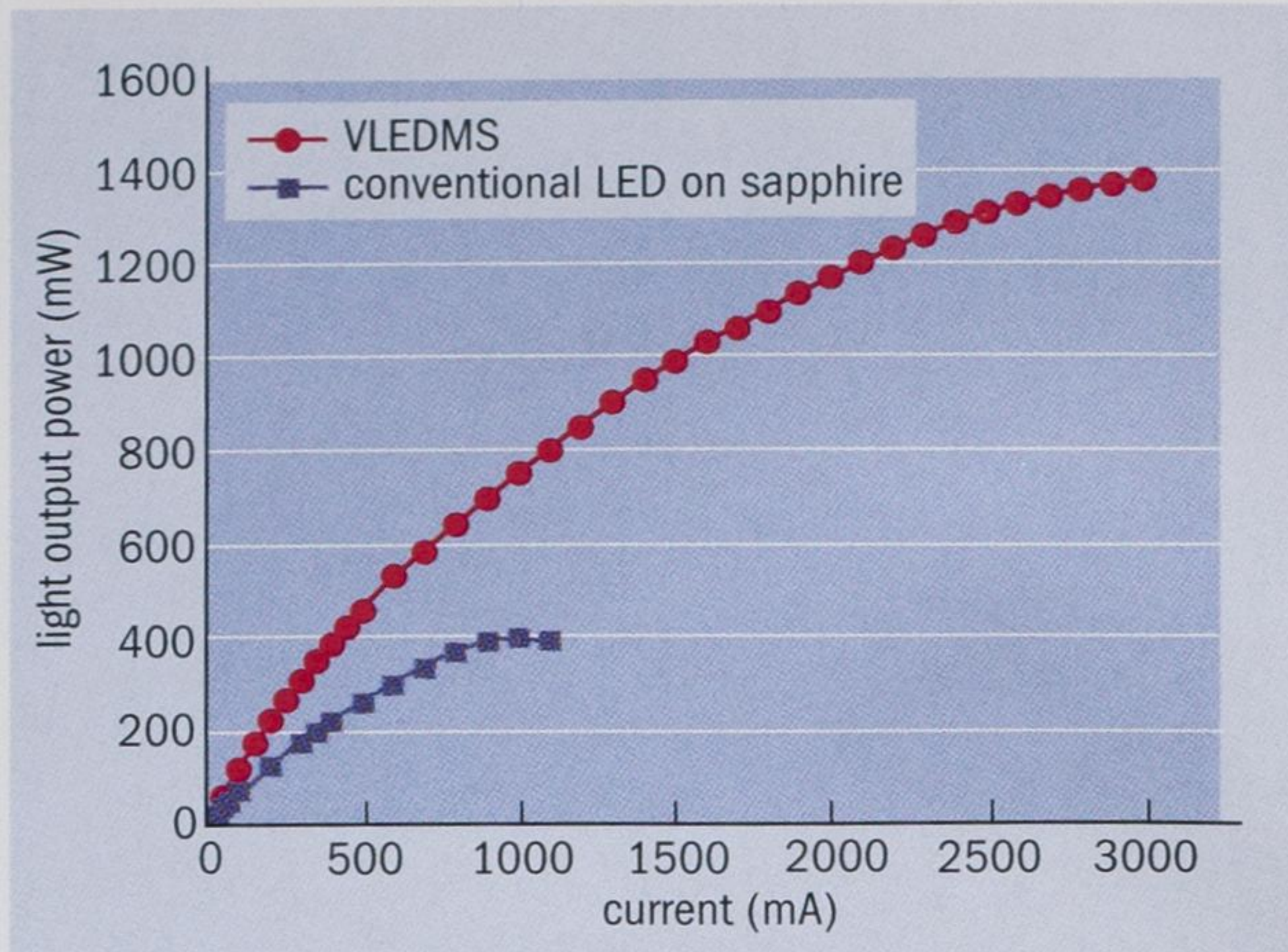


Fig. 5. (left) SemiLEDs' vertical LEDs can be scaled to larger sizes without any trade-off in performance, making them strong candidates for solid-state lighting applications. The efficiency was normalized to a 350 μm chip size.

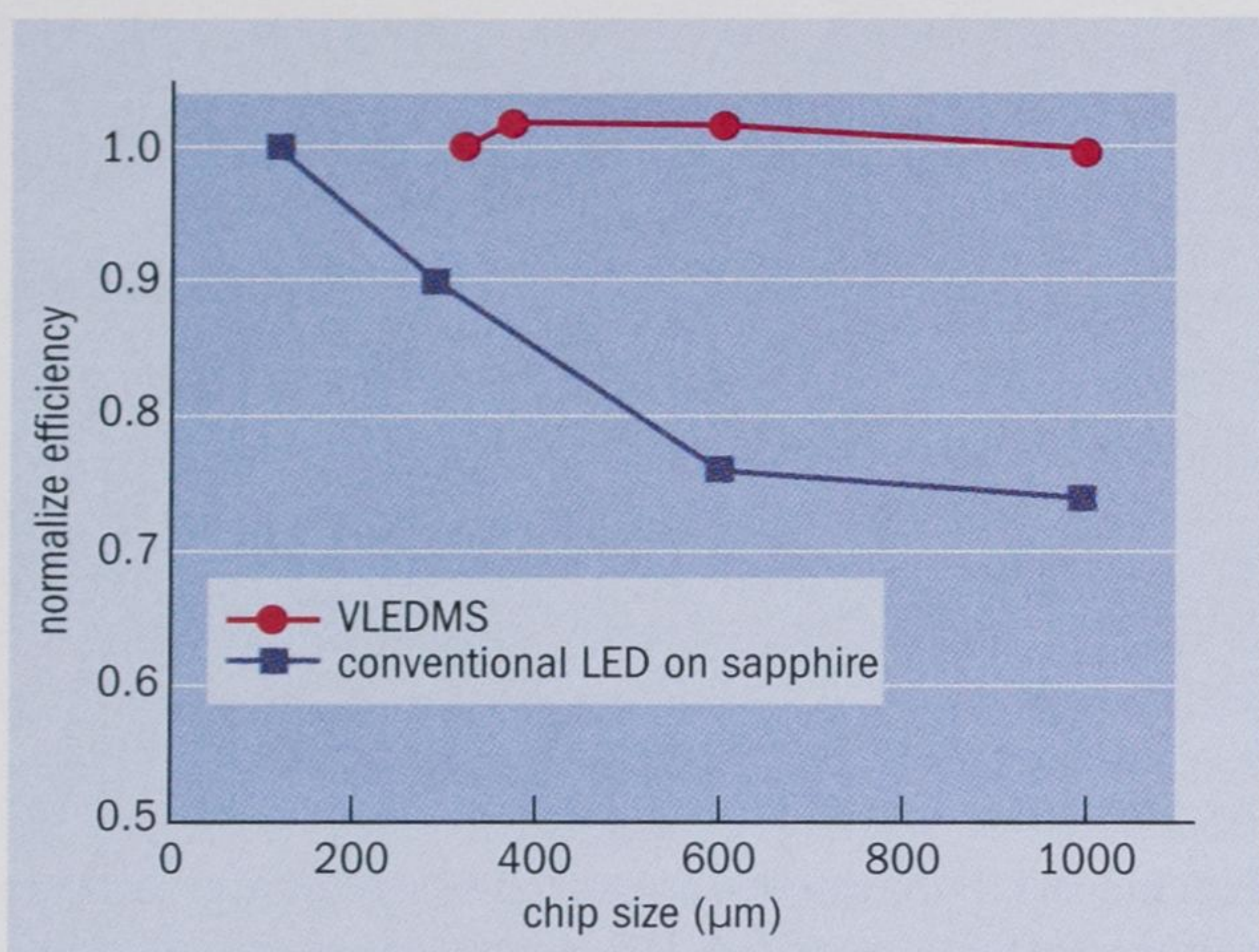
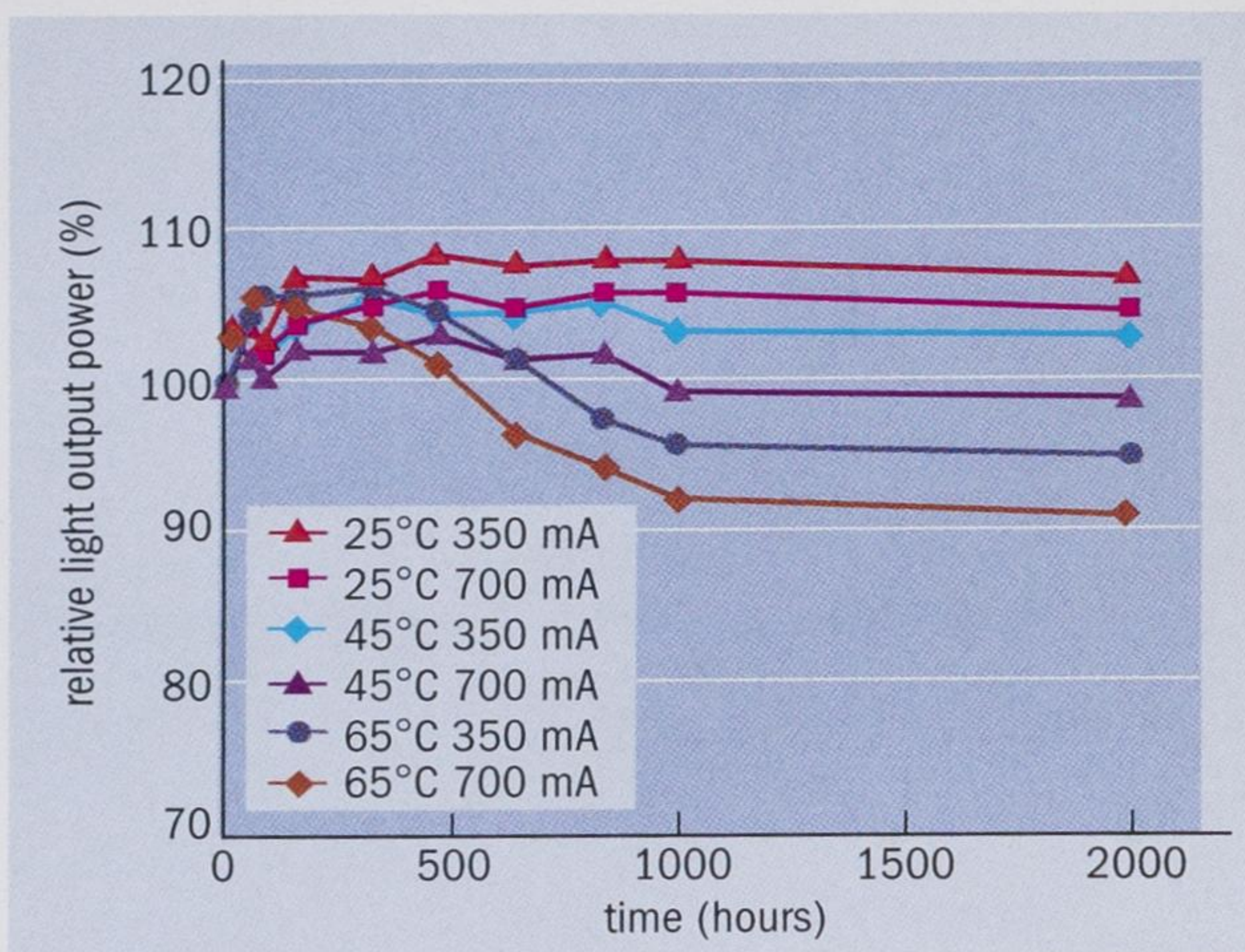


Fig 6. (right) These reliability tests demonstrate the long-term reliability of SemiLEDs' devices. Measurements were carried out in a closed space at a stable, ambient temperature.



removal of the sapphire. After the LED is formed on the metal alloy substrate, the n-GaN surface is patterned to reduce losses through total internal reflection.

Our VLEDMS have superior current-voltage (I-V) characteristics to conventional LEDs, including a 0.2 V reduction in the forward voltage at 350 mA drive current. These LEDs also have a dynamic resistance of 0.7 Ω , compared with 1.1 Ω for conventional GaN-on-sapphire LEDs, thanks to the switch to a vertical current path and a larger p-GaN contact area. These improvements increase the output efficiency of our VLEDMS over conventional designs.

The increased brightness of our LEDs is particularly significant at higher injection currents (see figure 4). The output from conventional emitters peaks at around 1000 mA and then falls off significantly with increasing current. This is due to poor heat dissipation that leads to device degradation. In contrast, our VLEDMS can handle currents of 3000 mA or more without light output power saturation, thanks to the superior thermal conductivity of metal alloy substrates.

Performance independent of size

We have demonstrated the excellent scaling properties of our VLEDMS by manufacturing a range of chips with various dimensions and measuring their output per unit area (see figure 5). While conventional sapphire-based LEDs suffer from a significant drop in efficacy at larger chip sizes, this problem does not appear

to impact on the performance of VLEDMS.

Figure 6 shows the results of our reliability tests on 1 mm² VLEDMS chips, which were packaged using a silicone filling and mounted onto a heat sink. The measurements were made at 350 mA and 700 mA drive currents, and ambient temperatures of up to 65 °C, which led to a range of junction temperatures of up to 120 °C. Our chips, which produce an output that is equivalent to more than 75 lm/W from a white LED, showed only a small decline in light output power over time and this change can be kept below 10% even after a 2000 h burn-in test. At room temperature – the temperature at which the majority of our customers will use these devices – we observed no degradation in light output.

This proven reliability, in conjunction with the excellent heat dissipation characteristics and output efficiencies of typically 75 lm/W or more, clearly illustrate the advantages of these devices over conventional LEDs. These LEDs are already being produced in large volumes at high yields and they offer a lumen/\$ figure of over 100, which makes these emitters the device of choice for solid-state lighting.

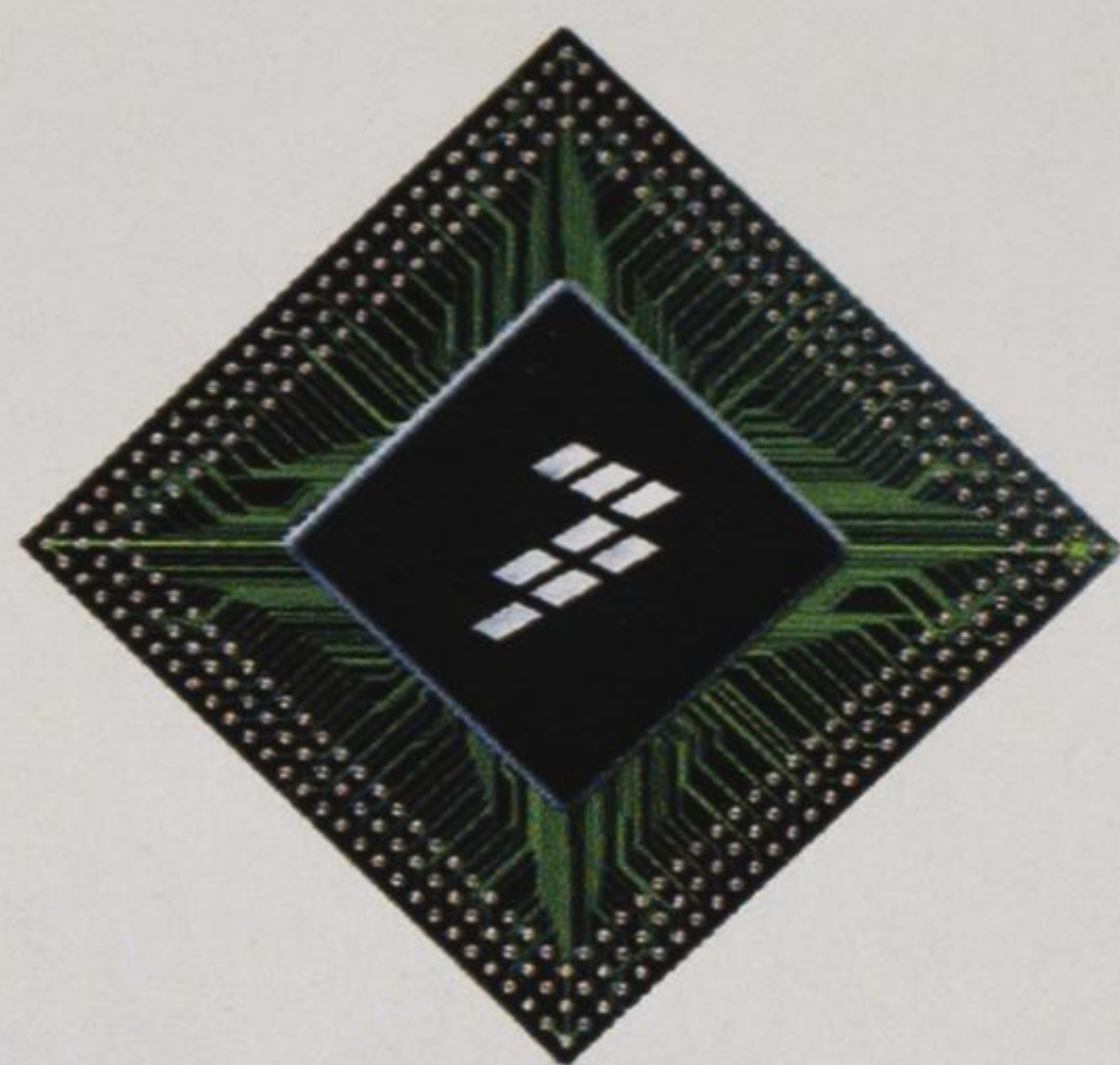
Further reading

Z S Luo Y 2002 *et al. IEEE Photo. Tech. Lett.* **14** 1440.
T Fujii 2004 *et al. Appl. Phys. Lett.* **84** 855.
T Doan *et al.* 2006 *Proceedings of SPIE* **6134** 61340G-1.
C F Chu *et al* 2006 *ISBLLED*.
<http://www.semileds.com>.



