

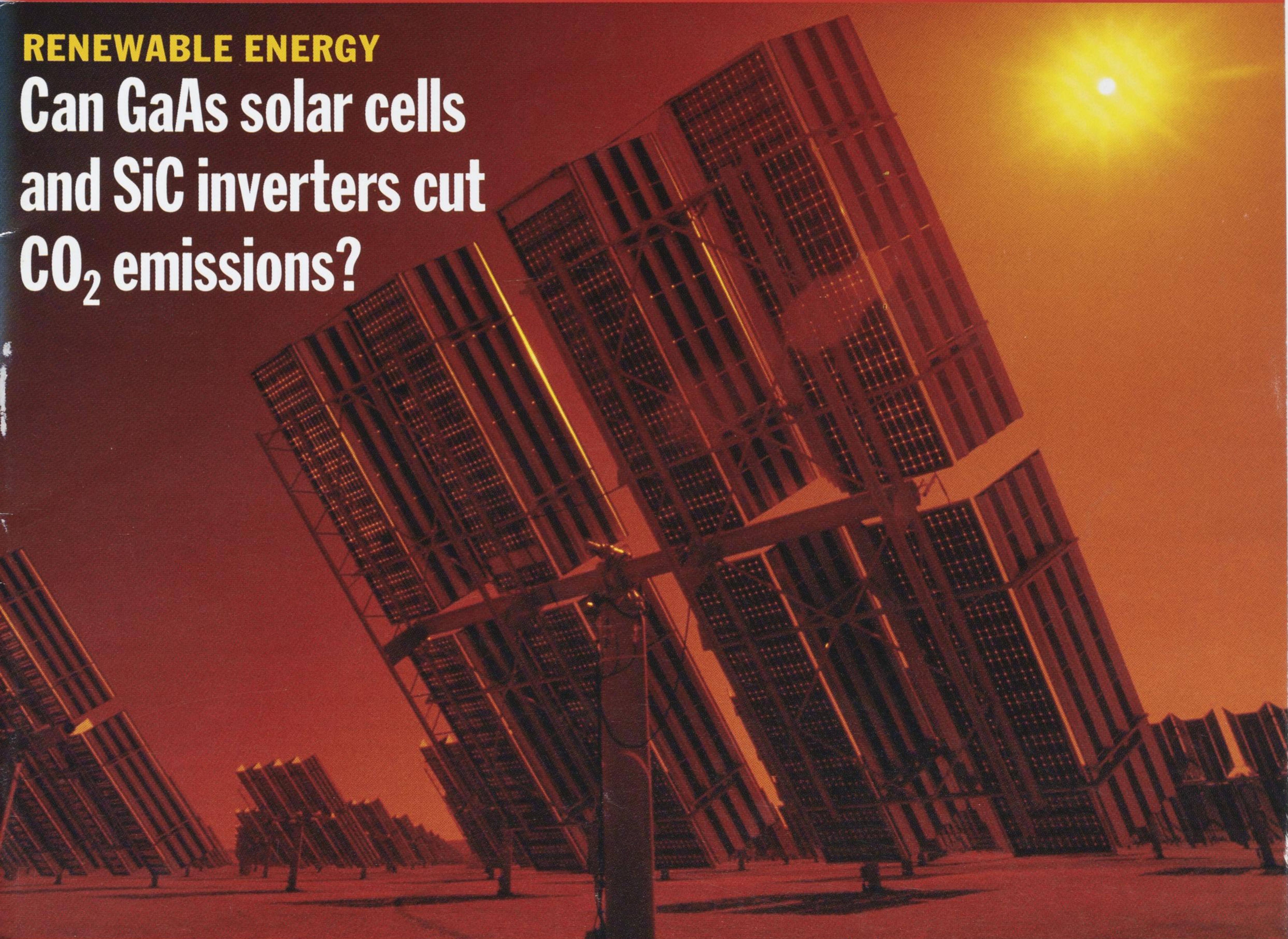
COMPOUND SEMICONDUCTOR

March 2006 Volume 12 Number 2

CONNECTING THE COMPOUND SEMICONDUCTOR COMMUNITY

RENEWABLE ENERGY

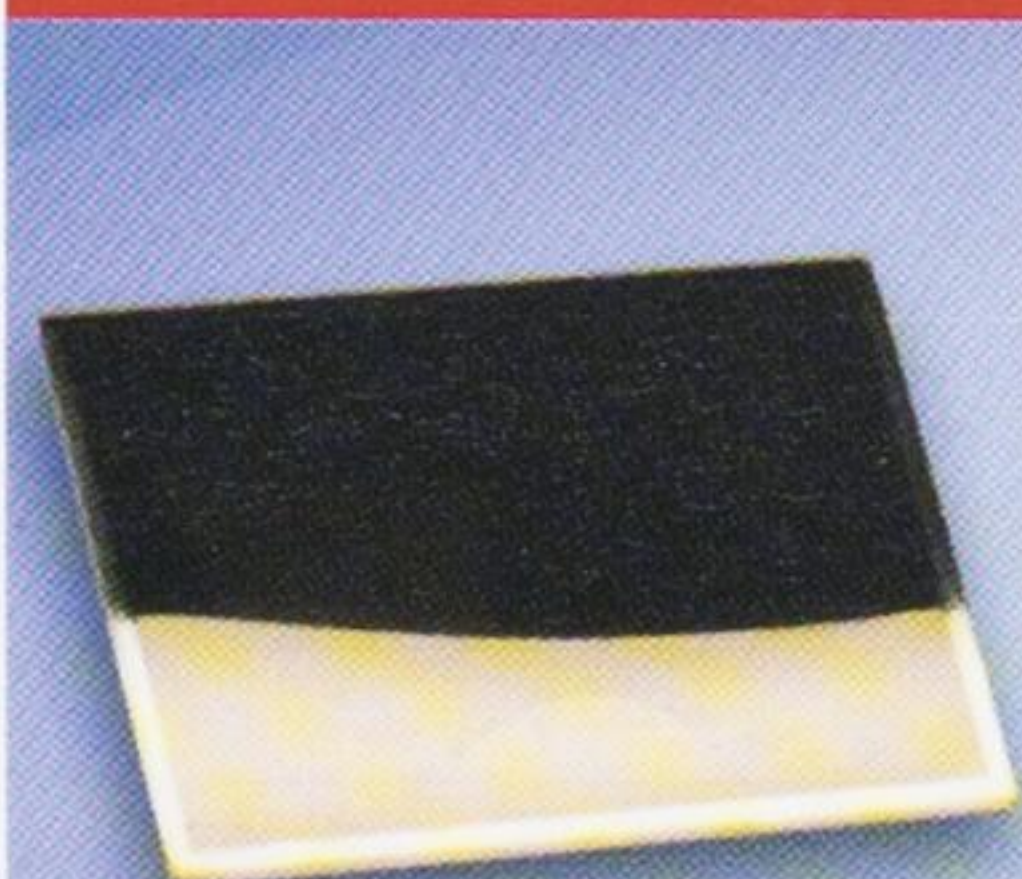
Can GaAs solar cells
and SiC inverters cut
CO₂ emissions?



BEHIND THE HEADLINES

Freescall puts GaAs
MOSFETs back on
the agenda **p15**

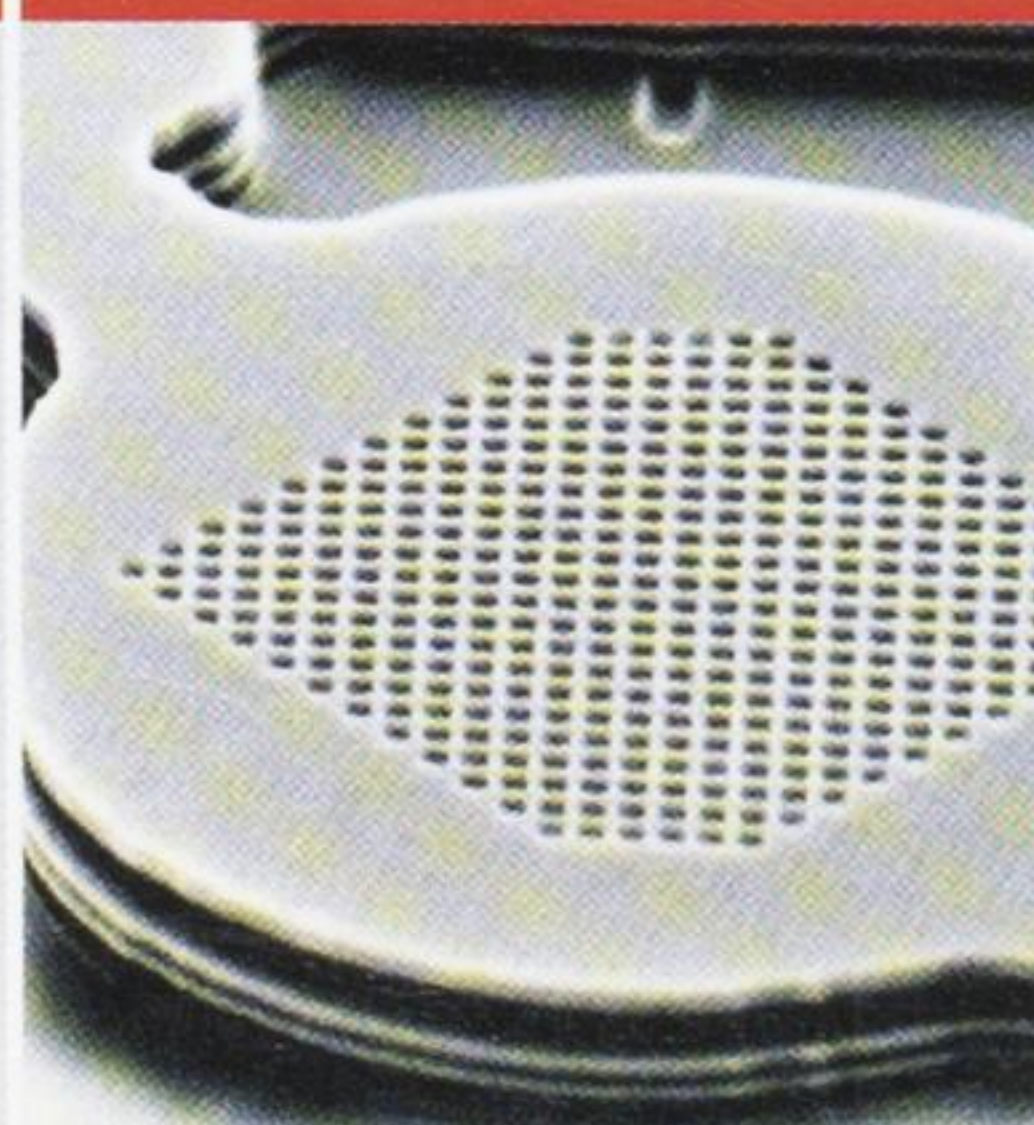
INDUSTRY



Diamond lights

California start-up
Group4 Labs moves out
of stealth mode with
GaN-on-diamond. **p5**