About the author

Trung Doan (Trung.doan@semileds.com) is SemiLEDs' chairman and CEO. Prior to founding the company he was vice-president of process development at Micron Technology, president and CEO of Jusung Engineering Ltd and vice-president of AGS products at Applied Materials. He is an inventor of over 200 patents, with more pending.



It's a bold step forward.

Freescale Semiconductor is looking for great engineering talent. Our Compound Semiconductor Fab in Tempe, Arizona is looking for a Process Integration Engineer. Successful candidate should have a B.S. or higher in Engineering and a minimum of seven years of experience in two or more of the following PA compound semiconductor manufacturing areas: process, device, yield enhancement and development.

Desirable qualities include:

- > Experience in leading and/or participation in cross-functional device and process teams
- > Experience in epitaxial growth, device characterization and device modeling in DC/RF
- > The ability to relate device response to process characteristics
- > Excellent verbal and written communication skills
- > Extensive knowledge of device simulation
- > Extensive application of DOE
- > Hands-on experience and understanding of process areas including photolithography, plasma etch, wet etch, metallization, dielectric film deposition and all associated metrology tools
- > The ability to problem solve using lot commonality studies, statistical software and analytical laboratory instruments

Depending on qualifications, candidate may also be considered for a management position. To apply, please send your resume to **R10895@freescale.com** referencing requisition No. 43939.



Realize True Colors for Your Displays

Feel the difference with more lively colors



Back Light Unit from Seoul Semiconductor

Wider color gamut LED: ZWTS1007

- Enable Display to create more colors on NTSC standard

Higher Brightness LED: SWTS100X Series

- More brightness with less LEDs

Thinner Side View LED: SWTS90B

- The smallest thickness of 0.4mm in the world



Seoul Semiconductor Co., Ltd.

Web site : www.seoulsemicon.com

Online store : www.zledstore.com



2006 MRS FALL MEETING

www.mrs.org/fall2006/

Meeting Chairs:

Babu R. Chalamala
Indocel Technologies, Inc.
Tel 919-244-1040
Fax 888-853-4407
chalamala@indocel.net

Louis J. Terminello
Lawrence Livermore National
Laboratory
Tel 925-423-7956
Fax 925-422-0029
terminello1@llnl.gov

Helena Van Swygenhoven
Paul Scherrer Institute
Tel 41-56-310-2931
Fax 41-56-310-3131
helena.vs@psi.ch

For additional meeting information,
visit the MRS Web site at

www.mrs.org/meetings/

or contact:



Member Services
Materials Research Society

506 Keystone Drive
Warrendale, PA 15086-7573
Tel 724-779-3003
Fax 724-779-8313
E-mail: info@mrs.org
www.mrs.org

SYMPOSIA

SOFT MATTER—ACTIVE MATERIALS, HYBRIDS, AND SENSORS

- A: Responsive Soft Matter—Chemistry and Physics for Assemblages, Films, and Forms
- B: Structure, Processing, and Properties of Polymer Nanofibers for Emerging Technologies
- C: Smart Dielectric Polymer Properties, Characterization, and Their Devices
- D: Biosurfaces and Biointerfaces
- E: Nanofunctional Materials, Nanostructures, and Novel Devices for Biological and Chemical Detection
- F: Integrated Nanosensors
- G: Fibrillar Aggregates as Materials—Assembly, Properties, and Applications
- H: Biofilm-Material Interactions—New Tools, Technologies, and Opportunities

ELECTRONICS, PHOTONICS, AND MAGNETICS

- I: Advances in III-V Nitride Semiconductor Materials and Devices
- J: Diamond Electronics—Fundamentals to Applications
- K: Zinc Oxide and Related Materials
- L: Group IV Semiconductor Nanostructures
- M: Quantum Dots—Growth, Behavior, and Applications
- N: Self Assembly of Nanostructures Aided by Ion- or Photon-Beam Irradiation—Fundamentals and Applications
- O: Nanostructured and Patterned Materials for Information Storage
- P: Nanoscale Magnets—Synthesis, Self-Assembly, Properties, and Applications
- Q: Nanowires and Carbon Nanotubes—Science and Applications
- R: Meta-Materials at the Milli-, Micro-, and Nanoscale
- S: Organic Electronics—Materials, Devices, and Applications
- T: Ferroelectrics and Multiferroics
- U: Advances in *In Situ* Characterization of Film Growth and Interface Processes

- V: Advanced Electronic Packaging
- W: Heterogeneous Integration of Materials for Passive Components and Smart Systems
- Y: Enabling Technologies for 3-D Integration

ENERGY STORAGE AND UTILIZATION

- Z: Hydrogen Storage Technologies
- AA: Solid-State Ionics
- BB: Mobile Energy
- CC: Solar Energy Conversion

MICROSTRUCTURE, MECHANICS, AND MODELING

- DD: Mechanics of Biological and Bio-Inspired Materials
- EE: Size Effects in the Deformation of Materials—Experiments and Modeling
- FF: Processing-Structure-Mechanical Property Relations in Composite Materials
- GG: Multiscale Modeling of Materials
- HH: Thermodynamics and Kinetics of Phase Transformations in Inorganic Materials
- II: Advanced Intermetallic-Based Alloys
- JJ: Structural and Refractory Materials for Fusion and Fission Technologies

CHARACTERIZATION TOOLS AND TECHNIQUES

- KK: Electron Microscopy Across Hard and Soft Materials
- LL: Focused Ion Beams for Analysis and Processing
- MM: Magnetic Resonance in Material Science

GENERAL INTEREST

- X: Frontiers of Materials Research
- NN: Scientific Basis for Nuclear Waste Management XXX
- OO: Actinides—Basic Science, Applications, and Technology
- PP: Materials Research at High Pressure
- QQ: Solid-State Chemistry of Inorganic Materials VI

MEETING ACTIVITIES

SYMPOSIUM TUTORIAL PROGRAM

Available only to meeting registrants, the symposium tutorials will concentrate on new, rapidly breaking areas of research.

EXHIBIT

A major exhibit encompassing the full spectrum of equipment, instrumentation, products, software, publications, and services is scheduled for November 28–30 in the Hynes Convention Center. Convenient to the technical session rooms and scheduled to complement the program, the MRS Fall Exhibit offers everything you need all under one roof.

PUBLICATIONS DESK

A full display of over 915 books will be available at the MRS Publications Desk.

STUDENT OPPORTUNITIES

Graduate students planning to attend the 2006 MRS Fall Meeting are encouraged to apply for a Symposium Assistant position and/or a Graduate Student Award.

CAREER CENTER

A Career Center for MRS members and meeting attendees will be open Tuesday through Thursday.

The 2006 MRS Fall Meeting will serve as a key forum for discussion of interdisciplinary leading-edge materials research from around the world.

Various meeting formats—oral, poster, round-table, forum and workshop sessions—are offered to maximize participation.

HB-LEDs

Portable DNA analyzer to use GaN LEDs

Forget about men in white coats. Soon police officers could be using LEDs to analyze and identify DNA evidence at the crime scene, discovers **Jon Cartwright**.

There is little doubt as to the importance of DNA analysis in today's society. A recent example would be the long-awaited conviction last month of the two brothers responsible for killing Damilola Taylor, a 10-year-old boy from London, UK, in 2000. The key piece of evidence – a small blood stain on one of the killer's shoes – was crucial to the prosecution's case.

Now, UK researchers are trying to push the boundaries of DNA analysis through the application of optoelectronics. In a joint project between the University of Hull and the Centre for Integrated Photonics (CIP), together with £721,000 (\$1.37 million) of funding from the Engineering and Physical Sciences Research Council, they are set to pioneer the use of high-brightness LEDs in integrated modules to optically detect DNA fragments. If the approach works, these portable DNA analyzers could revolutionize forensic science by giving scene-of-crime officers *in situ* access to genetic information.

Currently, DNA analysis is a notoriously inconvenient affair. Evidence must be taken to a laboratory and scrutinized, then possible samples must be subjected to a laborious profiling procedure involving fragmentation and polymerase chain reaction amplification. In the final step, the amplified fragments are separated using electrophoresis, whereby an electric field selectively pulls at the molecules based on their size and shape. It is the layout of the dispersed fragments left that characterizes the DNA "fingerprint" of the sample.

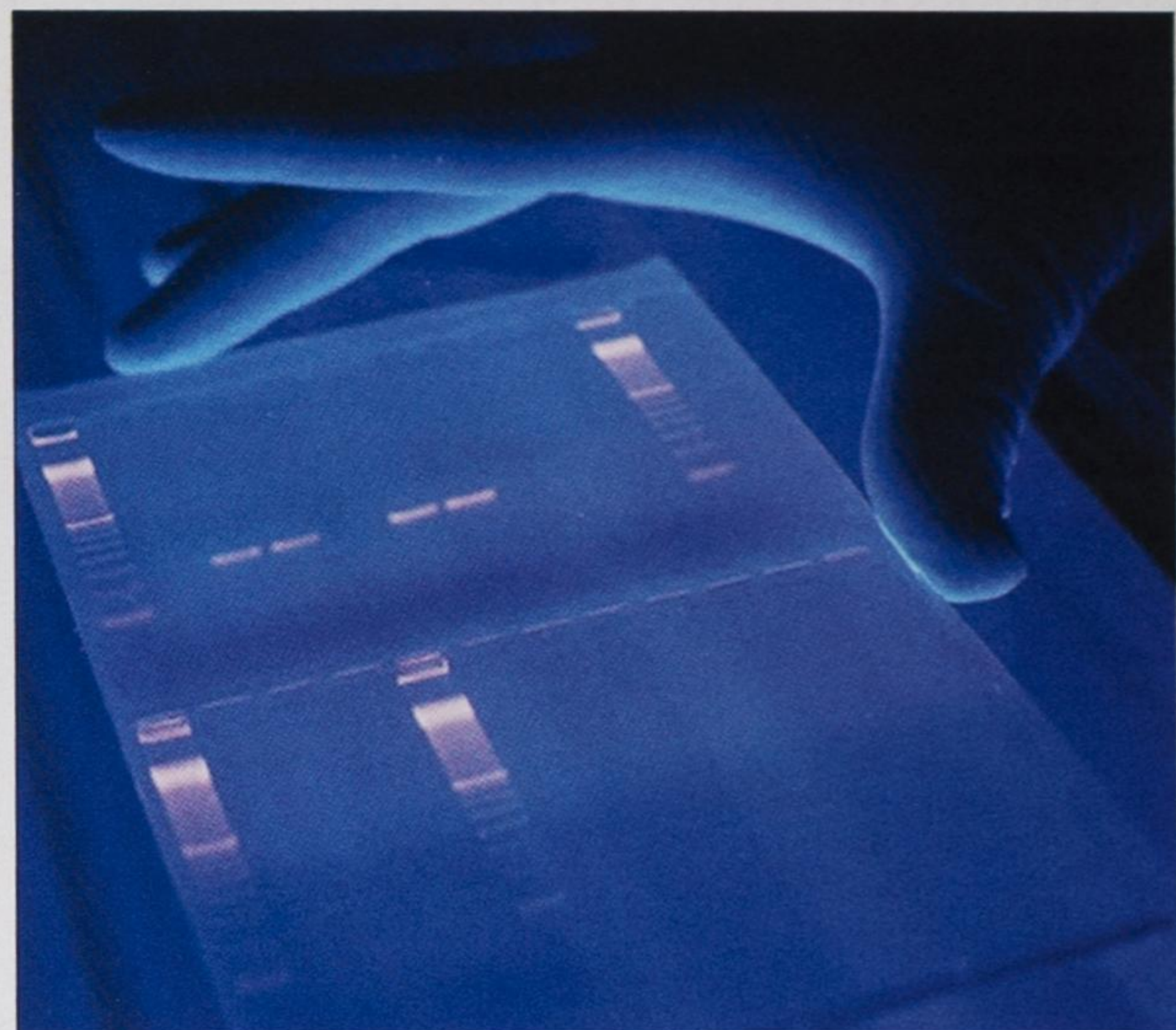
Apart from the obvious time expenditure, transporting samples to the laboratory leaves them dangerously susceptible to contamination. The device that CIP hopes to produce will combine all the stages together in one shoebox-sized unit – simultaneously circumventing possibilities of time-delay and contamination. It will also require an automated detection stage to output the fingerprint without human intervention.

According to Steve Oliver, project leader at CIP, units like this could be cheap enough to hand out to police officers for ruling out suspects within minutes. "It won't tell you their name and address, but it will tell you if they're human, Caucasian or not, male or female – that kind of thing."

The project has been split into two – the biological part will be done by the Hull team. The other part, which entails electrophoretic separation and optical detection of the DNA fragments, will fall onto CIP's shoulders.

"As far as CIP goes, the tricky part will be the optical detection," explained Oliver. "The idea is that you tag these pieces of DNA with different dyes. Depending on the mix of dye that comes through, you can tell something about where the DNA came from."

Once the DNA fragments have been tagged, the dyes will be illuminated using the light of a wavelength that they can absorb. This will stimulate fluorescence, where light is re-emitted by the dye at a longer wavelength. The



fluorescence signals then have to be filtered and fed to an optical detector and data processing system. Currently DNA evidence is analyzed using complex and laborious laboratory processes, but UK researchers hope to use GaN-based LEDs to develop a portable unit that could screen for basic human characteristics, such as sex and race, within minutes.

fluorescence signals then have to be filtered and fed to an optical detector and data processing system.

Sensing the color of these dyes will require components that satisfy two important criteria: cost and reliability. Presuming that it works, the only way that such an analyzer can be justified is if investigators can routinely carry them to crime scenes. CIP could produce bespoke light sources in-house, but these run the risk of being delicate and expensive, so instead the team is looking to commercial LEDs for the solution.

"We don't want to design a system and then build a light source to match it," explained Oliver. "In the first instance at least, we want to see how far we can go with what's commercially available."

Given that the tagged DNA fragments will be absorbing visible wavelengths between 400 and 500 nm, the obvious candidates for the light source are undoubtedly GaN LEDs. These could either be made into an array, with each LED corresponding to a different color of dye, or – preferably – the analyzer could rely on a single, superluminescent LED combined with several filters to cover all of the necessary wavelengths.

CIP's strong pedigree in optical telecoms should give it a firm grounding for developing these filters and squeezing the design into a manageable package. But the DNA analysis project is outside of its normal scope.

"There's been a lot of interest in microfluidics, but until now the devices have been quite simple," explained Oliver. "We're trying to do something with the integration technology and then apply it in that field. This is a deviation from the norm for us – we've never done anything in the biological sciences before."