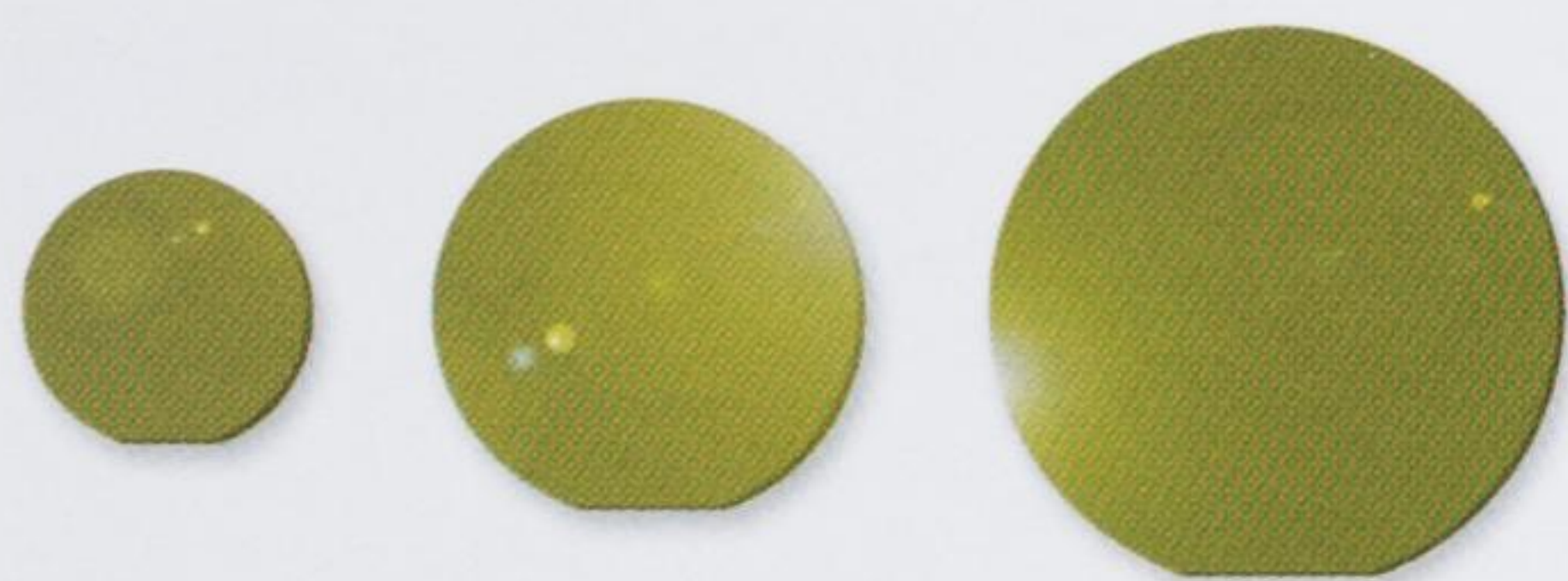
TECHNOLOGY



MEMS

Microdevices to sense
gases, detect explosives
and control car pollution. **p23**

For some, customer service is a department.
For INTRINSIC, it's a way of doing business.



INTRINSIC offers wafers in 2", 3", and 4" sizes.

At INTRINSIC, one of our most important deliverables is service. Sure, we supply high quality substrates and epitaxial services as well — including one of our newest offerings, a zero-micropipe SiC substrate. But we believe it's our dedication to customer service that has made us the go-to supplier for the world's most demanding manufacturers. It's how we keep customers not merely supplied, but satisfied.

Call us today at 1.703.437.4000, or e-mail us at sales@intrinsicsemi.com.
We want to serve as your materials and solutions partner.

Visit www.intrinsicsemi.com to learn more.

SiC SUBSTRATES • SiC EPITAXY • GaN EPITAXY

The Measure of Quality.

INTRINSIC
SEMICONDUCTOR

INDUSTRY

- 5** **Headline News:** Capacity crunch hits GaAs suppliers... Diamond outfit emerges from stealth mode with novel approach...Northrop Grumman signs SiC deal with APT.
- 6** **The Month in RFICs:** RFMD profit outstrips rivals' as Polaris chipset sales triple...Filtronic chief ousted despite GaAs ramp...3GSM World Congress showcases latest multi-band power amplifiers.
- 8** **The Month in HB-LEDs:** Sales hit as commoditization kicks in...Cree and Lumileds push lumen claims...Avago patent deal includes backlights...Dominant and Osram share spoils.
- 
- Looking forward**
Long-term growth in the white HB-LED sector will likely depend on the commercial success of automotive headlamps. **p8**
- 10** **The Month in Optoelectronics:** Bush administration backs solar as Emcore joins in DARPA effort...UK team wins a cool \$3 million...\$1.8 million laser diode contract for Modulight...'Serious concerns' for Avanex liquidity.
- 13** **Opinion: Quality to drive industrial revolution** Get ready for a wave of innovation to impact on the industrial sector, says JDSU's Toby Strite.
- 14** **Portfolio: Emcore stock hits four-year high** Analyst raises Emcore's target price by 33% as the fiber-optic market bounces back to form and the commercial production of triple-junction solar cells for terrestrial applications begins in earnest.
- 15** **Behind the Headlines: Freescale puts MOSFETs on the map** Michael Hatcher hopes that Freescale's GaAs MOSFET development proves more fruitful than the Motorola spin-off's previous attempt to bring together silicon and III-V technology.

TECHNOLOGY

- 16** **Resonant-cavity LEDs fire up latest in-car networks:** The plastic optical fiber networks that feature in many of today's cars have data transmission rates that are limited by LED switching speeds. This barrier can be overcome, though, says Firecomms' John Lambkin, if these light sources are replaced with resonant-cavity LEDs.
- 
- Driving ahead**
Plastic optical fiber networks are now used in many modern cars. **p17**
- 21** **SiC modules promise grid efficiency boost:** Power inverters look like becoming a big application area for SiC chips, and ought to help the global movement to cut greenhouse gas emissions, writes Michael Hatcher.
- 23** **Compound semiconductor MEMS community targets new applications:** Today's III-V MEMS community is producing a wide variety of devices for applications as diverse as gas sensing, monitoring sugar levels in water, detecting explosives and reducing pollution from diesel engines. Richard Stevenson reports.
- 26** **Classified:** Incorporating the **Product Showcase**.
- 27** **Modified photodiodes advance quantum communications:** Princeton Lightwave has commercialized a single-photon avalanche photodiode that is targeting quantum cryptography applications. Mark Itzler describes some of the benefits offered by the device's design, and explains how it could provide uncrackable communications.
- 30** **Suppliers Guide: Substrates and Epiwafers.**
- 32** **Research Review:** Patterned wafers cut dislocation density...Record terahertz output from QCL powers up astrophysics research...AlN interlayer boosts HEMT performance.

Main cover image: According to Emcore, the manufacture of GaAs-based solar cells for terrestrial deployment has now begun "in earnest" (p14). Also in this issue, a novel inverter module from Cree using SiC chips (p21) that promises to raise the efficiency of energy transmission between renewable sources like wind and solar power, and the AC grid. Both technologies should help to cut greenhouse gas emissions. Credit: Ken Biggs/Science Photo Library.

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

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 Molly Phillips
Phillips@ioppubusa.com
Tel: +1 215 627 0880. Fax: +1 215 627 0879

Circulation manager Jackie King
jackie.king@iop.org
Tel: +44 117 930 1218. Fax +44 117 930 1178

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

Senior production editor Ruth Leopold
Ad production Joanne Derrick, Mark Trimmell
Art director Andrew Giaquinto
Technical illustrator Alison Tovey
Publishing director Richard Roe

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.

BPA 8539 average total qualified circulation*
*June 2005 BPA audit statement

Editorial board

Mayank Bulsara Atlas Technology (USA);
Andrew Carter Bookham Technology (UK); **Jacob Tarn** Epistar/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

Everything's gone green



Now, as far as I know, the president of the US is neither a *Compound Semiconductor* reader nor a closet member of the Green Party. But after denouncing America's oil "addiction" in his recent State of the Union address, Bush's shifting attitude to renewable energy sources will be of interest to III-V enthusiasts and sandal-wearers alike.

While some might complain that the budget for renewable energy development has been merely rearranged rather than added to, those in the US solar business look set to receive far more financial assistance than they've been used to over the next couple of years. The Solar America Initiative, a scheme that is aiming to deploy enough photovoltaic capacity to power two million homes by 2015, has been hailed by the Solar Energy Industries Association (SEIA).

Applauding Bush and the Department of Energy, Rhone Resch, president of the SEIA, described the initiative as "a key victory for the next great high-tech growth industry in the US: solar energy". You would get a different opinion of the US administration's green credentials from the 32 workers recently laid off from the National Renewable Energy Laboratory, of course, but the president is at least "talking the talk". And with a proposed \$65.3 million hike in Bush's budget request for solar technologies to \$148 million in 2007, there looks to be a great opportunity.

Most terrestrial photovoltaic systems use polysilicon cells, but thanks largely to the heavy subsidies on solar power generation already in place away from the US, there is a squeeze on the supply of the material that is now helping GaAs-based cells become price-competitive in the terrestrial arena for the first time.

Emcore is feeling the benefits, with three terrestrial customers already lined up (see page 14 for more details). But the window of opportunity may not stay open forever. As the supply of polysilicon ratchets up to meet demand, the cost of III-V cells will need to be driven down, not least through improvements to conversion efficiency, to remain competitive. If Emcore and co manage to do that and the political wind continues to blow in their favor, we could be looking at a major new revenue stream.