"It will tell you if they're human, Caucasian or not, male or female"

Steve Oliver
CIP

Skyworks favors hybrid BiFET design

Skyworks believes that its hybrid design for BiFETs, which includes a quicker and lower-cost processing route, outweighs the greater versatility of a monolithic design. **Richard Stevenson** investigates.



Skyworks makes its BiFET products at its Newbury Park, CA, fab using 4 inch epiwafers from Kopin.

It's a competitive market for the manufacturers of GaAs-based chips for cell phones. Prices are eroding, and handset designers are demanding smaller components. So chipmakers must innovate to remain profitable, by developing products with a smaller footprint and cheaper material costs, or more advanced modules with greater functionality that can command a higher price tag.

Skyworks has been pursuing both of these strategies. According to Steve Machuga, vice-president of RF front-end development for Skyworks' Mobile Platforms' business, the Woburn-based outfit initially invested in design approaches that minimized the GaAs footprint in the phone, and this led to power amplifier (PA) costs that were close to those of their silicon counterparts. However, the firm has since shifted direction with the development of more sophisticated components, culminating in last year's launch of a range of BiFET chips featuring HBTs and FETs on the same die.

"The BiFET technology is an example of where we've been able to integrate an FET, for use in bias con-

trol circuits, at almost no extra incremental cost to the core HBT technology," says Machuga. The bias control circuit manages the PA's performance more efficiently, which leads to longer handset talk times.

BiFETs can be built using either a monolithic or a hybrid design, and Skyworks has evaluated both types of device (see "Different approaches to BiFET design" box). The company rejected the monolithic design and selected a hybrid design for manufacturing all of its BiFETs, which positions the FET on top of the HBT.

"Our motivation for choosing this approach is very simple," explains Ravi Ramanathan, Skyworks' manager of compound semiconductors advanced process technology. "We want to use a simple process that does not increase the epitaxial and processing costs, and a low-performance DC-type switch for bias control."

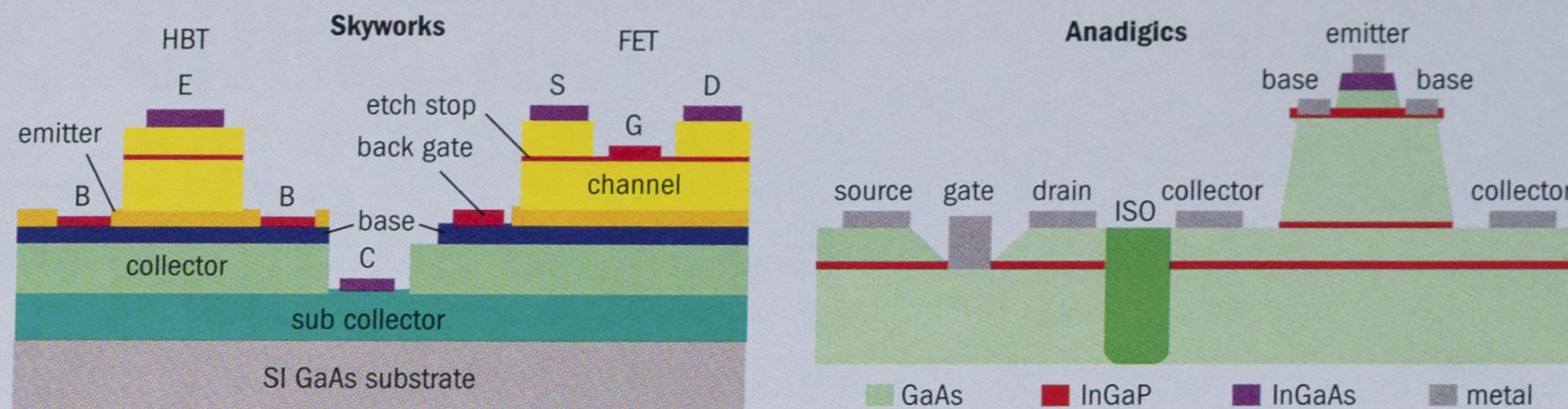
Skyworks believes that the benefits of the hybrid design include quick lot (QL) characterization of the HBT and FET, shared processing steps, a minimal impact on total processing time compared with stand-alone HBT manufacture, and the need for only two additional masking layers to define the FET. This device has its limitations, though, such as poor RF isolation and a compatibility with only n-type FETs.

The monolithic design, which is used by Skyworks' rival Anadigics, allows independent tuning of the FET and HBT, so that individual device characteristics can be tuned to the needs of the application. However, Skyworks claims that this design cannot be used for profitable manufacturing in today's market. Drawbacks include complex QL characterization procedures that can require further process steps, complicated electrolytic capacitance-voltage (C-V) profiling, and a longer "stabilization bake" step for the FET that increases the time to manufacture the final product.

With the monolithic design the BiFET's emitter and gate are typically separated by a few microns but have micron-sized heights differences, says Ramanathan, making it awkward to carry out the sub-micron-sized photolithographic process used for device manufacture. "You need a very high planarizing resist process, but the resist thickness will increase and reduce the line-width resolution, or you need to move the FET substantially further away from the HBT, to eliminate severe topology effects on the gate process," explains Ramanathan.

Anadigics, which has been manufacturing BiFET-based chips in volume since 2003, rebuts Skyworks' assessment of the monolithic design, claiming that all of the concerns "are either incorrect or do not apply". According to the Warren, NJ, company, its InGaP-based technology provides product performance and

Different approaches to BiFET design



Rival US chipmakers Skyworks and Anadigics are both manufacturing products that incorporate BiFET technology. But, while Skyworks prefers a hybrid approach (figure on left), Anadigics backs a monolithic design (figure on right).

Skyworks' hybrid epitaxial structures are grown by MOCVD on 4 inch semi-insulating GaAs (100) substrates. The FET layers, like the channel and the etch stop layer, are grown within the HBT's emitter. Dry etching defines the HBT's emitter (E) and base opening, while wet etching forms the collector opening, and helium ion implantation isolates the devices. Processing with the same fabrication step is reduced by the FET's drain (D) and source contacts (S) and the HBT's emitter. Dry etching and ion implantation provide device-to-device isolation, and metal evaporation forms the gate (G) contact.

Anadigics' monolithic designs are also grown by MOCVD, but in these structures the HBT is deposited on top of the PHEMT structure. This allows the two devices to be decoupled. The HBT and the PHEMT share a highly doped n-type GaAs layer, which serves as the PHEMT cap and the HBT's subcollector. At Anadigics, 6 inch epiwafers are processed with evaporation and lift-off techniques to form the ohmic emitter. Wet etching of the InGaP and emitter layer, followed by evaporated metal lift-off, form the base contact before selective wet etching with a photoresist mask defines the base mesa. A nitride passivation layer is added by plasma-enhanced CVD to protect the HBT. Like Skyworks, device isolation is produced by helium implantation. After isolation, a single AuGe/Ni metallization step is used to form the HBT collector contact and the PHEMT source and drain contacts, which completes the HBT fabrication process. Metal evaporation and lift-off is used to form the PHEMT gate, and a silicon nitride layer is deposited for device passivation.

integration improvements with no impact on either yield or cycle times. The devices are also more versatile than Skyworks' because PHEMT and MESFET structures can be constructed below the collector, says Anadigics, and the BiFETs offer an equivalent performance to stand-alone InGaP and PHEMT structures.

Anadigics also claims that its BiFET manufacture requires just two additional mask levels compared with a traditional InGaP HBT process, which is the same added complexity as Skyworks' BiFET process. Also, its chips do not need complex characterization procedures or a long stabilization bake. "The products are competitively priced in the market," says an Anadigics spokesperson, and its rising revenue and gross margin also suggest that a greater proportion of InGaP-based products in the company's sales mix is actually boosting its financial performance.

Skyworks, like Anadigics, does not produce its material in-house, and outsources growth to Kopin. The epiwafer supplier carries out a series of QL tests on large-area devices, which are typically $75 \times 75 \mu\text{m}$, to determine if the material's quality is suitable for chip production. These measurements reveal the DC gain, offset voltage, base-emitter and base-collector turn-on voltages, and junction breakdown voltages. However, because FETs are sensitive to process conditions that can mask growth variations, Kopin cannot predict the pinch-off voltage, saturation current and transconductance of BiFETs made from these epiwafers.

To overcome these issues associated with measuring the FET performance, Kopin and Skyworks have established a QL procedure based on C-V measurements that identifies run-to-run and machine-to-machine variations. Profiles of the emitter-base junctions reveal the FET's channel thickness and doping concentration, which are related to the characteristics of the fully processed FET.

The epiwafer batches that pass all the QL tests at Kopin are shipped to Skyworks and processed into BiFETs. Ramanathan says that the Ti/Pt/Au/Ti Schottky gate contact, which is formed by metal evaporation onto the channel layer, is the key component and is extremely sensitive to the gate processing steps.

Skyworks has evaluated gates produced by both photolithography and etching. The former approach produces a gate that is free from cracks and which allows SiN passivation on the gate metal, but it can also lead to Schottky contacts with undesired characteristics due to "gate sinking" and gold and platinum diffusion into the channel. As a result, Skyworks employs an etching process for BiFET manufacture that circumvents these problems, and also allows for gates with thicker gold layers that reduce contact resistance.

Skyworks has assessed its BiFET manufacturing yield by measuring 40–50 parameters related to the FET, HBT or the passive components. With a yield that is routinely above 95%, very little material is wasted in the production process.

"We want to use a simple process that does not increase epitaxial and processing costs."

Ravi Ramanathan
Skyworks



a head above the rest

Compound Semiconductor

BOC Edwards offers a broad range of equipment, materials and expertise for compound semiconductor manufacture. An impressive install base in compound semiconductor applications as well as a presence in every major silicon semiconductor fab in the world, puts us a head above the rest in supporting the production of devices such as LEDs, LDs, HEMTs, HBTs, MEMs and compound substrates.

Don't bury your head in the sand, contact BOC Edwards ... for better process results.

Gases . Vacuum . Exhaust Management
Chemical Management . Support Services
Temescal Deposition Systems

BOC EDWARDS
for Better Process Results

www.bocedwards.com/compsemi

TRACE ELEMENTAL ANALYSIS

of

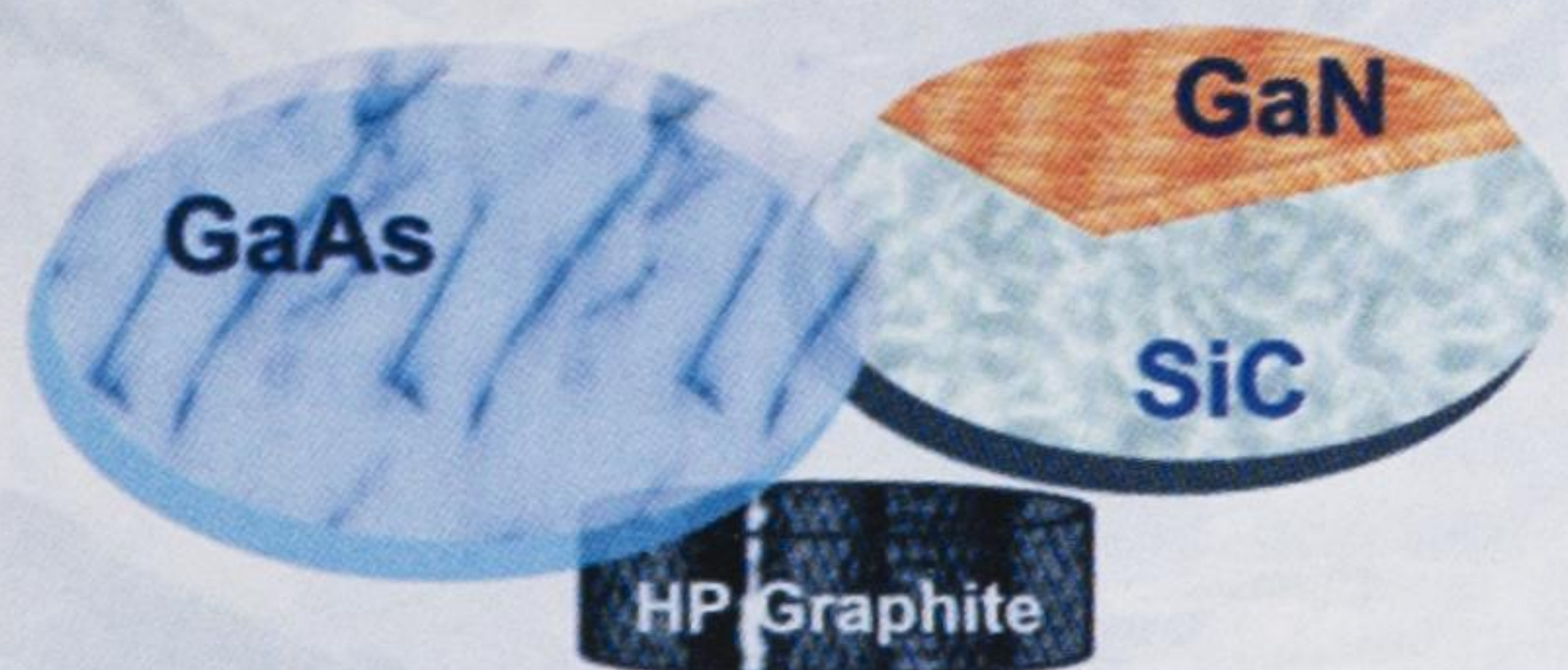
High Purity Materials, Films, and Coatings

Trace Elemental Analysis by High Resolution Glow-Discharge MS

High Performance NIST Method for Majors

Fractional Gas Analysis

Depth Profiling



SHIVA TECHNOLOGIES

6707 Brooklawn Parkway
Syracuse, NY 13211, USA

94, chemin de la Peyrette
31170 Tournefeuille, France

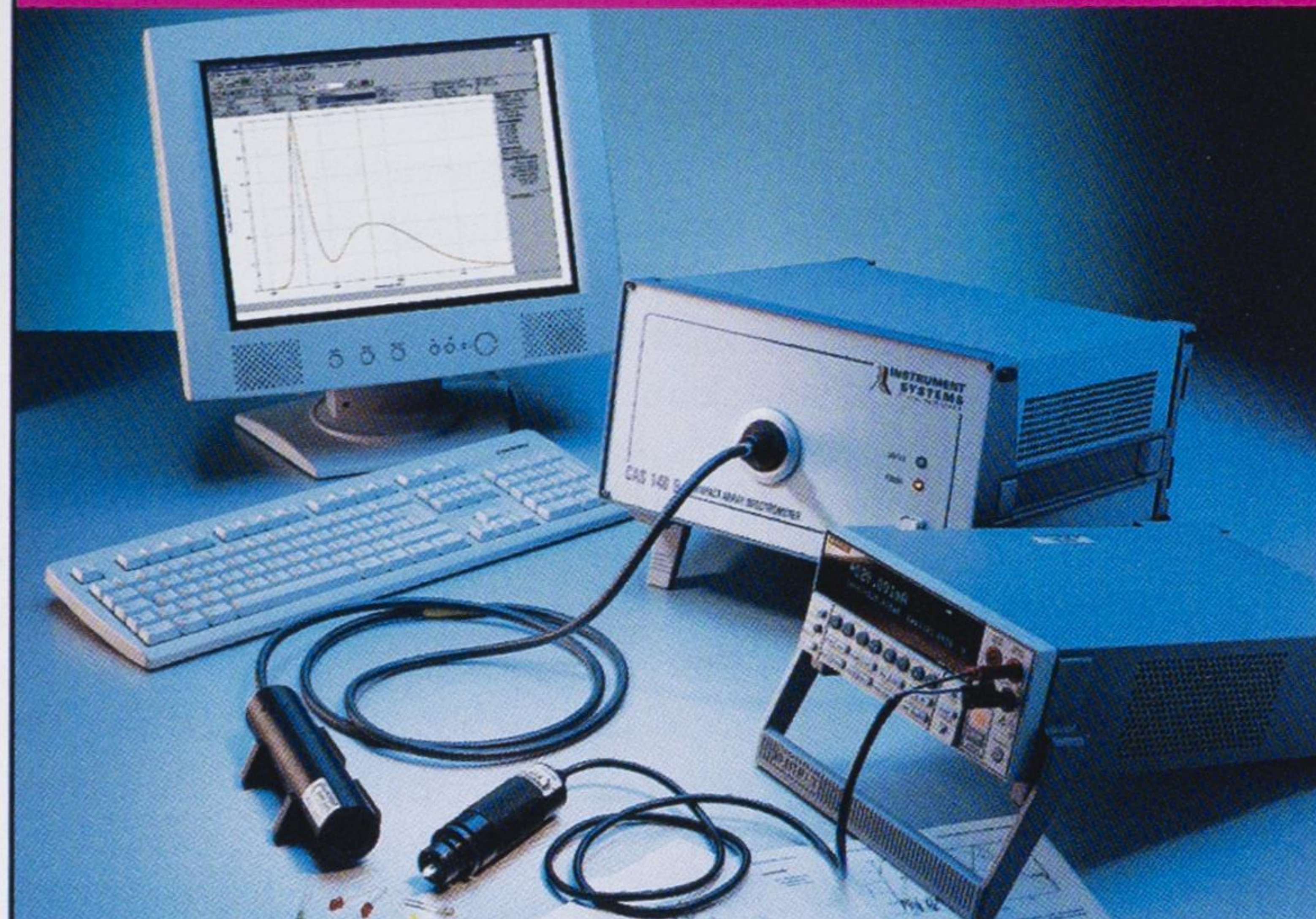
Ph: +1.315.431-9900 Fax: +1.315.431-9800
www.shivatec.com sales@shivatec.com

Ph: +33.561.73 15 29 Fax: +33.561.73 15 67
shiva_europe@shivatec.com



ISO 9001:2000, ISO 17025
Nadcap

LED Test and Measurement



Measure all optical and electrical parameters of LEDs and other light sources in conformity to international standards accurately and within seconds. With equipment from Instrument Systems – the world leader in LED metrology.