Michael Hatcher *Editor*

Advertisers' Index

Air Products & Chemicals Inc	11	JPSA Laser	8
Bandwidth Semiconductor	6	Keteca	19
BOC Edwards (USA)	29	KLA-Tencor	12
Crosslight Software	22	LayTec GmbH	10
Dowa International Corporation	22	NL Nanosemiconductor	3
EMF Limited	22	Raboutet	7
Epi Nova GmbH	19	Riber	IBC
Evans Analytical	9	Shiva Technologies	3
Indium Corporation of America	3	Suss Micro	20
Instrument Systems	19	Veeco	OBC
INTRINSIC Semiconductor	IFC	XSIL Ltd	19, 26

Quantum Dot wafers

GaAs Quantum Dot Wafers for:

- ▶ 1064 nm - 1.3 μ m lasers
- ▶ Superluminescent LEDs
- ▶ QDIPs
- ▶ Mode-locked lasers
- ▶ Customised design

Classical Quantum Well Wafers for:

- ▶ Standard and custom optoelectronic applications

Visit us at CLEO 2006

Contact us at:

NL Nanosemiconductor GmbH
Konrad-Adenauer-Allee 11 · 44263 Dortmund / Germany
Phone: +49 (0)231 / 47730 200 · Fax: +49 (0)231 / 47730 250
info@nanosemiconductor.com

www.nanosemiconductor.com

TRACE ELEMENTAL ANALYSIS

of

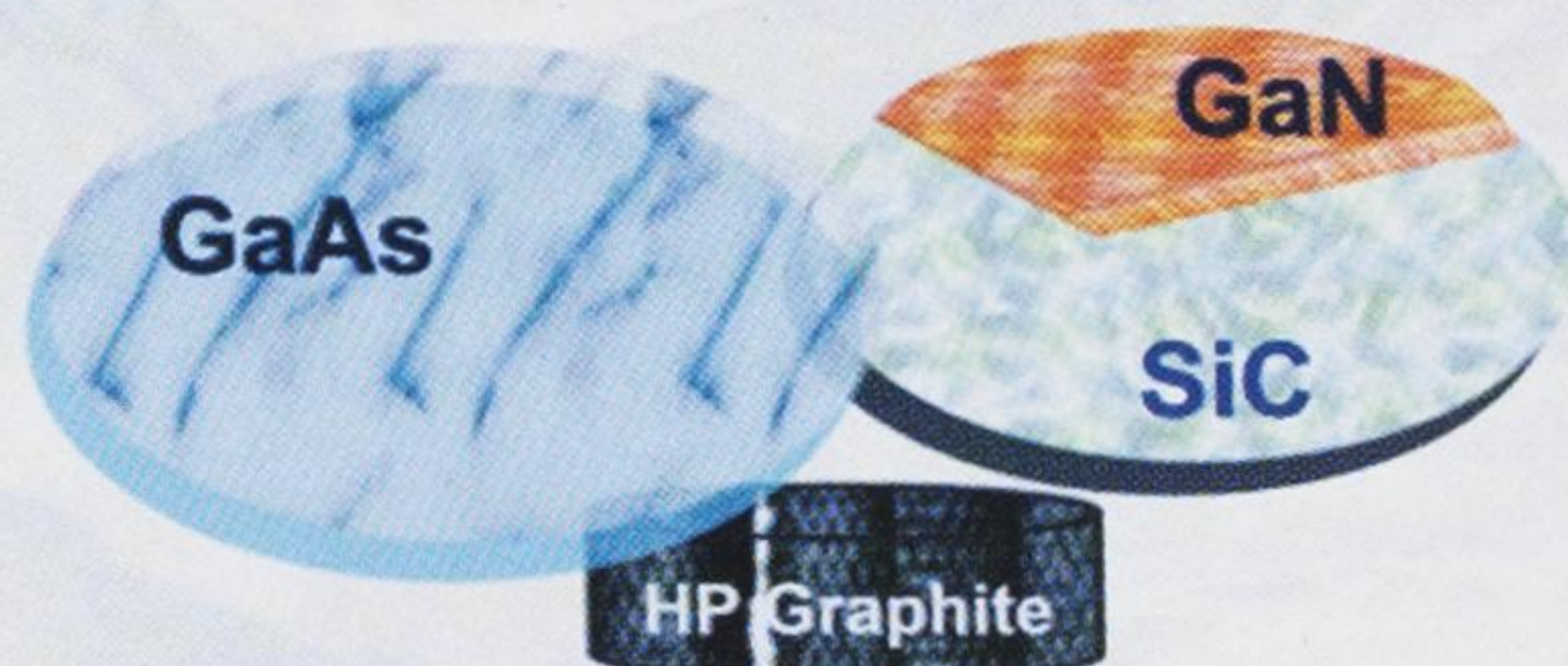
High Purity Materials, Films, and Coatings

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

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

94, chemin de la Peyrette
31170 Tournefeuille, France

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



ISO 9001:2000, ISO 17025
Nadcap

>INDIUM

Standard Materials:

- High Purity Indium Metal:
≥ 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.
0202@indium.com

INDIUM CORPORATION®

www.indium.com/0202
0202@indium.com
Asia: +65.6268.8678
Europe: +39.011.655331
USA: +1.315.853.4900



COMPOUND SEMICONDUCTOR WEEK 2006

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



DATES FOR YOUR DIARY

**November 12-15
2006**

Compound Semiconductor Week 2006 is being held in San Antonio, Texas from 12-15 November.

As always, the event presents a great networking opportunity, with over 80 exhibiting companies and delegates from the 2006 IEEE Compound Semiconductor IC Symposium and the executive-level Key Conference.

The conferences

The IEEE Compound Semiconductor IC Symposium is the pre-eminent international forum for R&D and design engineers exploring developments in integrated circuit technologies using GaAs, InP, SiGe, GaN, SiC and other devices.

The Key Conference is a must for senior management and market analysts focusing on the major technological and market trends that will dominate the future of the compound semiconductor industry.

The exhibition

The Compound Semiconductor Week Technology Exhibition will feature in excess of 80 companies showcasing a wide variety of products and services.

To request more information please visit our website:

www.compoundsemiconductor.net/csmax

**COMPOUND
SEMICONDUCTOR
WEEK 2006**



The Key
Conference 

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

Event organized by:



IEEE

Institute of **Physics** PUBLISHING

**COMPOUND
SEMICONDUCTOR**

SUPPLY CHAIN

Capacity crunch hits GaAs suppliers

Key semi-insulating GaAs substrate supplier Freiberger reached its maximum production capacity in early 2006, *Compound Semiconductor* has learned.

Now focusing on only its top clients in the GaAs RF device business, Freiberger has had to turn some smaller customers away and is currently deciding how many furnaces to add to its production facility to meet the increased demand. But after the turbulence of 2001, when the GaAs industry was hit by overcapacity, the German company is unsure how much expansion it should invest in this time around.

That's partly because the reason for the capacity squeeze is unclear. Companies such as RF Micro Devices, which is in the process of moving GaAs PHEMT production in-house, have increased manufacturing volumes considerably in recent months. The larger chips that are required for more complex RF functionality in cell-phone handsets could be a contributing factor.

The capacity crunch could play into the hands of Freiberger's rival substrate supplier

AXT. After overcoming problems with material quality through an overhaul of its management and operations, the California-based firm, which now does all of its manufacturing in China, has solid orders on its books for the remainder of the year.

That improvement in fortunes is yet to be reflected financially, however. In the quarter that ended on December 31, 2005, AXT made a \$2.7 million loss on revenue of \$7.7 million. Similar figures are forecast for the current quarter, before the expected turnaround begins.

START-UP

Diamond outfit emerges from stealth mode with novel approach

By Michael Hatcher in San Francisco

Group4 Labs, a Californian start-up with a novel twist on wide-bandgap materials that it says could dramatically improve thermal performance, has emerged from stealth mode with bold claims for its GaN-on-diamond templates.

Founded by former Novacrys CEO Felix Ejeckam in 2003, and keeping a deliberately low profile since then, Group4 has been backed through government and corporate funding, but has steered away from venture and equity financing. Ejeckam told *Compound Semiconductor* that Group4 was now engaged in early sampling of the GaN-on-diamond technology platform through some exclusive supply deals with the companies that backed its early-stage development.

While currently only square 10 × 10 mm substrates are available for \$450 from Group4, Ejeckam said that 2 and 4 inch diameter material would be released later in the year.

Rather than growing GaN onto diamond directly, the company processes sapphire- or SiC-based GaN epiwafers by first removing the host substrate and then attaching the GaN epilayer to CVD-grown diamond.

According to Ejeckam, both gallium- and nitrogen-facing material surfaces can be fabricated with a surface roughness on the nanometer scale, as verified by SEM and AFM inspection, and layer quality is unaffected by the transfer process.

Because diamond's thermal conductivity is far higher than the materials conventionally used to host GaN, the build-up of heat in transistors based on the new material platform should be dealt with much more effectively, leading to better reliability in wide-bandgap



Diamond performance: Group4 Labs reckons that its GaN-on-diamond approach will free the wide-bandgap material from the thermal problems that are often encountered with other substrate materials.

devices. "Diamond has great thermal properties," Ejeckam said. "There are no heat problems, so the power amplifier's efficiency is multiplied."

Although primarily targeting microwave, radar and base-station power-amplifier applications, Ejeckam says that the diamond substrate can be modified for LED production, which he says would result in far brighter devices than are currently possible – again thanks to the thermal properties of diamond.

As well as Cornell alumnus Ejeckam, Group4's management team includes no less than four vice-presidents of technology or engineering. These include co-founder Dan Francis, a photonics and materials specialist formerly with long-wavelength VCSEL developer Bandwidth9.

Should Group4's novel approach take off, plans for volume manufacturing are already in place with Asia-based compound semiconductor foundries.

MANUFACTURING

Northrop Grumman signs SiC deal with APT

Power chip specialist Advanced Power Technology (APT) has signed a license agreement with Northrop Grumman's Electronics Systems (NGES) division to manufacture SiC-based microelectronic devices.

This exclusive foundry-supplier relationship will see NGES license certain SiC technology to APT, including patents and manufacturing methods that will allow APT to fabricate high-performance microelectronic devices exclusively for the giant defense contractor.

Last year NGES won a \$9 million contract with the US Navy. Under that project the company planned to make SiC MOSFETs, insulated-gate bipolar transistors and PIN diodes at its Baltimore facility that should cut the weight and size of on-ship transformers dramatically. However, APT's license will also allow the Bend, Oregon, firm to make and sell SiC devices for commercial purposes.

"The development of SiC products for both switch-mode and RF power-conversion applications has been, and continues to be, a key strategic initiative for APT," said company CEO Russell Crecraft. "We expect this new relationship with Northrop Grumman to substantially accelerate our progress towards becoming the leading supplier of SiC power semiconductor products," he added.

Microsemi Corporation, which is in the process of acquiring APT, also welcomed the development. "We are impressed by APT's existing efforts in SiC, and with the combination of Northrop Grumman's extensive know-how, we expect to accelerate APT's progress towards becoming the leading supplier of SiC power products," commented Microsemi CEO James Peterson.

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

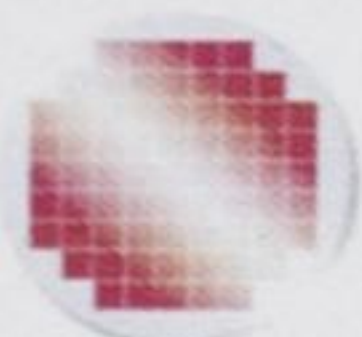
Bandwidth's extensive MOCVD experience and capacity enable the production of a wide range of GaAs and InP epitaxial structures to meet general or custom designs.

- 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

INDUSTRY THE MONTH IN RFICS

FINANCIAL RESULTS

RFMD profit outstrips rivals' as Polaris chipset sales triple

US-based chip makers RF Micro Devices (RFMD), Skyworks Solutions and TriQuint Semiconductor have all posted a profit for their most recent fiscal quarters, with RFMD leading the way. The Greensboro, NC, company enjoyed record sales of \$208 million for the holiday quarter ended December 31, and a \$14.7 million net profit.

The revenue represented a 23% increase on the same period in the previous year, thanks largely to the success of its Polaris transceivers and front-end transmit modules, which have increased RFMD's overall market share.

CEO Bob Bruggeworth said that the improved picture was set to continue throughout 2006, with increased demand from Motorola for GSM products, where RFMD's chips will feature in some of the handset maker's top-of-the-range phones. "Polaris chipset revenue more than tripled year-over-year," remarked a buoyant Bruggeworth.

RFMD will now set about further improving its profit margin. Having increased its wafer fab capacity by around 25%, the company will steadily ramp production of the GaAs PHEMT switches that feature in its front-end transmit modules. At the moment RFMD sources these components from UK-based Filtronic, but views this production switch as the single most effective way to improve its profit margin on goods sold.

While Filtronic will receive smaller orders for GaAs PHEMT switches from RFMD this year, Bruggeworth says that it plans to retain a second-source supplier of the components to ensure that it can meet customer demand.

As well as the increase in GaAs device

production, RFMD revealed some details about a longer term strategy to produce single-chip CMOS transceivers for the advanced cellular market using the Jazz Semiconductor foundry it owns a share of.

Meanwhile, TriQuint saw a 12.5% sequential rise in its fourth fiscal quarter revenue to \$84.7 million (up 26.3% year-on-year), thanks to increased sales of GSM handset products.

However, despite this improvement quarterly gross margin fell by 2.7% sequentially to 28.7%, due to reduced yields associated with new product ramps. Those yield losses have also impacted the company's profit margin, with the \$10 million sequential rise in sales increasing quarterly profit by just \$0.4 million to \$2.9 million.

Commenting on the results for both the recent quarter and for fiscal 2005, Ralph Quinsey, TriQuint's CEO, remarked: "During 2005 we absorbed the negative impact of both reduced handset filter revenue and aggressive pricing pressure while successfully executing our strategy to grow our overall module revenue."

The company expects year-over-year revenue growth of 20% in 2006, and quarterly profit to increase to \$5-10 million by the end of the year. Revenue for the first quarter is expected to be flat, with new product ramps offsetting the normally weaker period.

Seasonality is also expected to affect Skyworks Solutions. The Woburn, MA, head-quartered company posted sales of \$198.3 million for the first fiscal quarter of 2006 and a profit of \$4.3 million, but predicts March quarterly revenue of \$180 million.

RESIGNATION

Filtronic chief ousted despite GaAs ramp

Filtronic's compound semiconductor division has posted sales of £8.5 million (\$14.9 million) for the first fiscal half-year of 2005, an increase of £3.5 million sequentially, and up £4.9 million year-on-year. And sales in the current six-month period could be even higher, now that the company has won a second customer for its GaAs PHEMT switches for cell phones.

However, despite this positive outlook, CEO John Roulston has resigned from the UK-

based company with immediate effect and has been replaced by David Rhodes.

Rhodes, who was previously company chairman, will oversee £4 million of capital expenditure across the compound semiconductor division, which will increase Filtronic's 6 inch wafer foundry capacity from 17,500 to nearly 27,000 per year.

"The foundry ramp up supports compound semiconductors reaching run rate breakeven at the end of this financial year," explained Rhodes. In the most recent half-year this division recorded a loss of £5.1 million.

Overall, the company's loss for the half-year was £7.0 million, against sales of £110.7 million.

CELL PHONES

3GSM World Congress showcases latest multi-band power amplifiers

Several of the world's leading GaAs chip manufacturers unveiled their latest multi-band power amplifiers (PAs) at the 3GSM World Congress, which was held in Barcelona, Spain, last month.

Among other products, TriQuint launched a quad-band PA module (TQM7M5003) that it says is intended for use in GSM/EDGE handsets and has been optimized for Qualcomm's multimode transceiver chipsets.

"We believe that we're offering the customer exactly what the market has been asking for: a smaller module that occupies less board space with superior efficiency for longer talk times, all in a form factor that requires no external bypass components, no collector supply voltage routing and no directional coupler," boasted Paul Cooper, TriQuint's product marketing manager.

The module will be competing for market

share with Skyworks' quad-band front-end module, which is designed for linear modulation and was also launched at 3GSM. The $8 \times 8 \times 1.2$ mm component consists of two separate HBT PA blocks fabricated onto one InGaP die.

RF Micro Devices (RFMD) is also competing in the quad-band market with its latest PA, the RF3159. "[The RF3159] has already seen significant traction, with interest coming from both reference platforms and handset manufacturers," said Konrad Alvarino, general manager of RFMD's components business unit.

Meanwhile, Anadigics claims to be going one better with the launch of the world's first penta-band, multimode power amplifiers. The $6 \times 8 \times 1$ mm AWT6223 and AWT6225 modules feature bipolar and FET structures on the same InGaP die.



From our Web pages...

visit compoundsemiconductor.net for daily news updates

...Anadigics soars

Sales at Anadigics soared 49% year-on-year to reach \$33.3 million for the three months that ended on December 31. But the best is yet to come, reckons CEO Bami Bastani: "I expect our market share expansion in wireless handsets, coupled with the strong position in wireless LAN, tuner IC and CATV infrastructure markets, to enhance our market leadership and results in 2006." The current quarter is looking particularly good, with the company expecting to record an annual sales increase of as much as 60%.

...gross margin improvements

Fabless RFIC designer Hittite Microwave has posted revenue of \$22.7 million for the fourth fiscal quarter of 2005, along with a gross margin and profit of 70% and \$7.1 million. "We introduced 23 new products during the quarter, for a total of 80 in 2005," commented CEO Stephen Daly.

...3G network for China

China is to move ahead with the build-out of a 3G wireless network this year, using its own independent communication standard, TD-SCDMA. The Chinese news agency Xinhua reported that after recent tests on TD-SCDMA, the Ministry of Information Industry had decided

that the protocol could support 3G requirements in both handsets and network equipment.

...production MBE boost

Riber says that it has received an order for two production machines that will be used to make RFICs. The company saw its 2005 sales climb by more than 30% over the previous year, thanks to greater demand for production machines. In 2004 it sold 14 machines and posted total revenue of €17.7 million (\$21 million). Orders for 2006 are strongly up on 2005.

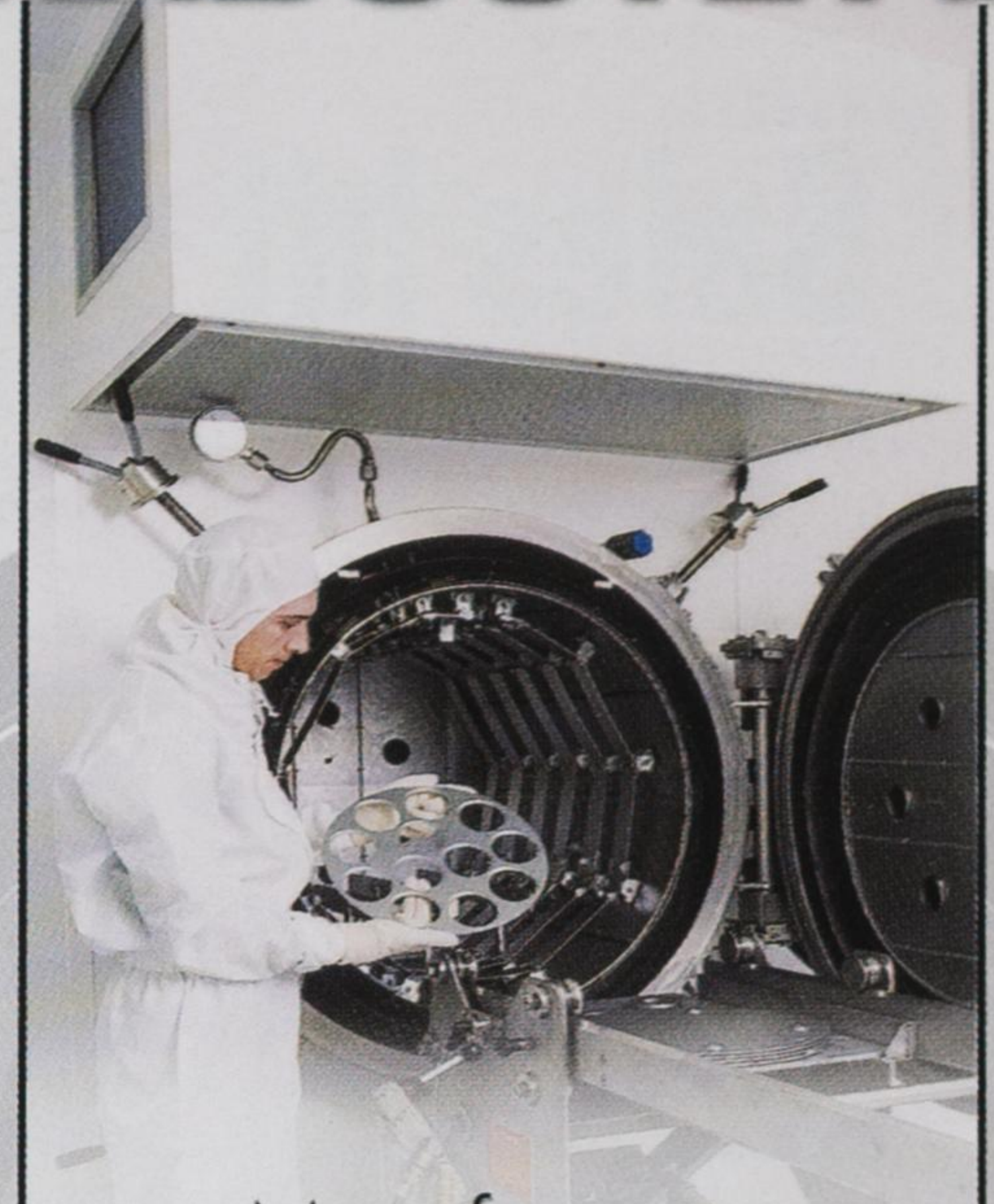
...200 mm GaAs substrates

The Semiconductor Equipment and Materials Institute has published a specification that defines various properties for 200 mm GaAs substrates, including surface orientation, the value and tolerance for wafer diameter and thickness, the position and depth of the notch, and the laser marking location.

...\$1 million plasma etch kit order

Tegal Corporation has received a multiple order from a wireless component supplier for 901ACS diode plasma etch systems featuring the Advanced Control System. Tegal says that the three new systems, valued at more than \$1 million, will expand its customer's existing GaAs production capacity.

RABOUTET S.A.