- Luminous intensity (candela)
- Luminous flux (lumen)
- Dominant wavelength (nm)
- Color coordinates (x, y, z)
- Spatial radiation pattern

**INSTRUMENT
SYSTEMS**
OPTISCHE MESSTECHNIK

phone +49 89 45 49 43-0
info@instrumentsystems.de
www.instrumentsystems.de

WE BRING QUALITY TO LIGHT

Etching and regrowth technique increases bipolar diode stability

The lack of forward voltage stability in SiC bipolar devices is hampering their deployment in electrical power transformers. However, this problem can be overcome with an etching and regrowth process, say **Joe Sumakeris**, **Brett Hull** and **Dave Grider** from US chip manufacturer Cree.



Cree's SiC device development, which is funded by the US Office of Naval Research (contracts N00014-02-C-0302 and N00014-05-C-0202) and the Defense Advanced Research Projects Agency, could allow traditional iron core transformers in military vessels to be replaced with smaller, more efficient solid-state power devices.

The improved switching efficiencies of high-voltage SiC discrete power devices have the potential to deliver significant energy and space savings in AC-DC power converters deployed in civilian infrastructure and in military vessels. But to fulfill these applications multi-kV SiC devices are desired to be run in bipolar conductivity mode for increased current density. Unfortunately this can lead to a forward voltage (V_f) drift under conductivity modulation, according to studies carried out by us and other researchers. The problem is so significant that it drove some companies to abandon pursuing this device technology.

The V_f drift stems from the propagation of basal plane dislocations (BPDs) that exist in the SiC substrate into the epilayer. Here, they are converted into Shockley stacking faults when the device is operated in bipolar conductivity mode. In vertical power devices, where current flow is essentially perpendicular to the basal plane, these stacking faults trap carriers and dramatically increase the device's resistance.

To combat the V_f drift we have developed specific techniques for substrate preparation, epilayer growth and device fabrication (see figure 1, p26). This enables us to reduce the number of BPDs in the parts of the device that experience conductivity modulation and produce stable, multi-kV bipolar power devices. We believe that this approach, which relies on substrate preparation and epilayer regrowth, represents the greatest recent advance in bipolar SiC device technology.

We started developing methods for reducing the V_f drift about six years ago. Our first incremental improvements in stability came by restricting the electron-hole plasma to regions of devices with fewer BPDs. By 2003 we had modified our PIN devices to include a thick, heavily doped n-type buffer layer between the substrate and the drift layer, and a relatively thick anode layer on top of the drift layer. The buffer layer isolates the electron-hole plasma from the BPDs in the substrate, while the anode layer separates the plasma from the ohmic regions and protects the drift layer from any

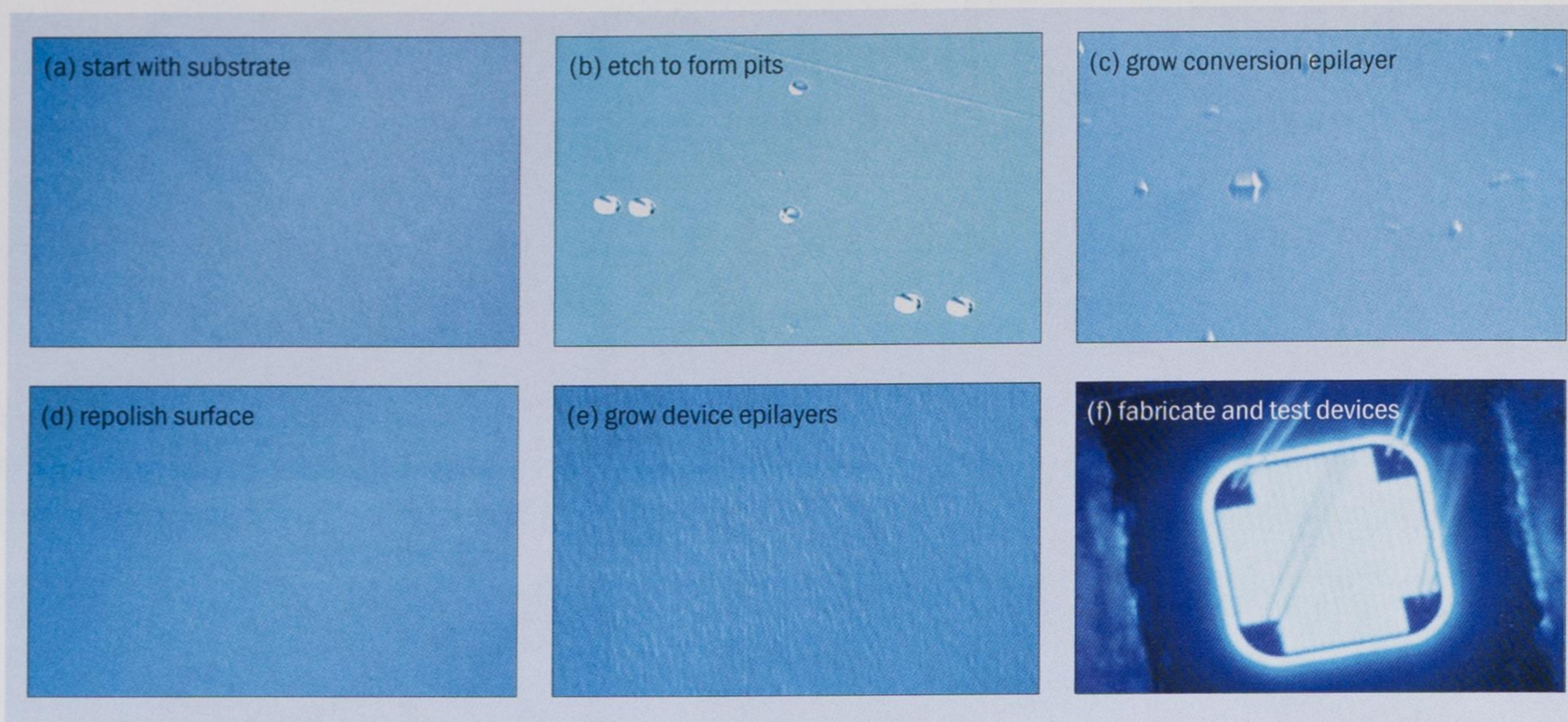


Fig. 1. Cree has developed an etch and regrowth process to reduce the number of basal plane dislocations in the epiwafers. This led to a significant reduction in the drift in forward voltage in bipolar devices of 10 kV, 20A PIN diodes.

mechanical damage that can occur during processing. Re-introduction of BPDs at growth interruptions is prevented by growing the modulated portion of the structure in a single uninterrupted step.

Although these steps are beneficial, most of the drift-inducing BPDs come from the substrate and propagate into and through the epilayers. If these BPDs could be eliminated from the substrates, this would improve device stability. However, this is an extremely long-term goal and instead we currently have to contend with the BPD densities of 10^4 – 10^5 cm $^{-2}$ that exist in commercial substrates.

We believe that this approach represents the greatest recent advance in bipolar SiC device technology.

not clear whether strained layers will have the same effect on BPDs in SiC and any efforts to develop this technology will be hampered by the lack of published information concerning the formation of SiC-compatible strained layers.

Making better defects

Device stability can also be improved by converting these BPDs into other forms of defects that cause fewer problems. Thankfully, this process can actually occur both naturally and efficiently during epitaxial growth, with BPDs being transformed into threading edge dislocations (TEDs) that have less impact on device performance (see figure 2). Normally more than 90% of the substrate BPDs will naturally convert to TEDs during epilayer growth, which cuts the typical epilayer

An alternative approach for increasing device stability involves the growth of a strained layer that can block and redirect the BPDs. This approach has already been applied to the GaAsP/GaAs material system, where it was used to prevent the propagation of threading dislocations. However, it is

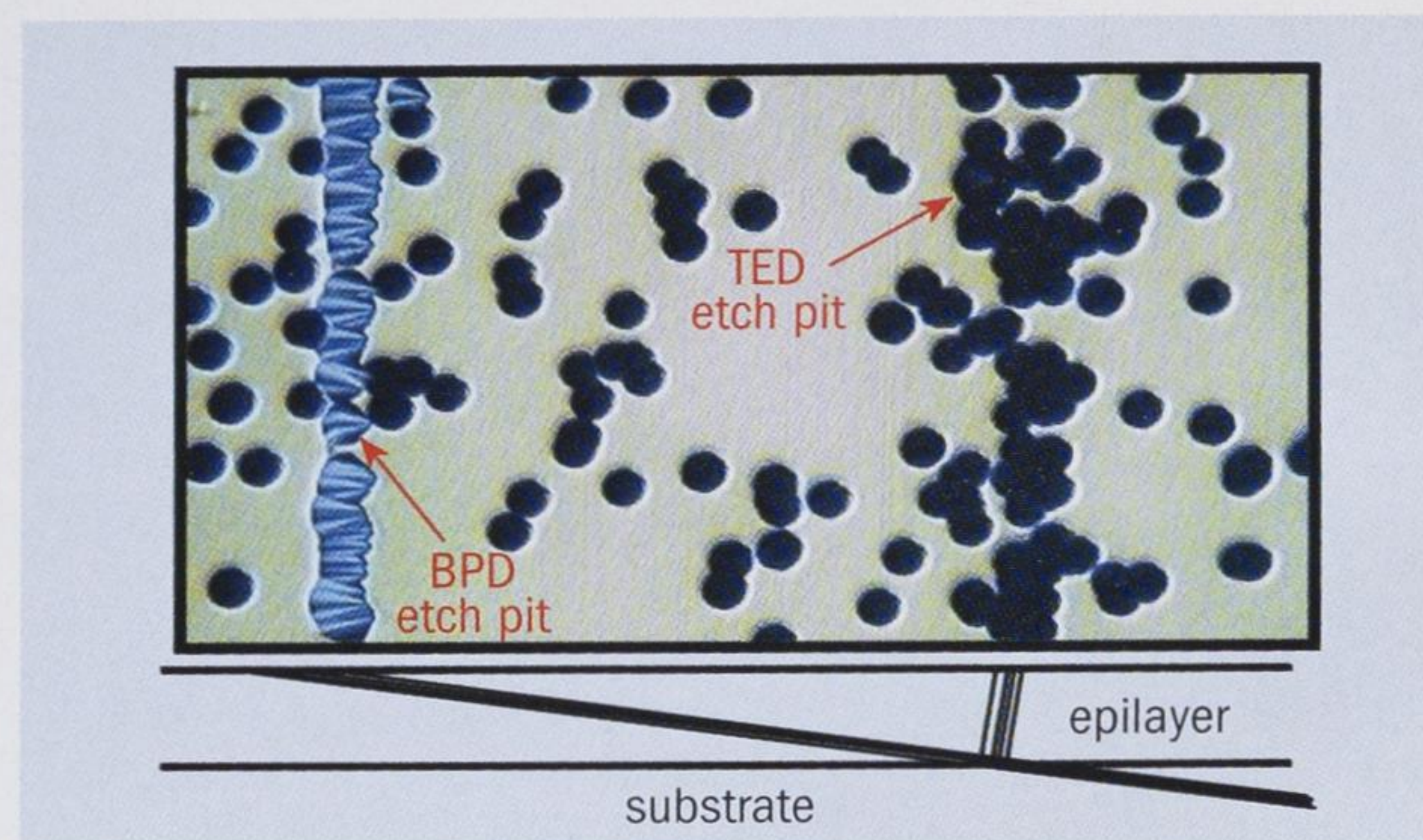


Fig. 2. Basal plane dislocations, which are largely responsible for the forward voltage drift that occurs in bipolar SiC power devices, cannot be eliminated but they can be transformed into less harmful types of defects. The conversion can be seen in this micrograph of a potassium-hydroxide-etched epilayer near a substrate slip band. Along the left side of this image is a line of characteristic, scallop-shaped, etched pits that occur where the BPDs intercept the surface. On the right there is a grouping of etch pits associated with the TEDs. Although the specific dislocations depicted in this image are associated with a localized slip band in the substrate (see the diagram just below the image), a similar BPD to TED conversion occurs frequently across the wafer.

BPD density to 300 cm $^{-2}$. On its own this natural reduction in BPD density is insufficient for the fabrication of commercially relevant SiC power devices. However, improving the efficiency of the natural BPD–TED conversion appears to offer the most promising solution.

Mark Skowronski from Carnegie Mellon University, PA, has suggested that a reduction in dislocation length can boost the subsequent conversion of BPDs into TEDs during epilayer growth. TEDs are preferred to BPDs because they are shorter and consequently produce a smaller increase in the system's overall energy.

In SiC substrates the BPDs exist in many different directions, while in epilayers they predominantly occur in one particular direction, which is determined by the

"How can I take control of my epi production?"

ORS

Optical Reference Systems

For accurate monitoring in any type of reactor environment, with real-time results you can trust, ORS is your answer.

We make the world's most advanced intelligent thin-film monitoring systems. Our unique, bespoke hardware and software packages offer innovative solutions for production and R&D.

Our fully customisable, bolt-on monitoring systems can be installed on any film-deposition reactor. Our software programs use fully automated, quantitative, real-time analysis to generate the information you need, second by second, leaving you free to recalibrate your processes at the earliest opportunity.

ORS – unparalleled knowledge and expertise at the forefront of today's cutting-edge technology.