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>

Representative office in : BOSTON
Component Sources Int'l, Inc.
Steve DOODY - Tel. (508) 485 - 5999
e-mail : steved@compsources.com

MARKETS

Sales hit as commoditization kicks in

By Michael Hatcher in San Francisco

The market for high-brightness LEDs grew just 8% in 2005, as severe pricing pressure hit the mobile appliance sector. Addressing a record 500 attendees at February's Strategies in Light 2006 conference in San Francisco, industry analyst Bob Steele said that the market for packaged HB-LEDs was worth \$4 billion last year.

That represents a massive slowdown in annual growth from the historical average of almost 50% seen over the past few years, and is largely the result of commoditization in the mobile appliance market. "We are now deviating from the historical pattern, and a slower growth period is quite obvious."

Despite sales of cell phones exceeding all expectations in 2005, excess capacity drove down keypad backlight selling prices by half, reported Steele, who added that the market slowdown had been widely foreseen. "The engine of growth stopped," he said. The impact of that has been largely felt in Taiwan, resulting in a series of mergers and acquisitions



Looking forward: with the cell-phone keypad and LCD backlight market now largely commoditized and expected to shrink in value, long-term growth in the white HB-LED sector will likely depend on the commercial success of automotive headlamps in the next couple of years.

among major LED producers.

However, increasing penetration of the LED-based camera flashes used in phones and a 24% ramp in the volume of chips shipped maintained the value of the market for HB-LEDs in mobile applications at just over

\$2 billion, similar to the 2004 figure.

While mobile applications still accounted for over half of total HB-LED sales revenue in 2005, stagnation in that market was balanced out by an average 21% growth in all other areas. Or, as Steele put it: "Mobile is not the only game in town."

As the mobile sector becomes increasingly commoditized, market growth will now rely on other, higher value applications. But that will take some time, and so Steele predicted a similar, relatively modest, growth figure for 2006 of 10%.

LED backlighting of notebook computers and televisions now appears to hold the key to future market growth, and Steele highlighted the early success of US company Luminous Devices, which is already supplying backlights for rear-projection TVs made by Samsung, Akai, HP, Sanyo and JVC.

One of the brighter spots for HB-LED chip makers in 2005 was the automotive market, which strengthened to show growth of 8% thanks largely to the introduction of solid-state tail lights in the Honda Accord and Volkswagen Passat. Steele believes that large-scale LCD backlights and automotive headlamp applications will contribute meaningful revenues in the 2007–2008 timeframe.

Nichia, the world's leading LED manufacturer – conspicuous by its relatively low profile at Strategies in Light – is expanding its development of white LED products for headlamps this year as it bids to free itself from commoditization pressures.

According to the *Nihon Keizai Shimbun* newspaper, the Japanese company was due to report sales of ¥195 billion (\$1.645 billion) for 2005 – down 5.5% on the 2004 figure. Nichia was also expected to report a fall in pre-tax profit of 17.6% to ¥78 billion. That would make 2005 the first year that both annual sales and profit have slipped since 1993, the year that the chip manufacturer launched its industry-changing blue LEDs.

Mirroring the challenge faced by the wider industry, Nichia's chip production ramped up strongly in 2005, but a 30% drop in white LED prices hit both sales and profit margins. Capital spending at the company continues apace, however, with Nichia reportedly allocating ¥35 billion for its new Naruto plant in Tokushima Prefecture, slated to come online in July, and its headquarters facility.

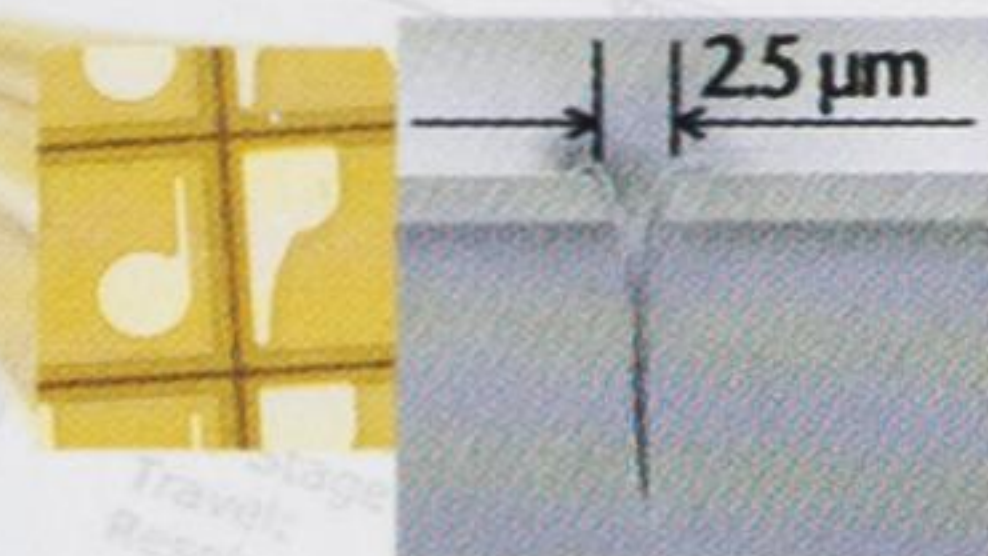
Nichia believes that the introduction of LED-based automotive headlamps could help to boost company sales to ¥300 billion in 2010, concludes the report.

High Precision UV Laser Micromachining

Featuring the JPSA IX-300 System!

Speed, Quality, and Reliability

- Advanced 266 or 355nm DPSS Laser Process
- Narrow Cuts: As Small As 2.5 Microns
- Excellent Die Yield: > 99%
- Low Operating Cost: < \$2 per Wafer
- 24/7 Maintenance-Free Operation
- User-Friendly Windows® 2000™ Software
- Automatic Alignment: < 1 Minute to Load & Align
- Excellent Results on GaAs, Si and Other Materials



Our advanced 266nm ChromaDice™ DPSS laser system produces 10 wafer/hour LED throughput with > 99% die yield at < \$2 US per wafer.

JPSA ADVANCED LASER TECHNOLOGY

Visit www.jpsalaser.com today and find out more!

J P Sercel Associates, Inc.

17D Clinton Drive, Hollis, New Hampshire 03049 USA
Tel. +1 (603) 595-7048 ■ Fax +1 (603) 598-3835

Asia Representatives:

Korea QMC, Ltd., Tel. 82-31-427-0710 ■ Fax 82-31-427-0714
Taiwan LST Technology Co., Ltd., Tel. 886-3-6563716 ■ Fax 886-3-6563717
Japan Hakuto Co., Ltd., Tel. 81-3-3225-8910 ■ Fax 81-3-3225-9001
China BOET, Ltd., Beijing, Tel. 86-10-64371588 ■ Web www.bjoet.com

GENERAL LIGHTING

Cree and Lumileds push lumen claims

HB-LED rivals Cree and Lumileds are both claiming to have pushed white LED technology to new levels.

Cree says that its latest, commercially available, white XLamp package delivers 47 lm/W at a drive current of 350 mA, while Lumileds' Luxeon K2 chips are said to output 140 lm in white.

As ever, the two claims are not directly comparable, but Lumileds does say that the K2 can be driven at currents as high as 1500 mA, thanks to its 185 °C maximum junction temperature.

Increasing the lm/W rating of LED chips is seen as a critical step before solid-state approaches can take a serious chunk out of the general lighting market. But driving down the cost of the chips to a level that is acceptable to the lighting community is becoming increasingly important.

At the recent Strategies in Light conference in San Francisco (see report, opposite page), there was evidence to suggest that the chip companies and the lighting industry had made some progress towards a better understanding of each other's needs, with less of a focus on technological innovation and more emphasis on the development of standards, binning and color calibration than in previous years.

CROSS-LICENSE

Avago patent deal includes backlights

Osram Opto Semiconductors and Avago Technologies have signed a limited patent cross-license agreement, with each side gaining the rights to use the other's LED technology.

Osram has granted Avago a license for several patents to manufacture and sell white LEDs with a specific conversion technology, as well as surface-mount LEDs. Avago has granted Osram a patent license covering LED systems, including those for projection and flat-panel LCDs.

Conversion technology for LEDs enables the production of white LEDs using blue-emitting InGaN-based chips and a suitable fluorescent converter.

Osram has previously signed patent licensing agreements with Nichia, Rohm, Everlight, Lite On, Stanley, Harvatek, Ya Shin, Vishay, Samsung Electro Mechanics and Lednium.

DISPUTES

Dominant and Osram share spoils

German LED manufacturer Osram Opto Semiconductors and its Malaysian rival Dominant Semiconductors have both claimed victory after a ruling in the US.

In Osram's view, the US International Trade Commission (ITC) decided that Dominant had violated US competition law by infringing Osram's patents. As a result, Dominant is banned from selling certain LED products into the US, while Osram has now filed an action for patent infringement against Dominant in its native Germany.

Dominant's interpretation of the decision was completely different, claiming that of the eight patents Osram claimed to be violated, only three complaints were upheld by the ITC.

"The court clearly established that Dominant used our technology illegally and has taken the necessary action in imposing an import ban," said Rüdiger Müller, Osram Opto's CEO. "The decision also highlights Osram's strength in patents. We are a highly innovative company."

The five patents where Dominant says that no infringement was found describe technologies relating to white-light emission. The other three, where infringement was identi-

fied, concern LED packaging technology, particularly for high-power LEDs in automotive lighting applications.

The ITC initially ruled that Dominant's products infringed the five patents relating to white LEDs, before Dominant pointed out that its white LEDs had been modified since Osram's action was filed.

"This determination supports our stand that Dominant respects intellectual property rights," said a Dominant spokesperson. "We possess our own unique know-how and will continue to develop new technologies."

● In what could become another damaging dispute, Nichia has sent a warning letter to rival Taiwanese LED manufacturer Harvatek over a design patent, which is mainly used for backlighting LCDs in cell phones. Nichia owns patents for this SMD-type design in several countries, including Taiwan. Meanwhile, Nichia is thought to be abandoning its claim to the notorious "404" patent, which was at the heart of its legal battle with Shuji Nakamura. Nichia claims to no longer use the technology in its production system.



We are now
ONE Company!