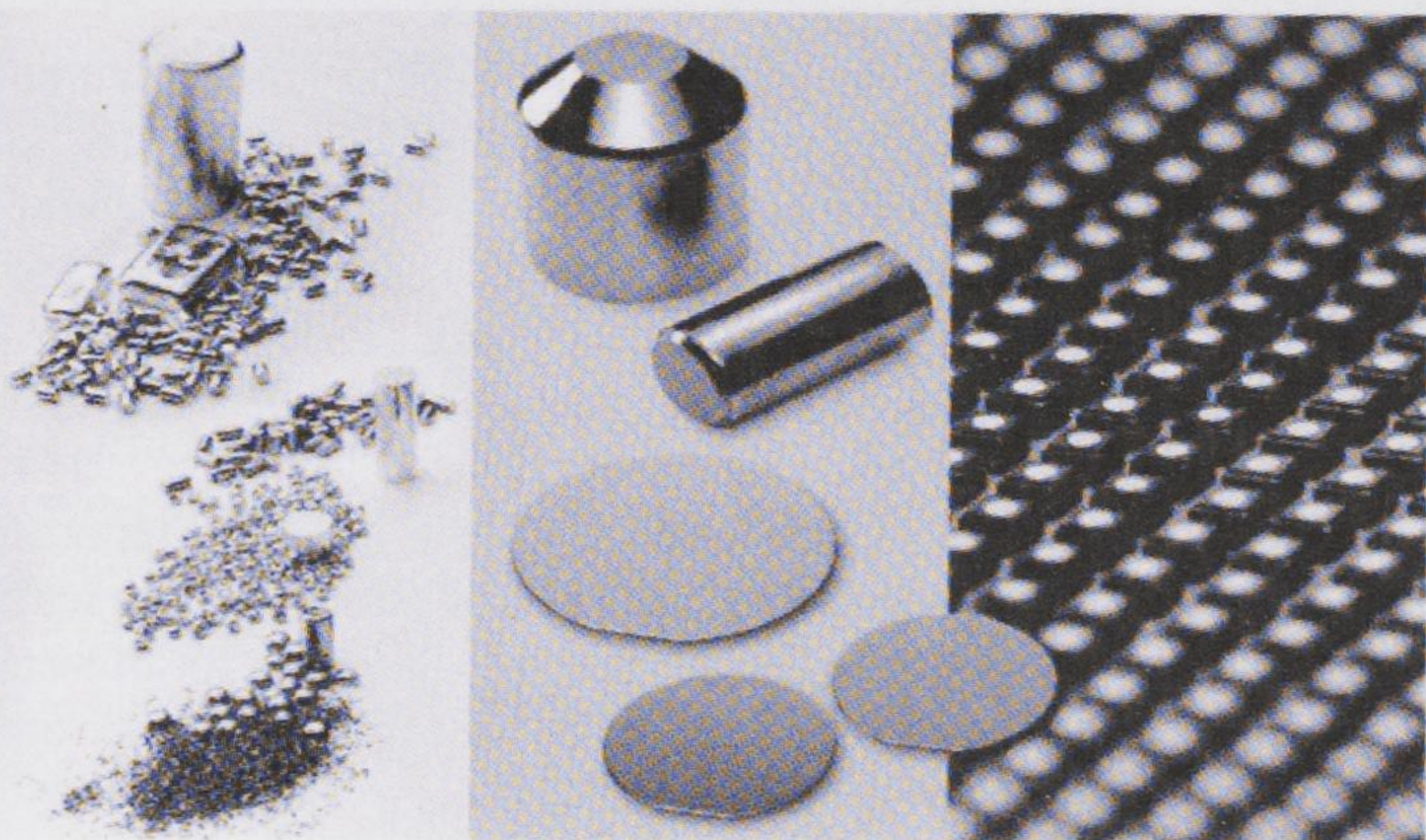
For more information: Tel: +44 (0)1745 535188 www.ors-ltd.com

take control

ORS

DOWA

URL: <http://www.dowa.co.jp/semicon>



High Purity Metals

- ◆ Gallium (Ga)
- ◆ Indium (In)
- ◆ Copper (Cu)
- ◆ Silver (Ag)
- ◆ Zinc (Zn)
- ◆ Antimony (Sb)
- ◆ Magnesium (Mg)

GaAs substrates

- ◆ Semi-insulating: 2, 3, 4, 6 inch
- ◆ Conductive: 2, 3, 4 inch

LED

- ◆ AlGaAs Red LED die (660nm)
- ◆ AlGaAs Near infrared LED die (700-800nm)
- ◆ AlGaAs infrared LED die (850, 870nm)

Nitride Epiwafers

- ◆ AlN on Sapphire: 2 inch
- ◆ AlGaN HEMT on Sapphire: 2 inch

DOWA MINING COMPANY LTD.

Semiconductor Business Unit, Electronics Materials Company
14-1, Sotokanda 4-Chome, Chiyoda-ku, Tokyo, 101-8617, Japan
Phone: +81-3-6847-1253 Fax: +81-3-6847-1260

>INDIUM

Standard Materials:

- High Purity Indium Metal: $\geq 99.99995\%$
- Indium-Tin Oxide (ITO)
- Indium Chloride
- Indium Oxide
- Gallium Metal
- Gallium Chloride
- Germanium Chloride

Custom Formulations:

We formulate custom compounds. Please contact our Materials Engineers to discuss your needs.

Our Materials Engineers are ready to provide support. Call or email today. askus@indium.com

INDIUM CORPORATION®

www.indium.com
askus@indium.com
Asia: +65.6268.8678
Europe: +39.011.655331
USA: +1.315.853.4900

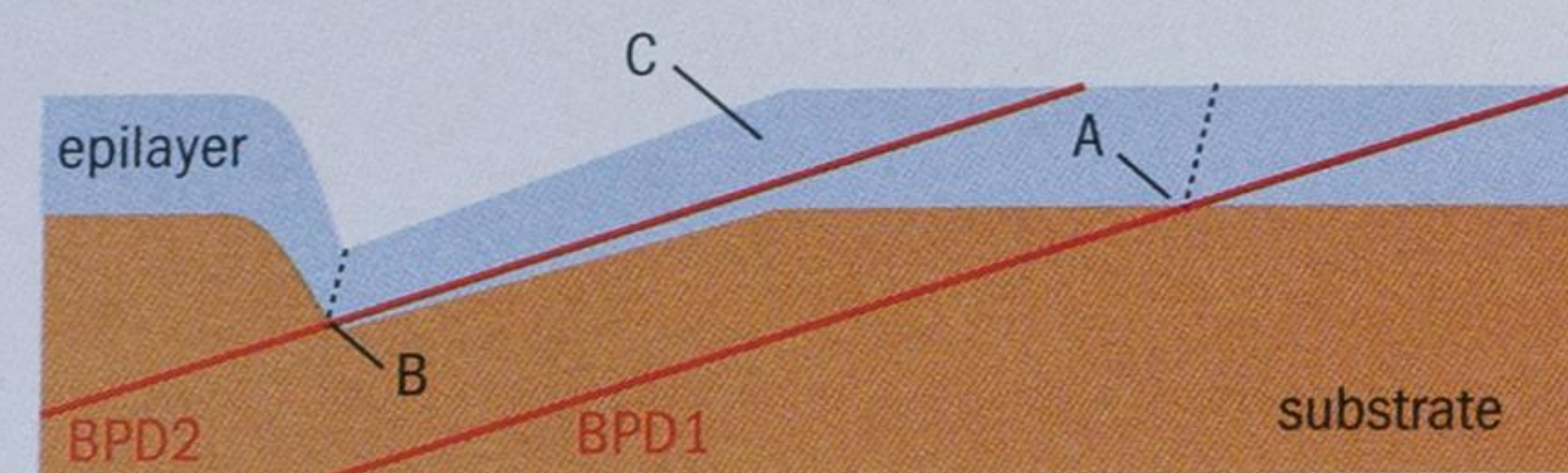


The benefits of selective etching

Selective etching can cut the density of BPDs by locally reducing the off-axis angle close to a BPD while retaining a more favorable off-axis angle for most of the SiC substrate. The benefits of this local etching are shown in the figure, which depicts two adjacent basal plane defects: BPD2, which has an associated pit, and BPD1, which does not.

Point A is positioned at the transition of BPD1 from the substrate to the epilayer. If BPD1 were converted into a TED, represented by the dotted line, then the defect line would have a much shorter length within the epilayer. The reduction in defect length would be greater, though, if BPD2 could convert from a BPD to a TED at point B.

The force of the mechanism favoring BPD to TED conversion is inversely proportional to the distance between the dislocation and the surface. So if BPD2 did propagate into the epilayer as a BPD, it would experience a large and prolonged force encouraging a conversion to TED character. This is partly because the dislocation line



would only slowly diverge from the surface during the epilayer growth near the etch pit, but it is also a consequence of the lower growth rates that typically occur within trenches and pits.

The differences in growth rate will cause the epilayer to grow more quickly at the top of the etch pit (point C) than at its bottom (point B). This means that if BPD2 started to propagate into the epilayer as a BPD, it is likely to encounter a thicker portion of the epilayer before it can exit the etch pit, which will block its propagation and encourage conversion into a threading-type defect.

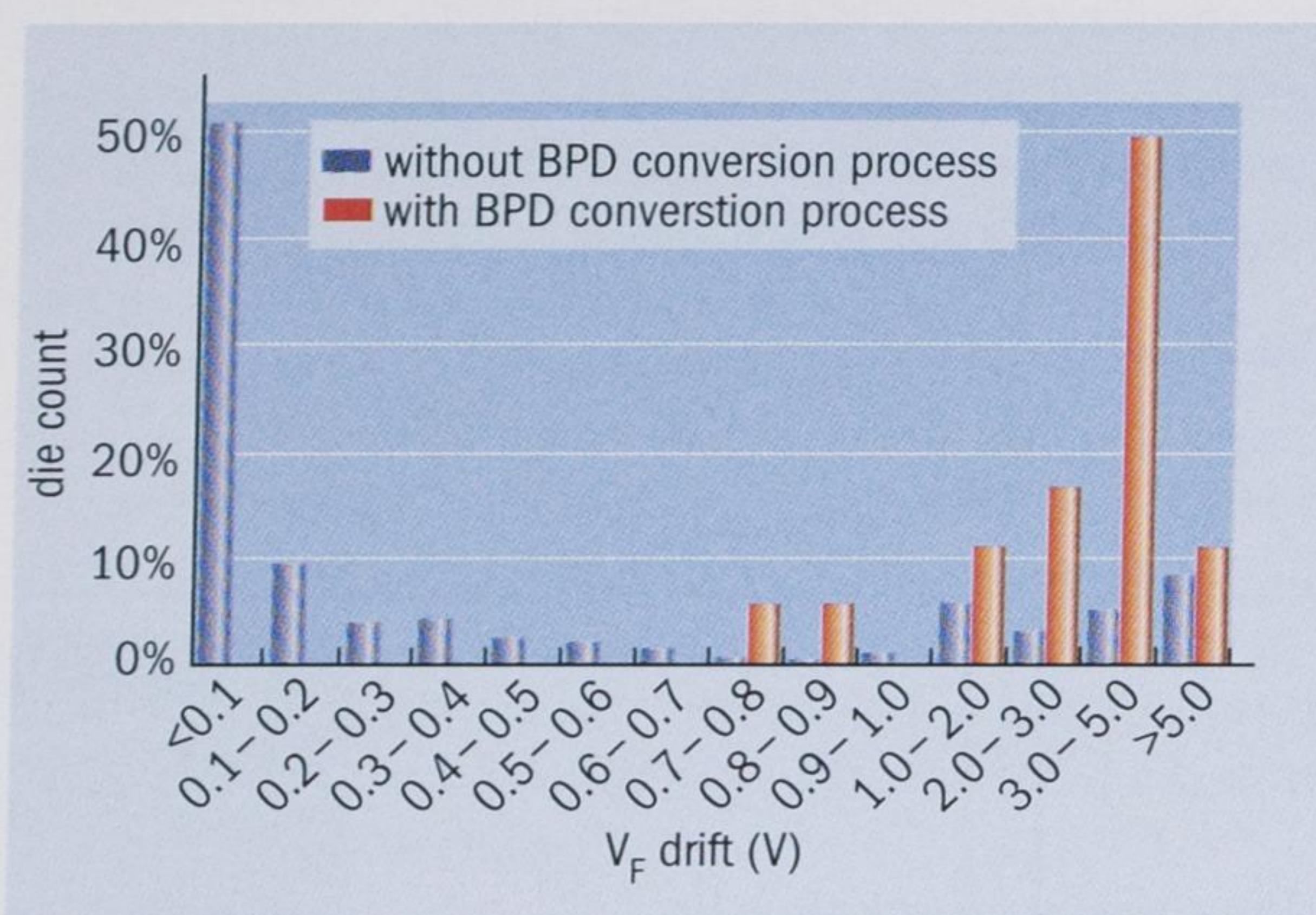


Fig. 3. Cree's process for reducing basal plane dislocations has dramatically reduced the voltage drift resulting from a 30 minute forward-conduction stress test at 100 A/cm².



About the authors

Joe Sumakeris (left) is a senior scientist at Cree. He is responsible for developing SiC epilayer growth technology for RF and bipolar power devices, and for developing high-temperature implant activation anneal technology.

Brett Hull (middle) is a process scientist at Cree. He is responsible for the fabrication of high voltage SiC rectifier and MOSFET devices.

David Grider (right) is Cree's manager for government contract R&D SiC power programs and customer commercial SiC power projects.

substrate's off-axis angle and orientation. For typical 8° off-axis material, the length of a substrate BPD that propagates into the epilayer without undergoing any transformation is roughly seven times that of a BPD that is converted to a TED during epilayer growth. Reducing the off-axis angle of the SiC substrate can increase this disparity and potentially enhance the dislocation conversion process. However, this approach also has its drawbacks and leads to poorer quality surfaces with higher overall defect densities.

Our new etching approach

Selective etching can be used to locally reduce the off-axis angle in the immediate vicinity of a BPD while maintaining a more favorable off-axis angle for the majority of the substrate (see box "The benefits of selective etching"). In this process, the SiC substrate is selectively etched before a BPD conversion epilayer is deposited (see figure 1, p26). The epilayer surface is then repolished to recover a smooth, pit-free surface for growth of the actual device structure.

To evaluate the benefits of our new process, we grew

a batch of epiwafers on which we fabricated 10 kV, 20 A PIN diodes. Seven wafers were produced with low-BPD processing, along with one control wafer that did not have any low-BPD processing. The V_f stability of the diodes was evaluated by comparing the change in V_f after 100 A/cm² was passed through the on-wafer devices for 30 minutes (see figure 3). The pass mark was set at a drift of less than 0.1 V.

The results show that 51.3% of the diodes fabricated on low-BPD wafers had a stable V_f. In contrast, none of the diodes fabricated on the unprocessed substrate exhibited forward-voltage stability and 80% of the devices drifted by more than 2 V.

Clearly, this low-BPD technology delivers a substantial improvement in bipolar SiC device's V_f stability and brings us closer to a commercially viable product. However, the low BPD conversion process is cumbersome and costly, the yields need to be improved, and there are several issues to be resolved before this process is ready for production.

First, the current process needs to be shortened and simplified, but this should be possible because we are currently using conservative conditions for pre-etch, regrowth and polish. In fact, we expect that as the quality of each stage is improved the overall process will become much more manageable. Second, we must continue to reduce the defect density in low-BPD material, as this will increase the overall device yield. Even with an intermediate repolishing step, the legacy of the selective etch process contributes to higher defect densities in the device epilayers. Last, we have to confirm the long-term reliability of low-BPD material. While the 30 minute stress test provides a convenient metric, it fails to deliver the rigor required to ensure that the devices are stable throughout a typical service life.

If we are able to address these three issues, we will be in a position to manufacture stable, high-voltage SiC PIN diodes that can deliver significant energy savings for power conversion.

TDI cracks AlN template trouble

GaN HEMT manufacturers and ultraviolet LED developers are using large crack-free AlN-based templates thanks to a new deposition process, say TDI's **Vladimir Dmitriev** and **Alexander Usikov**.

AlN substrates are well suited to the fabrication of ultraviolet LEDs and could boost the performance high-frequency transistors used in base-station infrastructure. The LEDs benefit from AlN's transparency at wavelengths greater than 200 nm, while the performance of RF devices is aided by AlN's very high thermal conductivity, electrical insulation and a crystal lattice that closely matches that of AlGaIn.

However, despite years of development, it is still very difficult to grow single crystals of AlN with low enough defect densities and their size is insufficient for commercial applications. For example, our work at Technologies and Devices International (TDI), MD, has been restricted to the fabrication of 2 inch AlN wafers using a free-standing approach, while 2 inch substrates only became commercially available very recently through Crystal IS. Although the availability of 2 inch material represents some progress, this size is unable to satisfy the demands of electronic device manufacturers who want to use 3 and 4 inch substrates now, and 6 inch substrates in the future. This appetite for larger substrates has led to various AlGaIn-based devices being developed on foreign substrates.

One way of accelerating AlGaIn-based device development and commercialization is to use engineered templates, which consist of a native AlN surface for subsequent device epitaxy and a base made of a different material, like silicon, sapphire or SiC. An advantage of this is that the wafer's size is then determined by the dimensions of the base substrate (see figure 1).

Using this technique, templates are produced by depositing a single-crystal AlN epitaxial layer onto a foreign substrate at a high growth rate to form a thick, low-defect layer. Thick AlN is essential for reducing the defects that result from growth on a foreign substrate because the defect density rapidly decreases with distance from the AlN/substrate interface.