Contact us at: info@eaglabs.com
www.eaglabs.com

SEMICON Korea Booth 813
SEMICON China Booth 3750

Evans Analytical Group
810 Kifer Road
Sunnyvale, CA 94086
+1 408 530 3500

SIMS Technology Advances at EAG

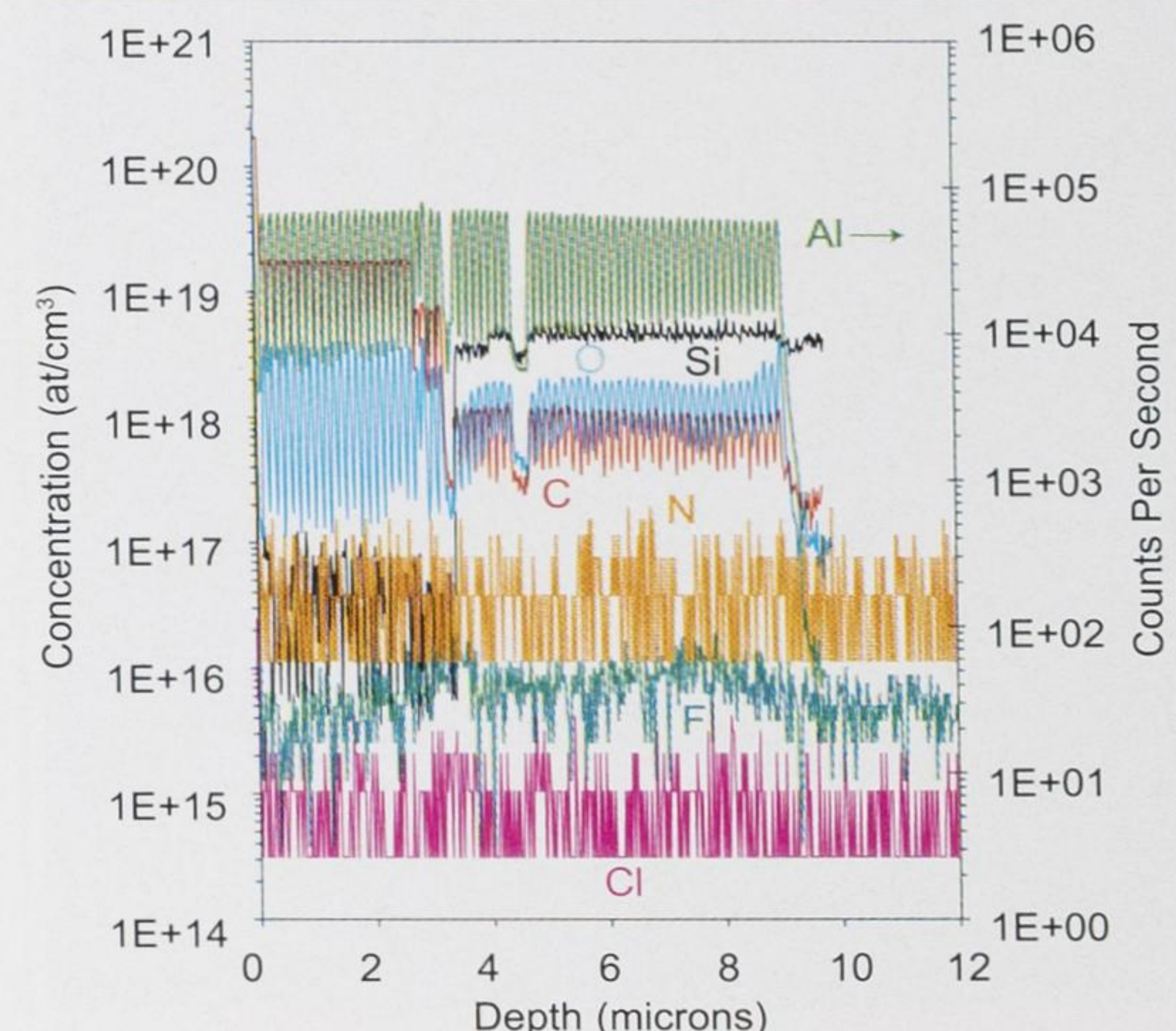
Most Accurate SIMS Characterization of

- Shallow Boron, Arsenic, Phosphorus Implants
- SiGe and devices
- Ultra thin (1nm) SiON
- Very small area (10 x 10µm) devices
- Dopants and Impurities of SOI films
- SiC and GaN

Characterization of Multi-Compositional III-V epitaxial Films

- AlGaAs, InGaP, GaInAsN, InGaAsSb, InP: HBT, FET
- AlGaAs/InGaAs, AlGaAs/InGaP: HEMT
- AlGaAs/InGaAlP/InGaP: VCSEL
- AlGaAs/InGaAs: Laser
- InGaAlP, GaN/InGaN: LED, HEMT

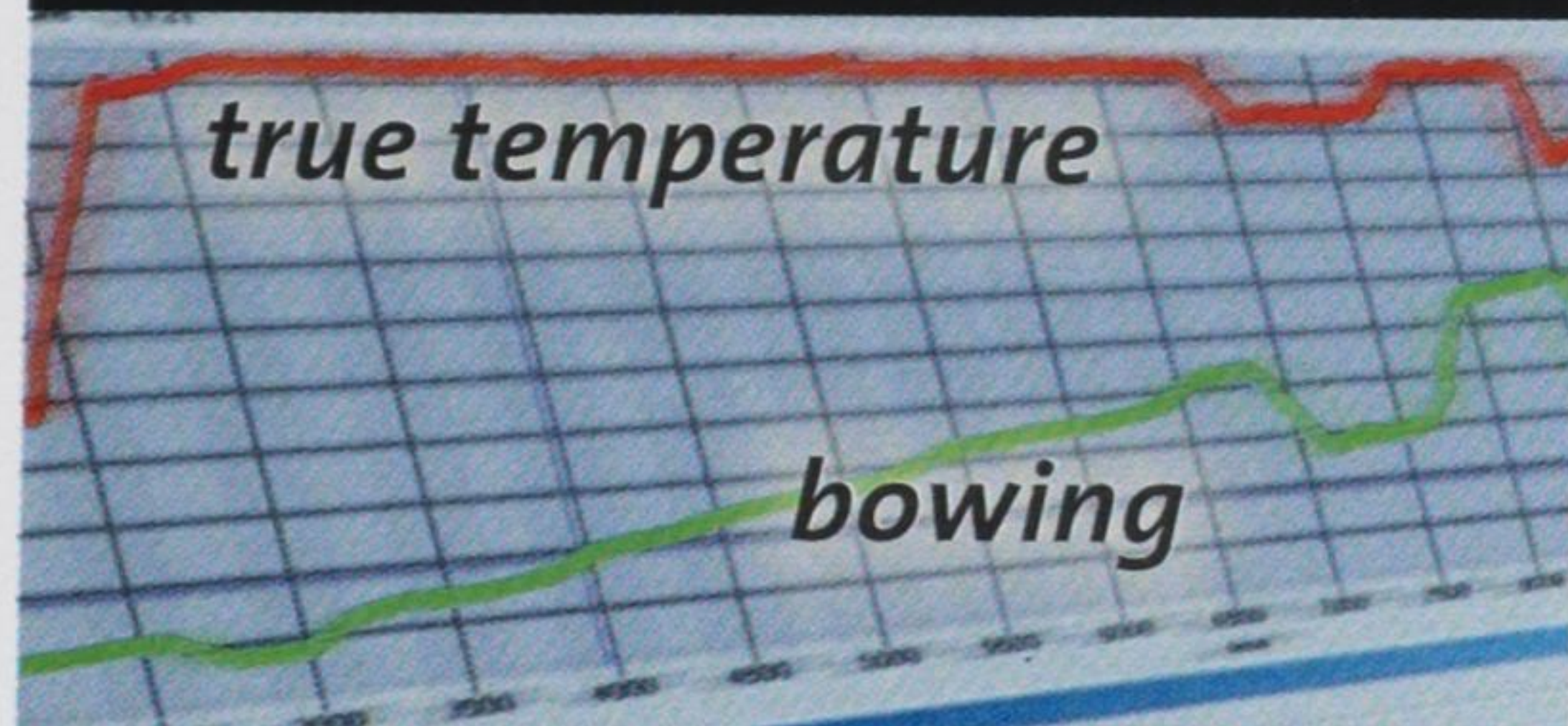
Small (50µm dia.) Area Analysis on a VCSEL Device



Get the bows out

The new EpiCurve TT measures real-time wafer curvature.

As the demand for larger compound wafers rises, bowing measurements become indispensable. LayTec's new in situ monitor EpiCurve TT measures wafer curvature online during growth. Optimize your growth and maximise your yield with EpiCurve TT's unique combination of bowing, true temperature and growth rate measurement!



LayTec GmbH
Helmholtzstr. 13-14
D-10587 Berlin · Germany
Tel.: +49 (30) 39 800 80-0
Fax: +49 (30) 31 80 82 37
Email: info@laytec.de
www.laytec.de

LayTec
optical sensors for epitaxy

No Surprises!

SOLAR CELLS

Bush administration backs solar as Emcore joins in DARPA effort

Emcore has joined the Defense Advanced Research Projects Agency (DARPA) effort to develop solar cells with at least 50% photoelectric efficiency. The very high-efficiency solar cell (VHSEC) project, which is being run by the agency's Advanced Technology Office, has potential total funding of \$53 million over the next few years.

The Somerset, NJ, chip manufacturer has also joined a consortium formed by VHSEC's prime contractor – the University of Delaware.

Emcore's top-rated triple-junction solar cells operate at around 36% efficiency in terrestrial applications currently, and one way to boost this would be to add more junctions based on III-V heterostructures.

Reducing the cost of the cells is critical if the GaAs-based devices, which are fabricated on germanium substrates, are to cross over from high-value satellite applications to terrestrial deployment. However, Emcore is enjoying some early success in the terrestrial market and already has three customers lined up – one in Spain and two in Asia. The com-

pany has started manufacturing solar cells for the first of those customers one quarter earlier than expected.

In a further boost, the political mood in the US now appears to be strongly in favor of solar energy. In contrast to previous measures that have resulted in cuts at the National Renewable Energy Laboratory (NREL), the Bush administration has proposed a \$148 million fund for the Solar America Initiative in 2007, up \$65 million on the 2006 figure.

The US president, much maligned in some quarters for his support of traditional oil-based energy production and apparent disregard for the environment, used his State of the Union address to espouse the virtues of solar energy as part of an initiative to replace over 75% of US oil imports from the Middle East by 2025. "The best way to break the addiction to oil is through new technology," said Bush.

Emcore now expects to witness a total addressable market of over \$1 billion by 2010 for its solar energy products, mostly in utility-scale solar energy farms connected to the grid.

LASER DEVELOPMENT

UK team wins a cool \$3 million

A UK collaboration has netted £1.7 million (\$3 million) to develop high-speed, uncooled photonic components. The project involves the Centre for Integrated Photonics (CIP), Bookham, Epichem, Loughborough Surface Analysis (LSA) and two universities.

The UK's Department of Trade and Industry will fund the two-and-a-half-year project entitled "Extended Temperature Electronics".

The key aim is to fabricate a range of AlInGaAs active devices that can operate uncooled at higher temperatures than current commercial offerings. Fixed-wavelength and tunable lasers, semiconductor optical ampli-

fiers (SOAs), superluminescent diodes and avalanche photodiodes will all be investigated.

The project's other goal is to grow ruthenium-doped semi-insulating current-blocking layers, which should ultimately reduce power consumption and allow closer stacking of optical interfaces.

CIP and Bookham will carry out growth and device testing, and contribute to structural design and modeling with Sheffield and Surrey universities. Materials specialist Epichem will develop stable ruthenium precursor technology, while LSA will carry out material and device characterization.