Template substrates with sufficiently thick AlN layers can also deliver excellent electrical insulation for the upper device structure because AlN's electrical resistivity is higher than $10^{11} \Omega \text{ cm}$ at room temperature. In addition, the AlN layer has a thermal conductivity of at least $3 \text{ W cm}^{-1} \text{ K}^{-1}$, which can boost device performance, and a native AlN surface for lattice-matched growth.

In our opinion the only suitable method for producing such thick epitaxial layers is hydride vapor phase epitaxy (HVPE). MOCVD and MBE have typical growth rates of less than $1\text{--}2 \mu\text{m}$ per hour and using these methods to deposit $10 \mu\text{m}$ or more of AlN is too expensive and time-consuming. HVPE, however, can

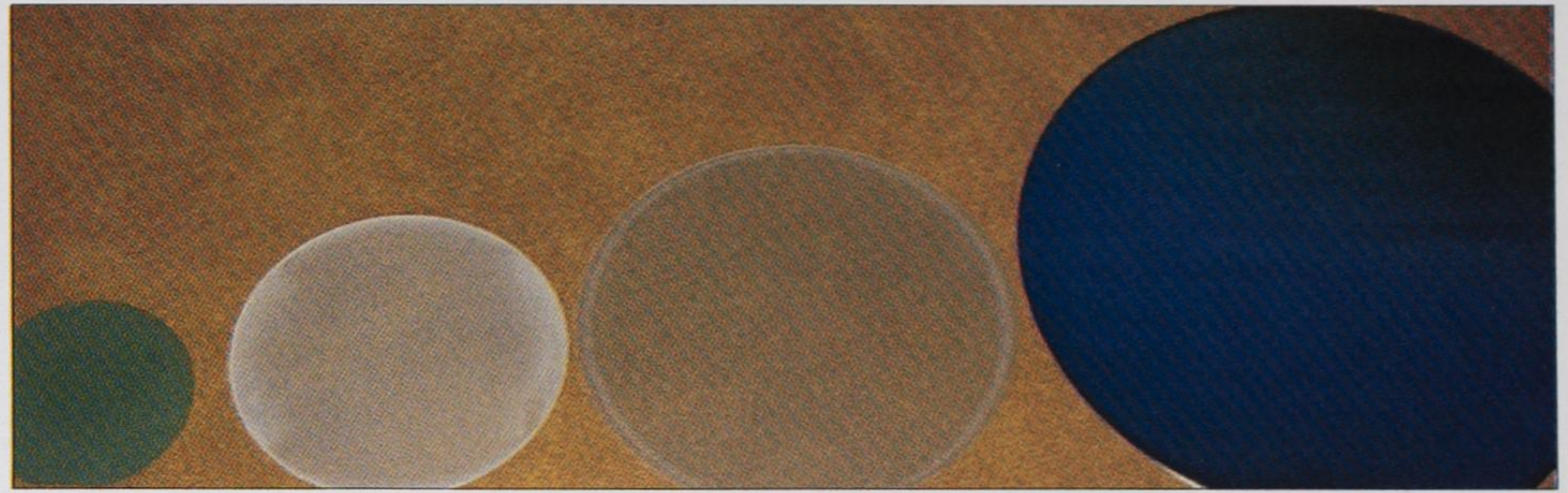


Fig. 1. Technologies and Devices International can produce different templates by HVPE, including 2 inch AlN-on-SiC, 3 inch AlN-on-sapphire, 4 inch GaN-on-sapphire and 6 inch AlN-on-Si.

produce low-defect GaN and AlN layers at much lower costs and at rates that can exceed $1 \mu\text{m}$ per minute.

Unfortunately, the standard HVPE technique suffers from the same major drawback that hampers the MBE and MOCVD approach – severe cracking of the AlN layer when its thickness exceeds a couple of microns. The cracking results from differences in the thermal expansion coefficients and crystal lattice dimensions between AlN and its foreign substrate, and can produce crack densities in the range of hundreds per millimeter.

Modifying the HVPE process

To address the problems associated with cracking we have developed a deposition technique called stress-control HVPE. This process, which we have developed using our proprietary and patented home-built multiwafer machines that feature a hot-wall quartz tube and a resistively heated furnace, is able to produce crack-free AlN layers up to $75 \mu\text{m}$ thick. It has also been used to grow crack-free AlN films from $10\text{--}30 \mu\text{m}$ thick on 2 inch SiC that have defect densities in the high 10^7 cm^{-2} range, which is an improvement by at least an order of magnitude over device structures grown directly on SiC that suffer from a small distance from the SiC substrate.

These templates can even be built using electrically conducting substrates, such as silicon or conducting SiC. The key is to grow the electrically insulating AlN layer thick enough to prevent high-frequency signal loss in microwave devices. For GaN-based HEMTs operating at 2 GHz this thickness should be a minimum of $10 \mu\text{m}$ and for higher-frequencies devices it should be even thicker. AlN templates offer important advantages to manufacturers of this type of device because they can be produced from conducting SiC, which is available in larger



The cleaved edge of an AlN-on-SiC epitaxial wafer with a $26 \mu\text{m}$ -thick AlN layer, showing that it is possible to grow crack-free AlN using TDI's stress-control HVPE process.

The appetite for larger substrates has led to various AlGaIn-based devices being developed on foreign substrates.

Fig. 2. (left) The high degree of crystalline quality in the AlN layers is revealed through X-ray characterization. This image shows full-width at half-maximum (FWHM) values from a ω -scan of the (00.2) AlN reflection on a 3 inch AlN-on-sapphire epitaxial wafer with a 15 μm -thick AlN layer. For this reflex the average FWHM value is 234 arc sec, while in the (10.2) reflex the average value is below 800 arc sec.

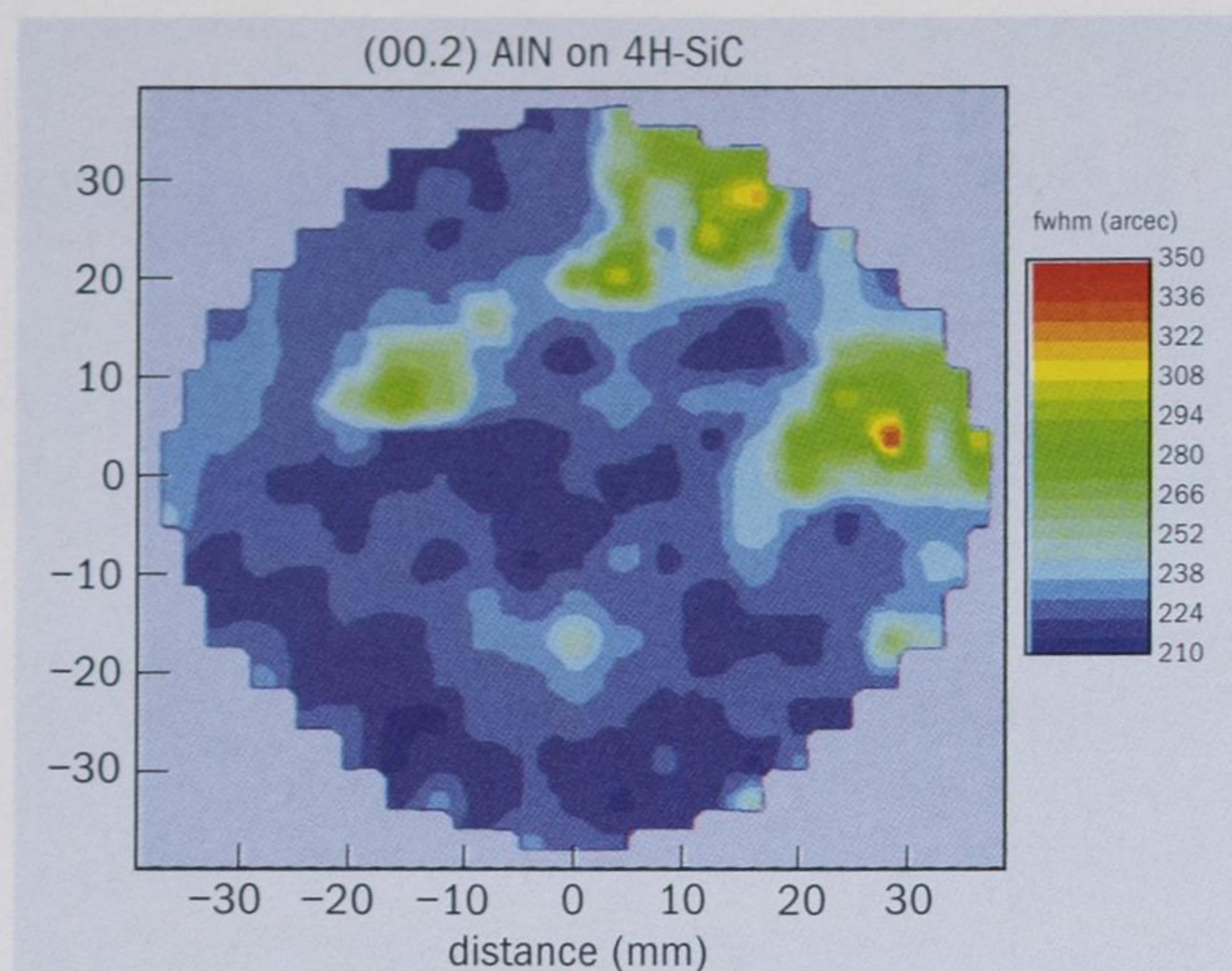
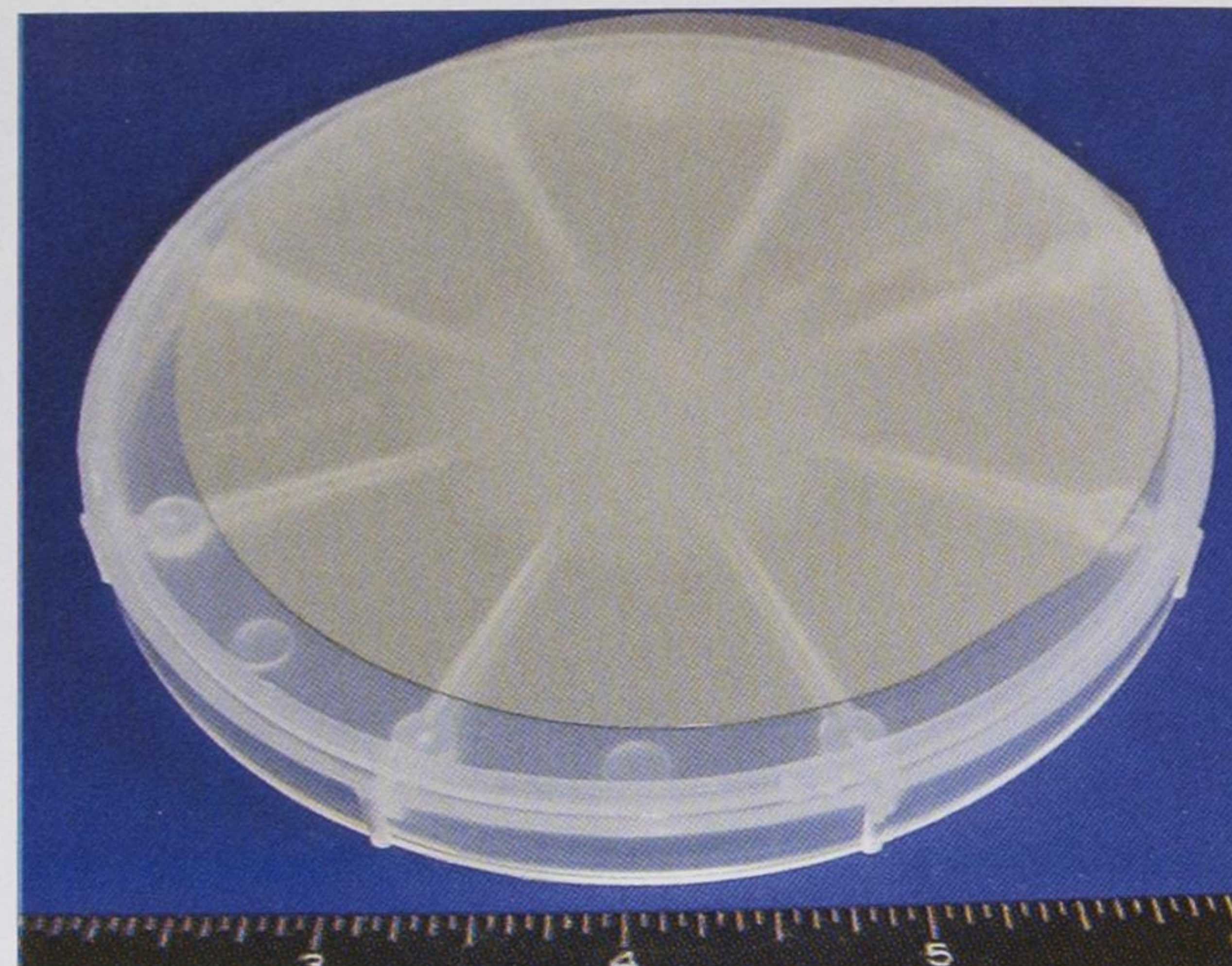


Fig. 3. (right) TDI has recently produced 4 inch AlN-on-SiC template substrates with 12 μm -thick crack-free AlN layers on conducting SiC. The company plans to launch these templates by the end of 2006.



sizes than semi-insulating SiC, and at a significantly lower cost. The benefits have led a customer of ours to develop a process for manufacturing GaN HEMTs for 3G base stations using low-cost AlN-on-SiC templates.

We used stress-control HVPE to manufacture 3 inch diameter AlN-on-conducting SiC template substrates with an AlN thickness of 10–25 μm . This product, which was launched last year, features high-crystalline-quality AlN layers (see figure 2). These wafers are also relatively flat, and a 20 μm -thick AlN layer produces a bow of less than 40 μm , making this platform ideal for sub-micron processing of microwave device structures. The templates can also be polished to produce substrates with a surface roughness below 0.5 nm.

More recently, we have expanded our stress-free deposition process to 4 inch conducting SiC and produced templates with 10–15 μm -thick crack-free AlN layers (see figure 3). Preliminary X-ray diffraction data from these wafers, which we plan to release commercially by the end of the year, shows that they have a similar crystal quality to their 3 inch predecessors. They are the first semi-insulating 4 inch AlN substrates for high-power microwave devices and will allow manufacturers to use standard 4 inch microwave processing lines for the production of AlGaIn HEMTs and amplifiers. They can even be scaled to 6 inch substrates when conducting SiC substrates of that size become available.

Improving UV LED output

Stress-control HVPE can also be used to deposit thick AlN layers on other substrates and we have used it to produce crack-free material up to 20 μm -thick on 2 inch sapphire. These AlN-on-sapphire templates are transparent at ultraviolet wavelengths and make an ideal platform for the production of AlGaIn-based LEDs and ultraviolet photodetectors. These devices benefit from the high thermal conductivity of the AlN layer and a low defect density, thanks to lattice-matched growth on an AlN surface.

Michael Kneissl and his colleagues at Palo Alto Research Center (PARC), CA, have used an AlN-on-sapphire variant, AlGaIn-on-sapphire, to grow ultraviolet LEDs. After chemically cleaning the 2 inch

templates, they used MOCVD to grow various LED structures featuring magnesium-doped p-type layers and an active region of five 4 nm-thick InAlGaIn quantum wells separated by 8 nm-thick InAlGaIn barriers. Chemically assisted ion-beam etching formed square LED chips from the epiwafers with dimensions of 100–900 μm . By intentionally varying the quantum well and barrier compositions, the LEDs' emission wavelengths were adjusted from 289 nm to 373 nm.

The largest 330 nm-emitting devices tested on the wafer produced a continuous-wave (cw) output of 11 mW at 400 mA drive current. Output was limited by thermal rollover and would have been higher in packaged devices because of improved heat dissipation. When driven in pulsed mode (1 μs pulse widths, 10 kHz duty cycle) the output of these LEDs rose to 55 mW. 100 μm square devices emitting at 330 nm produced external quantum efficiencies (EQEs) of 1.5% in cw mode and 2.3% in pulsed mode. These results compare favorably with LEDs built by other researchers on sapphire substrates, which have EQEs of typically 1% at 350 nm, and 0.1% between 324 nm and 269 nm.

These promising results on ultraviolet LEDs, allied to the development of GaN HEMTs on AlN-based templates, illustrate some of the benefits that result from the stress-control HVPE process. Our launch of the 3 inch AlN-templates for high-power devices is already offering substantial cost savings and benefits for high-power device manufacturers, and we expect our planned release of the 4 inch AlN-on-SiC later this year to speed the development and commercialization of high-power microwave electronic components and systems and ultraviolet optoelectronic devices. ●

Further reading

- V Soukhoveev *et al.* 2006 *Phys. Stat. Sol. (c)* **3** 1653.
- V Dmitriev *et al.* 2006 Hydride vapor phase epitaxy of group III nitride materials. In: *III-Nitride Semiconductor Materials* pp1–40, (ed. Z C Feng), Imperial College Press. ISBN 1-86094-636-4.
- O Kovalenkov *et al.* 2005 *J. Cryst. Growth* **281** 87.
- M Kneissl *et al.* 2006 *Jap. J. Appl. Phys.* **45**, 5A 3905
- V Soukhoveev *et al.* 2006 *Mater. Res. Soc. Symp. Proc.* **892** 743.



About the authors

Vladimir Dmitriev (right) is TDI's president and CEO. He has previously developed SiC high-power devices at the Ioffe Institute and GaN LEDs at Cree. **Alex Usikov** (left) is TDI's senior scientist and R&D program manager.

COMPANY BULLETIN BANNER

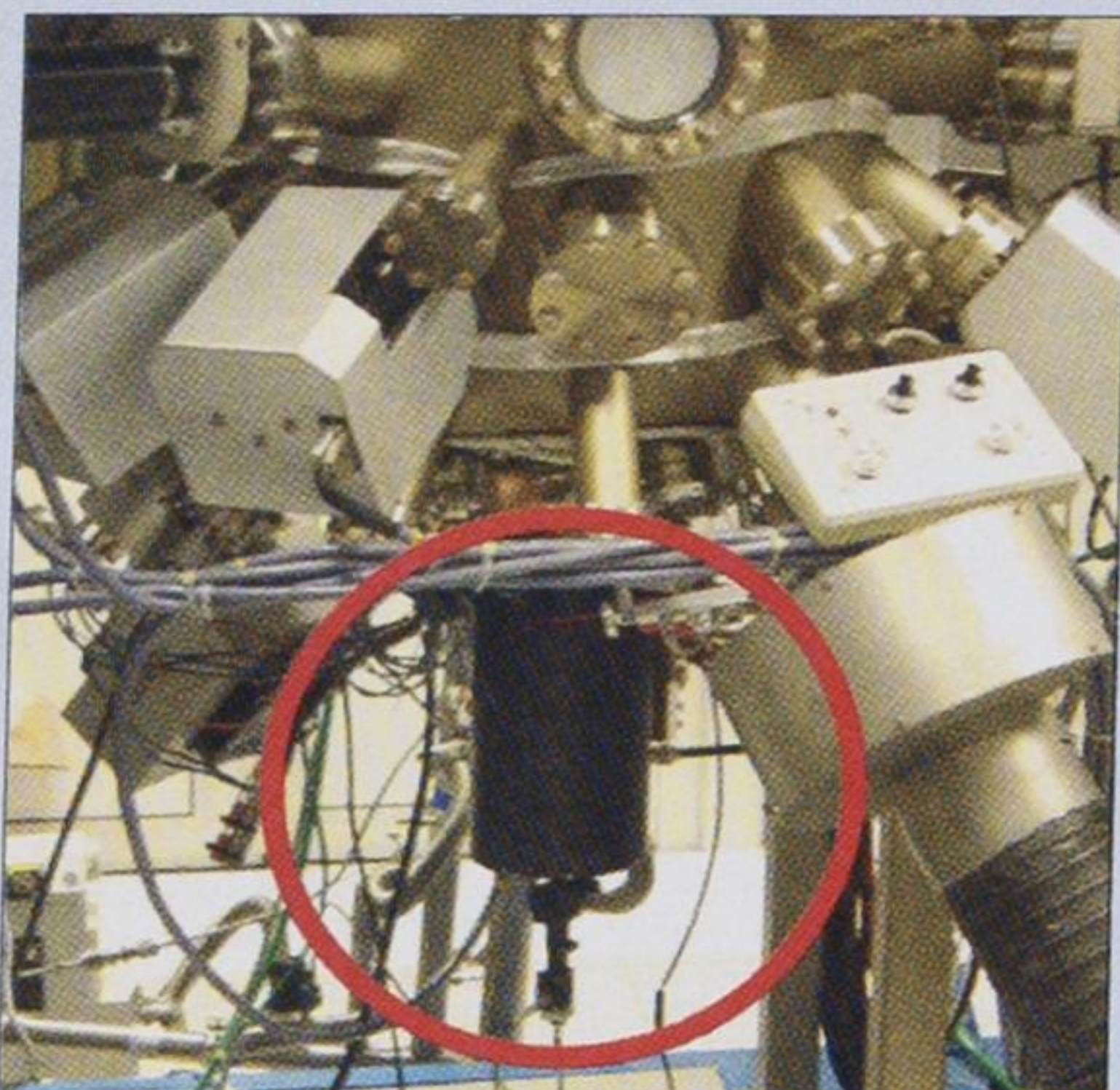
Promote your company message, products and jobs with this banner for only **£500 per issue**. Contact David Iddon on +44 117 930 1032, e-mail: david.iddon@iop.org or Rosemarie Guardino on +1 215 627 0879, e-mail: guardino@ioppubusa.com

COMPOUND SEMICONDUCTOR

EpiCurve goes MBE

LayTec GmbH

LayTec's *in situ* curvature sensor EpiCurve is now also available for MBE systems. EpiCurve is the only *in situ* sensor that combines wafer bowing measurements with reflectance and emissivity-corrected pyrometry, allowing high-resolution curvature and accurate online surface temperature



measurements, as well as growth rate analysis at once! EpiCurve is ideally suited for GaN, GaAs, solar cells and other applications.

Contact: LayTec GmbH,
Helmholtzstr. 13-14,
D-10587 Berlin, Germany
Tel: +49 30 39 800 80-0
Fax: +49 30 39 800 80-80
E-mail: info@laytec.de
Web: www.laytec.de

Logitech Limited

Enhanced III-V substrate preparation with NGS systems

NGS lapping systems provide significant throughput enhancements for III-V compound semiconductor back-thinning operations. NGS (Next Generation Systems) are highly automated lapping machine systems designed specifically to provide the increased yields and faster throughput required when production volumes of especially brittle and delicate materials such as III-V compound semiconductors are being processed. Features such as four fully automated load/unload workstations, Intelligent Jigs, which automatically measure and control the level of load required to provide the optimal level of stock removal, and automatic lapping plate flatness control provide increased system



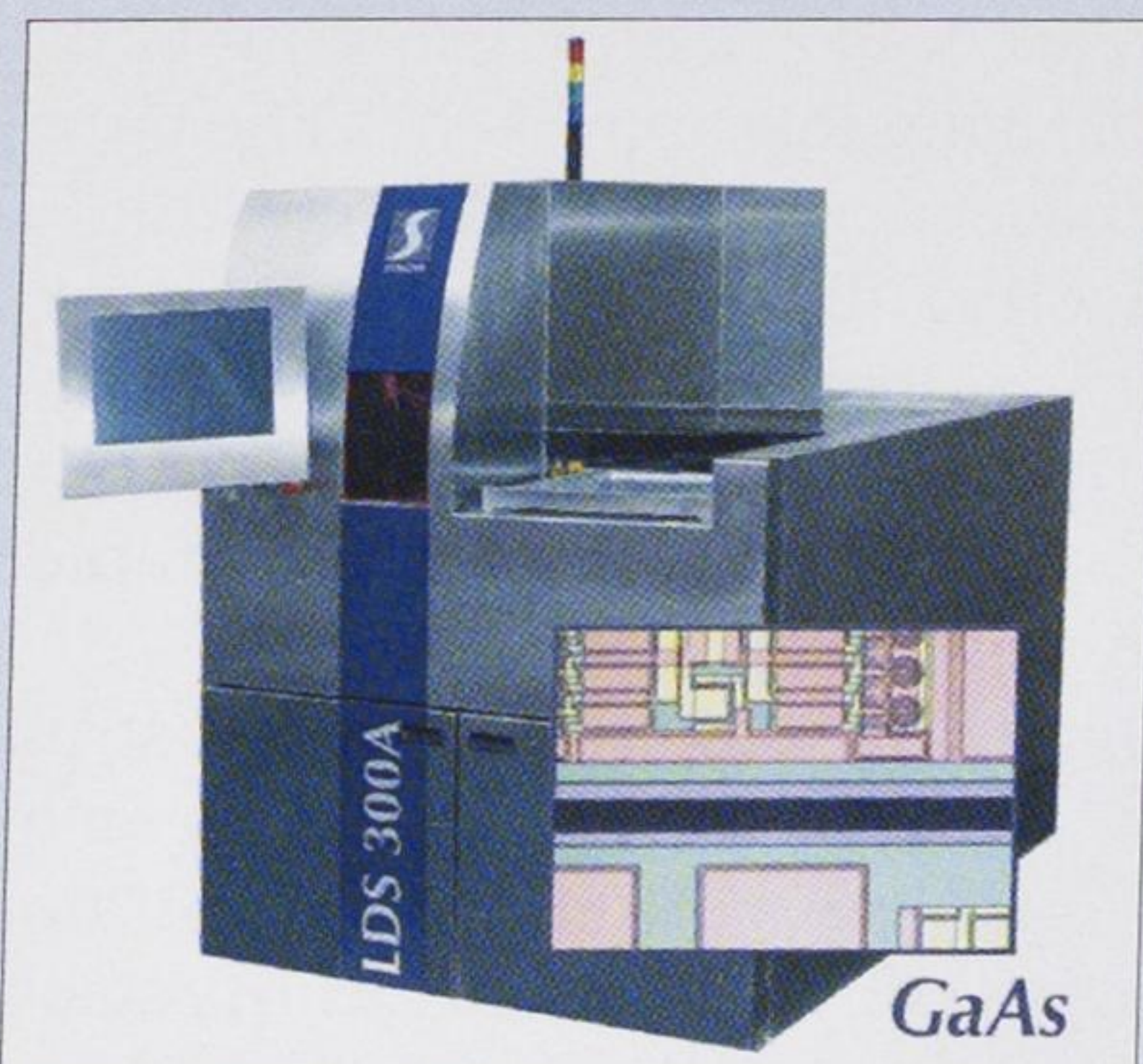
throughput and yield-enhancing performance.

Contact: Logitech Limited, Erskine Ferry Road,
Old Kilpatrick, Glasgow G60 5EU, Scotland, UK
Tel: +44 (0)1389 875 444
Fax: +44 (0)1389 890 956
E-mail: info@logitech.uk.com
Web: www.logitech.uk.com

Damage-free laser dicing of GaAs wafers with the new LDS 300 A

Synova SA

Synova's dicing systems are all based on the revolutionary Laser MicroJet technology. Combining water and laser provides outstanding results, especially in processing brittle materials such as GaAs: no mechanical or thermal damage,



negligible contamination, no toxic product emitted during machining; active areas are undamaged and chips show high fracture strength.

Contact: Synova SA, Chemin de la Dent-d'Oche, 1024 Ecublens, Switzerland
Tel: +41 21 694 35 00
E-mail: info@synova.ch
Web: www.synova.ch

Magneto-Transport Measurements

Lake Shore Cryotronics, Inc

Hall effect measurements on dilute magnetic semiconductors and compound semiconductors. Resistance ranges from 10 $\mu\Omega$ to 200 G Ω , fields to 9 T and temperatures from 2 K to 800 K. Quantitative Mobility Spectrum Analysis software resolves individual carrier mobilities and



densities for multi-carrier devices and compound semiconductors. Anomalous Hall Effect measurements for spintronics and an AC current option measures resistance down to 10 $\mu\Omega$, and increases resolution to 10 ppm at 2 m Ω .

Contact: Lake Shore Cryotronics
Tel: +1 614 891 2244
E-mail: info@lakeshore.com
Web: www.lakeshore.com

Cutting and Grinding of Compound Materials

Advanced diamond wire cutting and precision grinding technologies

High-speed smooth cutting with Diamond-Multi-Micro-Wire-Saw, DMMWS. A multi-wire-grid of diamond wire results in high throughput and smooth surfaces. Precision ultrathin grinding down to 20 microns with TTV 1 my.

Service contracting and sales of machines and clusters for Si, SiC, Al₂O₃, GaAs, GaN, quartz, piezo and many other compound materials.

Exhibiting at CS Week 2006 in Austin, TX.



Contact: my-Chip Production GmbH,
Prof.-Hermann-Klare-Str. 6,
07407 Rudolstadt, Germany
Tel: +49 (0) 36 72 - 47 82 60
Fax: +49 (0) 36 72 - 47 82 65
E-mail: info@german-my-chip.com
Web: www.german-my-chip.com

FOR SALE

www.goindustry.com

On behalf of Beam Express, Lausanne, Switzerland of

one Agilent ParBERT System and
one Mindready VCSEL Test System

The ParBERT System includes:

- 1 x 81250 A opt. 013, IEEE 1394 PC link to VXI
- 1 x 81250 A, opt. 149 Mainframe
- 1 x 81250 A, opt. 014 External PC
- 2 x E4861B, 3.3 G GEN/AN Module
- 4 x E4862B, 3.3 G Generator Front end
- 4 x E4811A, 3.3 G Analyzer Optical module with FC/PC connectors
- 1 x E4808A, 10.8G Clock Module
- 1 x 15444A, 17" CRT Monitor

The VCSEL Test System includes:

- Main rack with 24 modules for 16 devices each (3.5V/40mA/150°C)
- Current/ Voltage control unit
- Computer and software
- Water cooling unit
- UPS
- Manuals
- Mains inlet 230V

Location of Assets: Lausanne, Switzerland

On View: by appointment only

For further information please contact Karl Freedman
Tel: +49 (0) 89 1255 5876, Email: karl.freedman@goindustry.com
For details on this sale please visit our website www.goindustry.com



TEL: +49 (0) 89 12 55 58 0
FAX: +49 (0) 89 12 55 58 12
Landshuter Allee 38, D-80637 Munich



GaN TRANSISTORS

US Air Force makes diamond advance

Engineers at the US Air Force Research Laboratory (AFRL) claim to have fabricated the first operational GaN-on-diamond high-electron mobility transistor.

Although details from the AFRL team are sketchy, with no mention of output power or frequency of operation, the team did reveal the following: "Initial transistor results show that the AlGaIn/GaN material survived all the process steps, including high-temperature ohmic contact anneal."

Because of its very high thermal conductivity, diamond has long been regarded as the ideal material on which to base high-power transistors. However, the lattice mismatch between it and GaN alloys has proved to be a major stumbling block.

To get around that issue, the transistor epi-

layers were first grown on a sacrificial "non-SiC" substrate using MOCVD by Ivan Eliashevich and colleagues at Emcore's electronic materials division (EMD). Next, GaN-on-diamond specialists at California-based Group4 Labs took the epitaxial structure and carefully attached it to a chemically vapor deposited (CVD) diamond substrate.

A thin, thermally conductive attachment layer is sandwiched between the CVD diamond and the epitaxial structure, ensuring that the transistor channel is close to the diamond. Critically, this enables almost-instantaneous heat extraction from the device. In theory, this should mean that transistors with an extremely high power density could be processed using the novel combination of materials.

"We are excited by the promise of this tech-

nology," said Eliashevich, the director of research and development at EMD. "It combines the most robust semiconductor material with the best heat spreader."

Eliashevich expects that transistors based on the novel material combination will be initially deployed in high-performance military applications. However, he adds that because the CVD diamond and epitaxy approaches are inherently scalable to 4 inch or even larger wafers, the technology could eventually penetrate lower-cost, higher-volume commercial markets.

Apart from RF and power switch applications, the approach may also turn out to be useful for improving heat dissipation in optoelectronic devices, which could enable brighter LEDs and more powerful laser diodes.