POWER DIODES

\$1.8 million laser diode contract for Modulight

Modulight, the laser specialist with a semiconductor fab in Finland, is to develop high-power laser diode bars under a new \$1.8 million contract. Due for delivery this year, the bars will pump high-power solid-state lasers.

Meanwhile, rival makers of high-power diodes touting their latest laboratory achievements at the recent Photonics West conference held in San Jose, US, included JDSU, Bookham, Alfalight, Jenoptik Laserdiode and Coherent.

German firm Jenoptik, which recently built a new 3-inch GaAs fab in Berlin to make high-power devices, claimed to have broken the 500 W barrier with its 1 cm diode bar, thanks to improved mounting techniques.

OPTICAL COMPONENTS

'Serious concerns' for Avanex liquidity

US-based photonic chipmaker Avanex had to restate its latest financial results after incorrectly recording a single \$4.5 million non-cash gain.

That figure, which relates to leases at the US company's French operation that also houses its chip-fabrication facility, will now be spread over a 12-year term.

Revised loss for the quarter ended December 31 was \$18.5 million, on revenue of just \$36.1 million. Avanex had already warned that operational problems would impact on sales, which were down \$5.7 million on the same period in the previous year. "These included capacity constraints at our contract manufacturers, raw materials shortages, logistics issues and manufacturing yield issues for some of our new products," reported the company.

Although it is expecting sales of \$36–40 million for the current quarter, Avanex's immediate future looks increasingly perilous. "We have serious concerns that...our existing cash balances [may] not be sufficient to fund operations for the next 12 months," admitted the company in its quarterly filing to the Securities and Exchange Commission (SEC).

Avanex had only \$13.8 million in cash and

cash equivalents on its books as of December 31, with a further \$27.4 million in short-term investments. "These factors cast substantial uncertainty on our ability to continue as an ongoing enterprise for a reasonable period of time."

With a desperate need for cash, Avanex and its prime customer and shareholder Alcatel have also changed the terms of their long-term supply agreement. Alcatel agreed to advance Avanex's French subsidiary around \$6 million that will be offset against future orders.

Alcatel has also agreed to restrictions on how much Avanex stock it can sell over the course of 2006. The network system supplier owns 28.3 million shares – approximately 20% of the company – but has agreed to sell up to a maximum of one-third of its holding in the first half of the year. A similar restriction will apply in the second half of 2006, unless the Avanex stock price near-doubles to more than \$2.

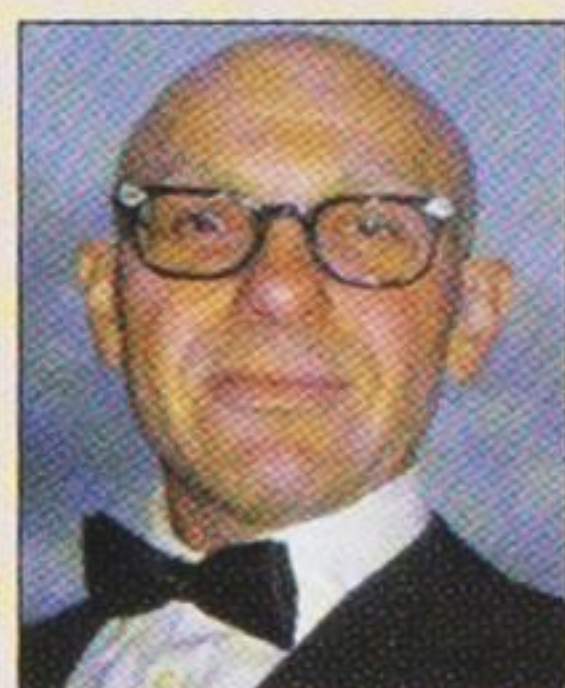
Alcatel's supply agreement still has a way to run before it expires in October 2007, but Avanex's cash position will be under more pressure during that time as it continues to pay off its former workforce and facility lease termination charges following major restructuring.

**From our Web pages...**

visit compoundsemiconductor.net for daily news updates

...President Lebby

Arpad Bergh has retired as president of the Optoelectronics Industry Development Association (OIDA). Michael Lebby (pictured), a proponent of the InP optoelectronics foundry model steps in.

**...JDSU sells Ottawa site**

JDSU will sell its site in Ottawa, Canada, to partner Fabrinet for an undisclosed sum. Some 300 JDSU staff produce optical subsystems and certain test and measurement products at the site. The transaction, expected to close in the third fiscal quarter of 2006, will not affect JDSU's chip manufacturing operation in San Jose, CA.

...Firecomms certified

The media oriented systems transport (MOST) fiber optic transceiver (FOT) made by Irish company Firecomms, which uses a resonant cavity LED, has been certified by RMCtech for compliance with the MOST standard. "Not only did the FOT easily pass the rigorous certification tests, [it] delivered an additional 8 dB of optical power over the specification," said Firecomms project manager Brian McGarvey.

...AOI targets CATV

Applied Optoelectronics, Inc., a manufacturer of laser diodes, photodetectors, and optical modules for fiber optics, has released a module for low-power forward-path CATV transmitters. Key features of the new module include a patent-pending modular design, a hermetically-sealed laser and photodiode, a field-replaceable thermoelectric cooler, and an output power up to 8 mW. Volume shipments begin at 300 modules per month in the second quarter of 2006.

...Opnext goes medical

Hitachi-backed chip manufacturer Opnext has made its low-operating-current red laser diodes available for use in a variety of new applications. The New Jersey company's diodes are said to be suitable for laser levelers and measurement equipment, as well as medical and display applications.

...Dage raises profile

Characterization equipment and materials supplier Dage has shipped an electrochemical CV wafer profiler to the Instituto de Energia Solar in Madrid. The CVP21 will analyze carrier concentration profiles in both III-V and silicon solar cells.

AIR PRODUCTS

Ask the Expert

Rajiv K. Agarwal, Ph.D.

Lead Research Engineer

Q

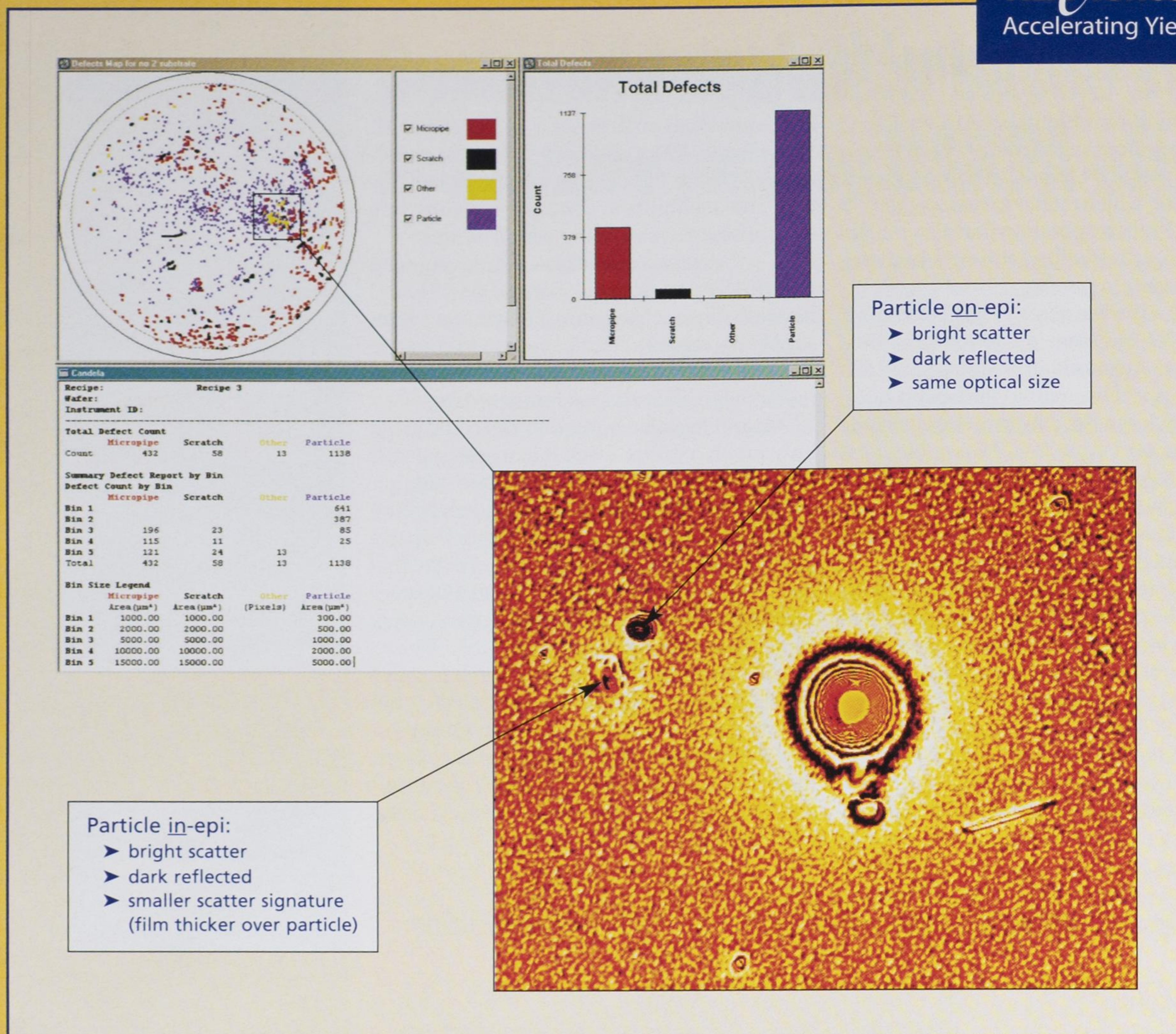
I am experiencing high n type background doping levels in my MOCVD process when I grow GaAs and AlGaAs devices. I think the problem is in the arsine I use. I'm buying the best grade available. What can I do?

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



©2005 KLA-Tencor Corporation

Do you know the three W's of epi-layer inspection? Only Candela™ finds where it is, what it is, and when it occurred.

Differentiating between subtle optical characteristics can provide critical information on defects. A particle under the epi layer is a very different problem than a particle on the surface. Our Optical Surface Analyzers (OSA) are unique surface inspection systems that employ a combination of measurement technologies to automatically detect and classify a variety of defects. Defects are binned by size into user-defined categories, and displayed on a defect map. The OSA images remain linked to the report, for quick and effective review.