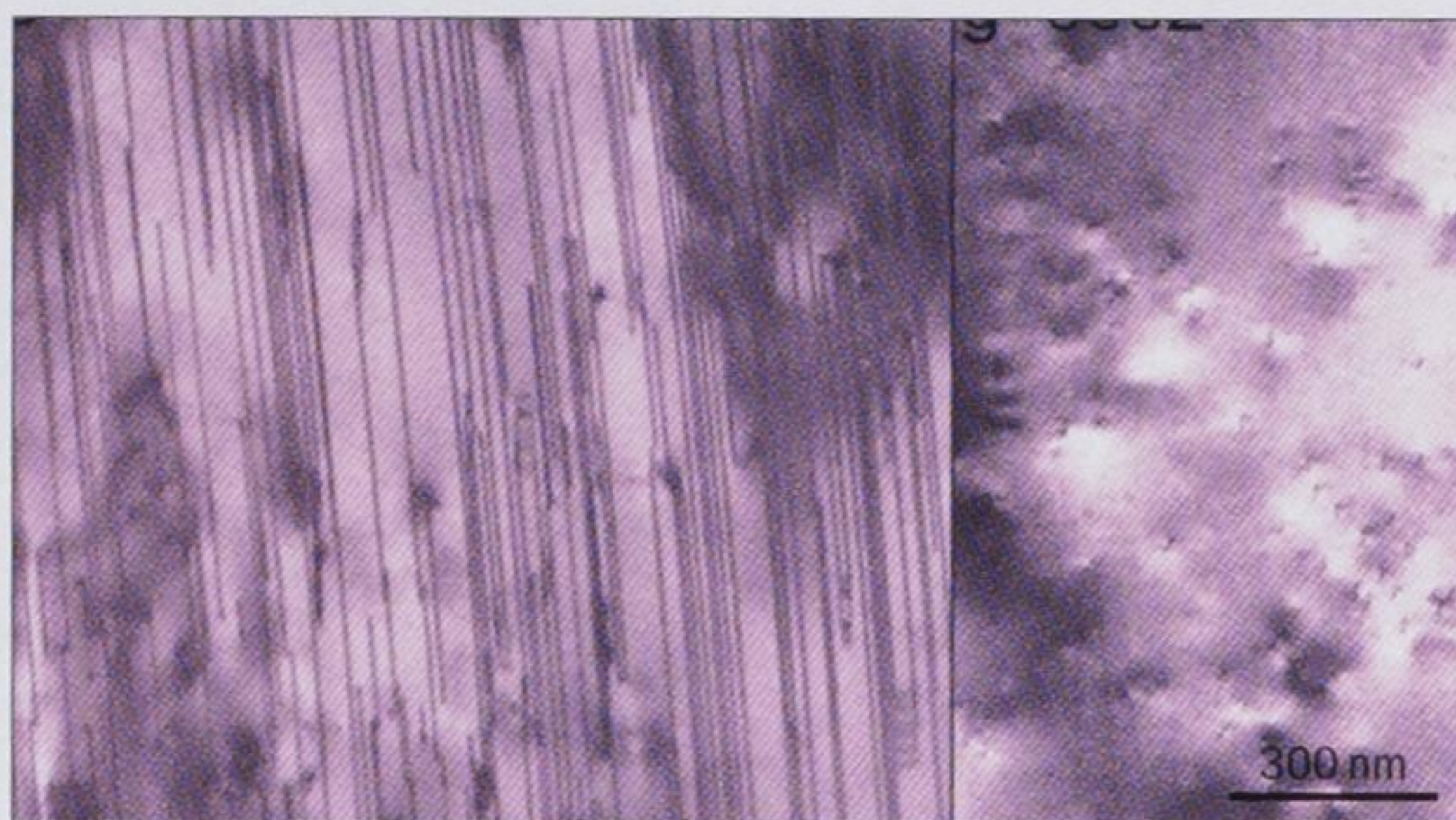
OPTOELECTRONICS

Introducing thin SiN layer cuts GaN defects

Non-polar GaN-based devices are attracting considerable attention because they do not suffer from polarization-related electric fields, but at the moment their performance is restricted by high defect levels.

However, that could all change now that Steven DenBaars' group at the University of California, Santa Barbara, has shown that it is possible to reduce the defect density by inserting a very thin SiN layer between GaN epilayers. The process cuts the stacking fault density in *a*-plane non-polar films from $8 \times 10^5 \text{ cm}^{-1}$ to $3 \times 10^5 \text{ cm}^{-1}$, and the dislocation density from $8 \times 10^{10} \text{ cm}^{-2}$ to $9 \times 10^9 \text{ cm}^{-2}$.

The Santa Barbara team produced the low-defect density films on *r*-plane sapphire by MOCVD. According to team member Arpan



Transmission electron microscopy images can reveal the defect density in non-polar films incorporating a SiN layer. Plan view images revealing the stacking faults (left) and threading dislocations (right) were produced by a University of California team using the diffraction conditions $g = 1100$ and $g = 0002$, respectively.

Chakraborty, depositing SiN *in situ* was a relatively straightforward process: "Silicon does not exhibit a memory effect and the experiments were pretty reproducible."

Chakraborty told *Compound Semiconductor* that the team based its optimization of the SiN

layer on previous studies of *c*-plane GaN, which had shown an ideal thickness of about one and a half monolayers. Defect reduction did not occur if this layer was too thin, explained Chakraborty, but if it was too thick it could hinder the coalescence of the overgrown GaN film.

The researchers are now growing GaN-based LEDs using this approach. "The initial photoluminescence data from our multiple-quantum-well calibration samples look very promising," remarked Chakraborty, who revealed that the emission intensity had increased by almost one order of magnitude with the new process.

The group is also studying the microstructural evolution of the overgrown GaN layer by various techniques, including transmission electron microscopy, which can identify stacking faults and dislocations.



Journal reference

A Chakraborty et al. 2006 *Appl. Phys. Lett.* **89** 041903.

GaN PHOTODETECTORS

Photodiodes produce highest optical gain

Russell Dupuis' team from Georgia Institute of Technology, GA, the US Army Research Laboratory and Kyma Technologies, claim to have produced the highest optical gain yet seen in GaN-based avalanche photodiodes.

The devices deliver a maximum optical gain of more than 1000 when illuminated by 360 nm radiation. At 50 μm in diameter, they also have the largest area yet reported for any III-N

avalanche photodiodes.

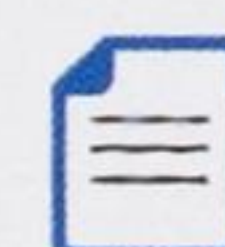
Despite the gain improvements, the photodiode's sensitivity is still well below that of photomultiplier tubes (PMTs) that can produce gains as high as 10^6 at ultraviolet wavelengths. However, the team points out that PMTs need a high-voltage supply and cooled photocathode, which makes them quite large, expensive, bulky and fragile.

GaN photodiodes also have advantages over ultraviolet-enhanced silicon avalanche photodiodes, such as a lower dark current, and do not need complex filters for solar blind detection.

The detectors were grown by MOCVD on n-type GaN substrates with a dislocation den-

sity of 10^5 – 10^6 cm^{-2} . They featured a 2.5 μm thick silicon-doped GaN layer, a 0.3 μm thick unintentionally doped GaN drift region, and a 0.12 μm thick magnesium-doped GaN layer. Inductively coupled plasma etching defined the device geometry, before ohmic contacts were formed by metal evaporation.

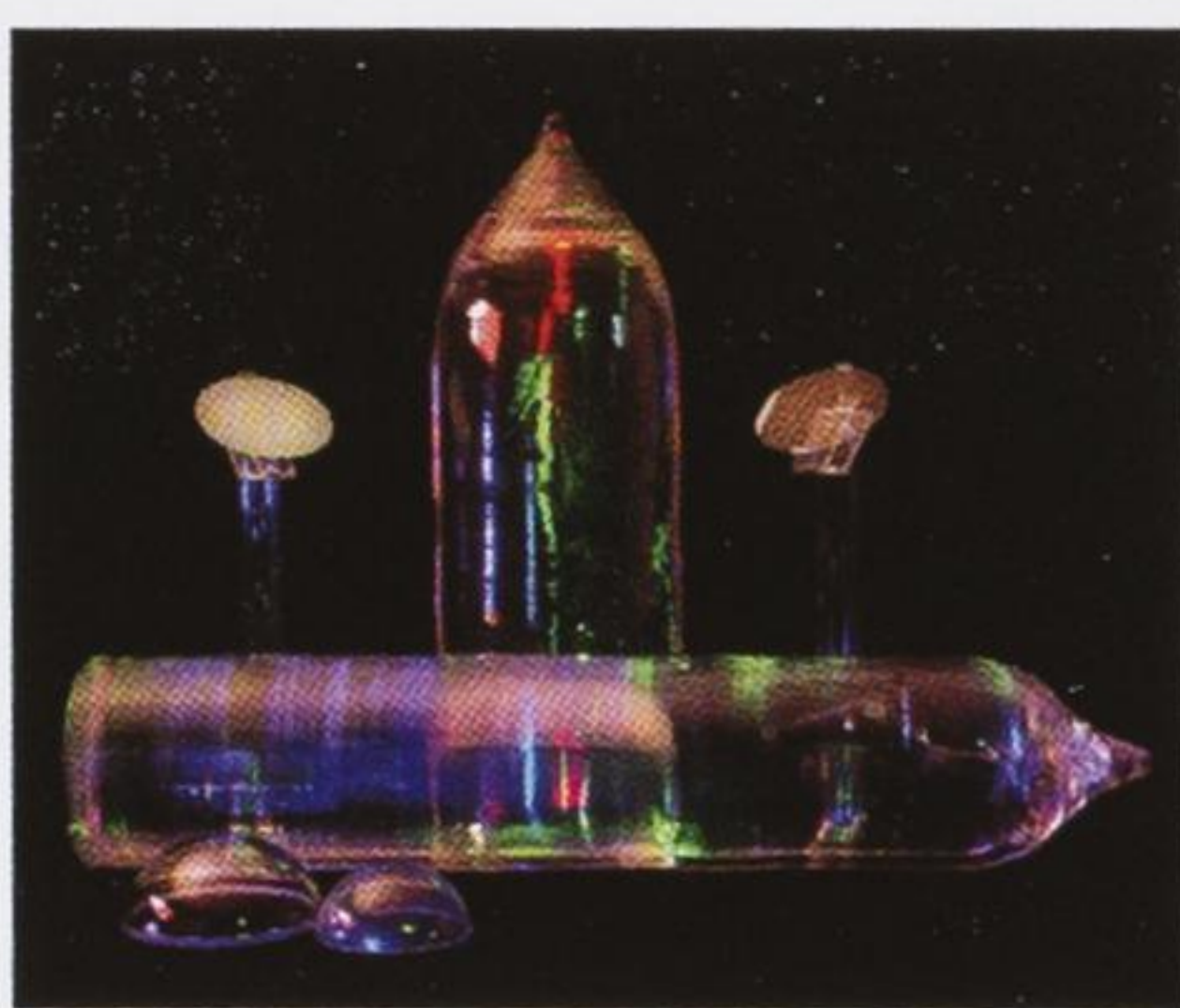
The team believes that the detector's noise performance could be reduced with a separate absorption-multiplication structure featuring impact ionization engineering.



Journal reference

J B Limb et al. 2006 *Appl. Phys. Lett.* **89** 011112.

deliver nonstop



Honeywell Sapphire Substrates—increase your confidence in your process, thanks to some of the world's most consistent materials.

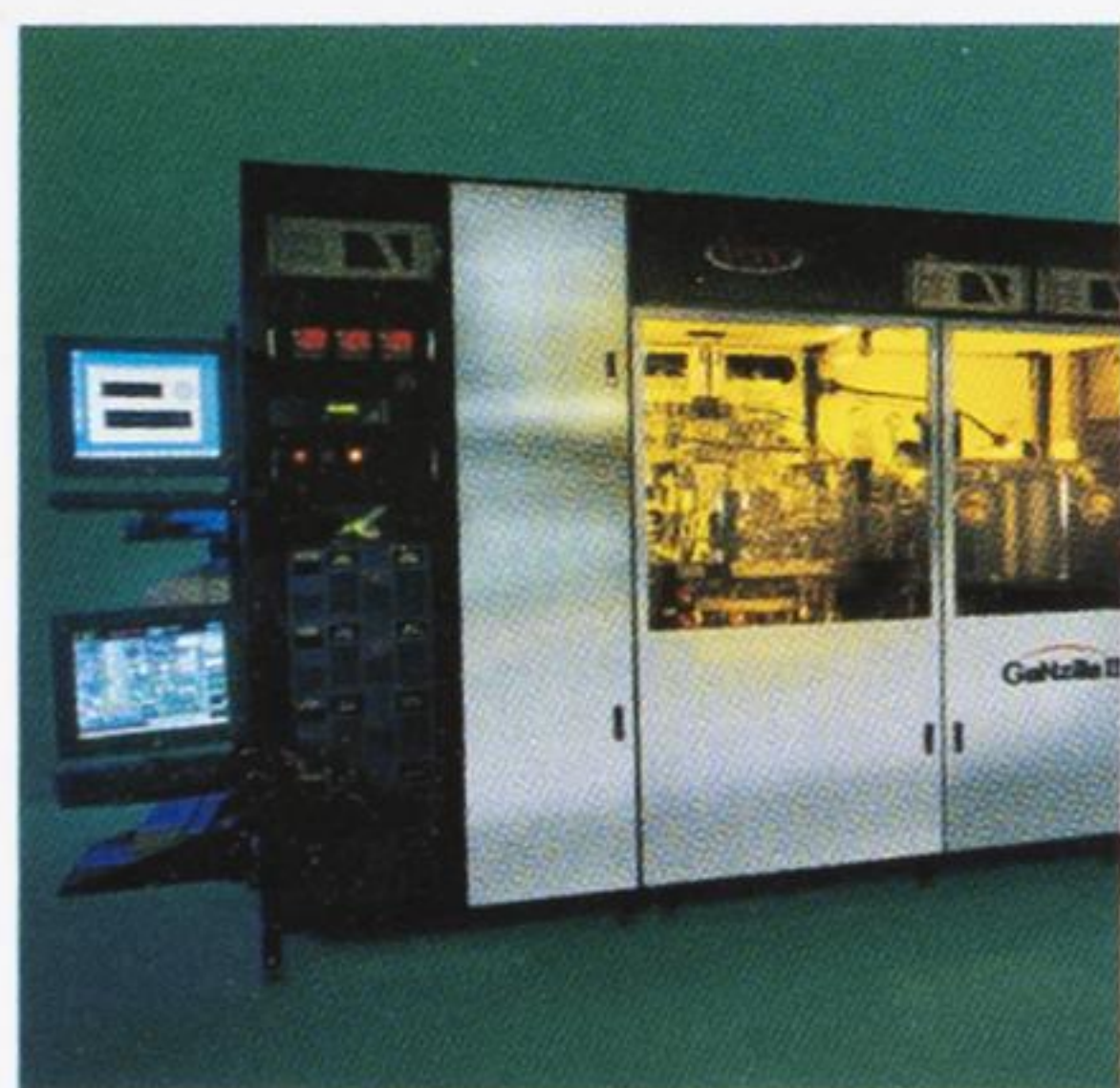
To achieve the most consistent yields in your products, you need sapphire materials that consistently perform. Our wafers, formulated within critically tight tolerances, ship with detailed certificates of analysis, pinpointing the exact manufacturing data of your order. And our rigorous Six Sigma process helps us produce materials that consistently meet your precise specifications — so, while you strive to perfect your process, you can take the performance of our sapphire substrates for granted. We're always good to go.

Honeywell

Go consistently. Get more information by visiting
www.honeywell.com/sm/em or call 1-408-962-2000.

© 2006 Honeywell International Inc. All rights reserved.

As/P productivity that goes straight to your bottom line.



Veeco E450 MOCVD System

VEECO'S E450 MOCVD SYSTEM:

THE COMPETITIVE EDGE FOR ALL OF YOUR As/P APPLICATIONS

Bottom line: Veeco's E450 MOCVD System delivers the highest productivity of any As/P system available today, whether you are making LEDs, solar cells, red lasers, HBTs or pHEMTs. So you can make more wafers than ever before, with the lowest cost of ownership of any MOCVD system available today. And, with the financial stability of Veeco, you have a partner who can take you confidently into the future. Discover Veeco's E450 MOCVD system today by calling 888-24-VEECO or visit www.veeco.com/asp.



Solutions for a nanoscale world.™