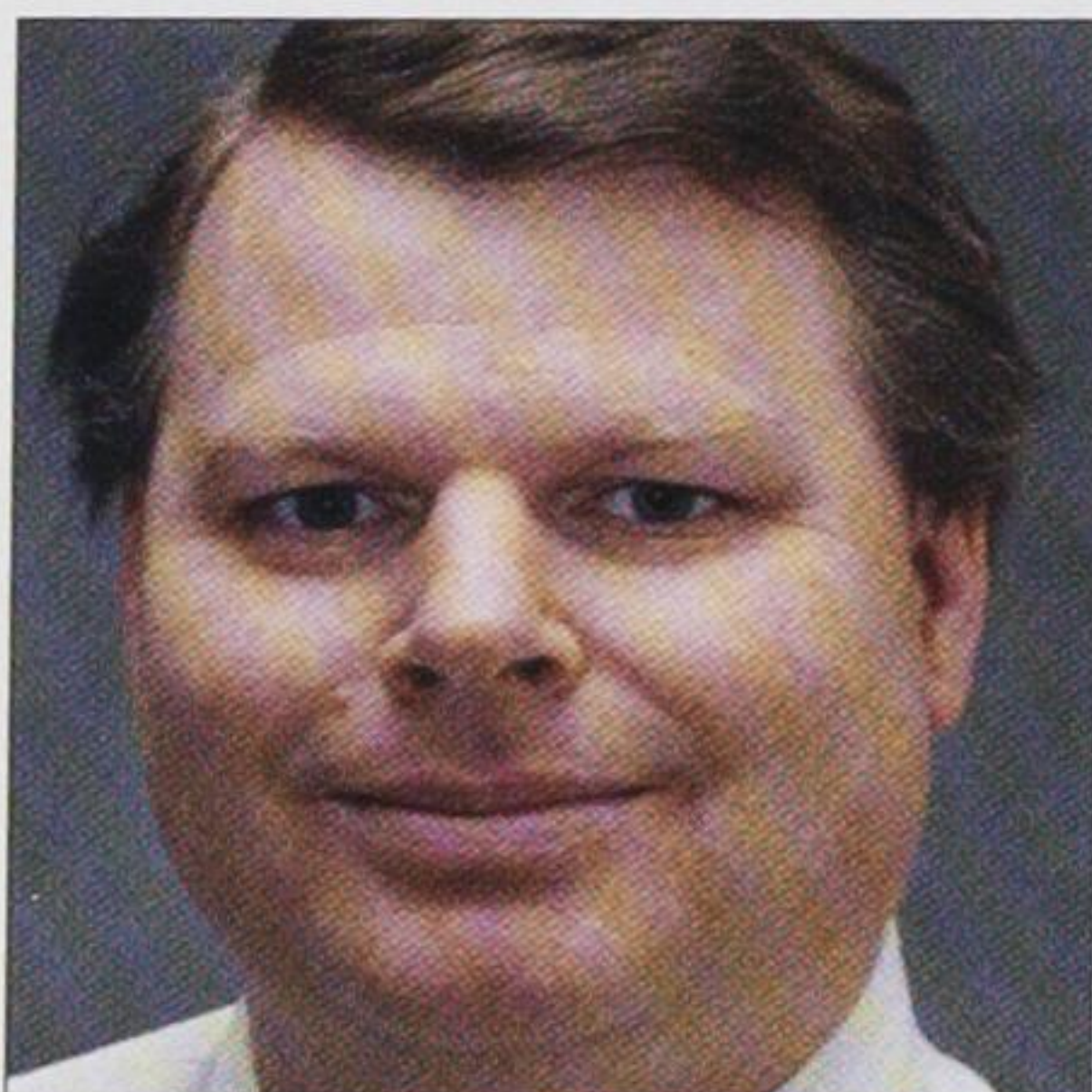
- Automatically classifies particles and scratches as "on" versus "in or under" the epi layer
- User-defined defect classifications allow automated detection and reporting of unusual defect types
- Crystal defects such as dislocations and polytype changes are automatically detected and counted
- Manual or automated cassette-to-cassette operation
- Accommodates wafer sizes from 50 to 300 mm
- For more product information, go to:



OPTOELECTRONICS

Quality to drive industrial revolution

Get ready for a wave of innovation to impact on the industrial sector, says JDSU's **Toby Strite**.



Toby Strite (toby.strite@jdsu.com) manages marketing for the High Power Lasers group within JDSU's Components and Modules Business Unit based in San Jose, California.

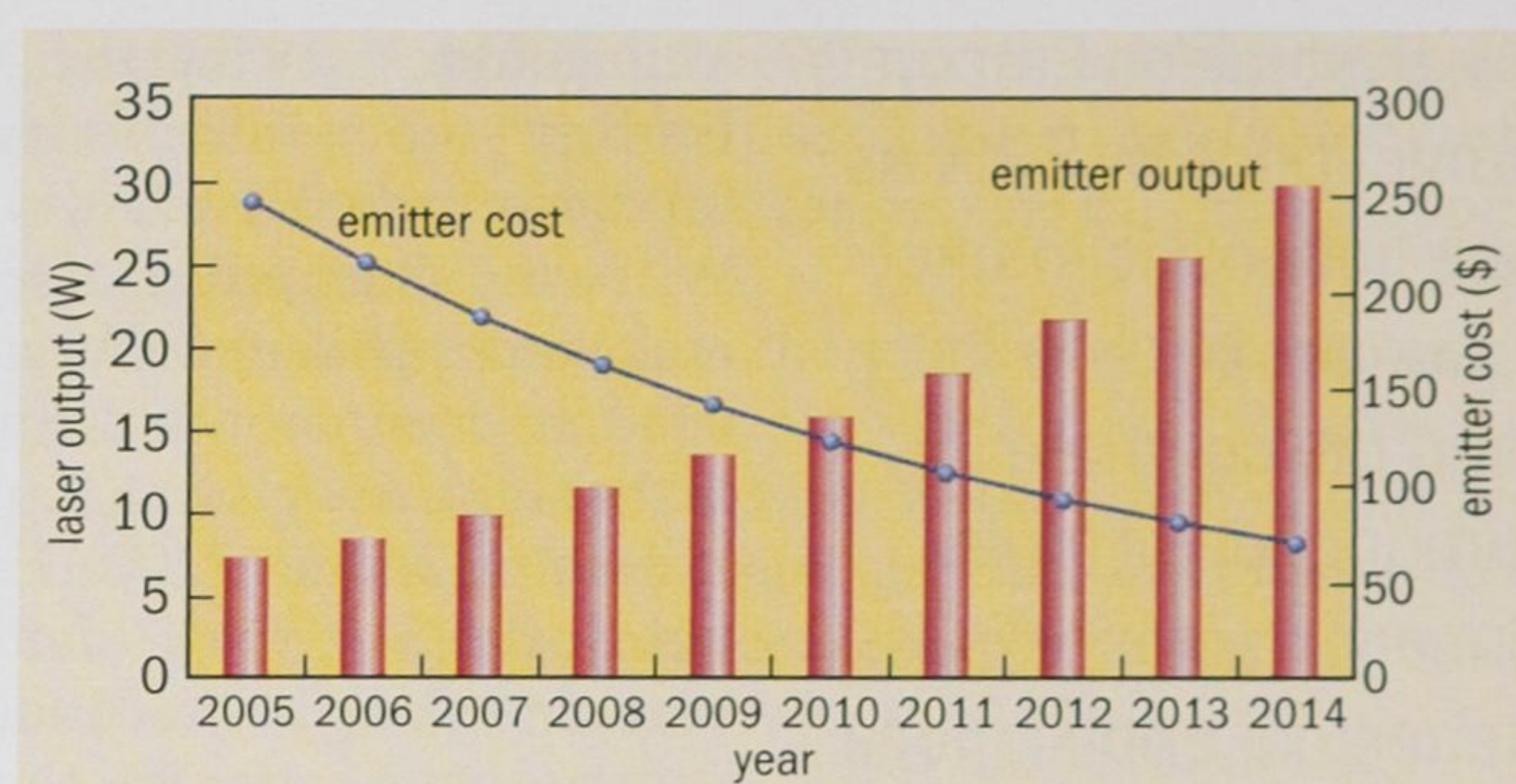
While the telecom boom was driving 980 nm pump laser innovation at an astonishing rate, a largely distinct set of companies was servicing industrial customers with lower-brightness diode lasers. Telecom pumps enabled fiber-optic system bandwidth to progress rapidly, while their industrial diode cousins' reliability and cost often disappointed, ultimately slowing the transition from lamp-pumped to diode-pumped solid-state lasers (SSLs). The telecom bust left a handful of high-performance suppliers eager to diversify their sizeable wafer fabs and offshore diode laser assembly and packaging facilities. The resulting influx of quality and manufacturing excellence into the industrial diode marketplace has begun to spark an industrial laser revolution.

Diodes are the single most efficient method of converting electricity into useful optical power. The most mature semiconductor diode laser material is AlGaInAs, which offers the highest demonstrated optical power density and electrical-to-optical power conversion efficiency, while covering the 800–1000 nm band that is critical for neodymium- and ytterbium-based SSL pumping. If reliable AlGaInAs diode lasers are finally brought to market at industrial laser price points, the effect will be dramatic.

Industrial diode laser reliability is bounded by problems of heat removal and power-cycled operation. To remove heat from multi-emitter diode arrays (bars), purified water is pumped through copper-microchannel coolers, which erode and oxidize to the extent that plumbing and water purity are as much of a talking point in the industrial laser community as semiconductor physics. Bars are commonly bonded to heatsinks with soft, indium-based solder, which has proven unreliable for industrial on-off cycles. In contrast, AuSn-soldered single-emitter and arrayed diode lasers introduced by telecom houses have set new benchmarks in sustainable power and mean time before failure (MTBF). Telecom-grade hard AuSn-soldered laser diodes show few to no ill-effects under power-cycling. Single-emitter versions save by using simpler, more reliable cooling systems.

If thermal limitations are sidelined, sustainable AlGaInAs laser power is limited by facet oxidation which liberates metallic arsenic. Eventually the facet is so absorptive that runaway heating drives failure via catastrophic optical mirror damage (COMD). Telecom suppliers developed various facet passivations to eliminate COMD more than a decade ago, but were unmotivated during the go-go 1990s to offer their technology to industrial customers. Filling the void were cheaper, unpassivated AlGaInAs devices, which delay COMD onset by de-rating optical power density, and "aluminum-free" InGaAsP diode lasers aiming to circumvent the facet corrosion mechanism altogether.

Aluminum-free devices generated considerable excitement and telecom-driven venture capital investment, but are still virtual no-shows in the telecom pump marketplace. InGaAsP enjoys more success in low-brightness industrial applications, at least matching the



Future trends: if historical price cuts and technological innovation continues, the \$2/W level will be breached in 2016.

benchmark 1 W, 100 μ m emitter for around 20 kh performance of AlGaInAs 1 cm $\times$ 1 mm 50-emitter bars. Bookham has shaken up the industrial bar market of late, introducing hard-soldered AlGaInAs bars based on its telecom diode technology with life-test data suggesting that reliable 100 W operation is possible. Much higher-brightness AlGaInAs single-emitter diodes that are available from both Bookham and JDSU sustain 8 W, 100 μ m power at 940 nm with an MTBF of at least 300 kh.

While telecom migrants have greatly raised the bar for reliable power, they remain challenged to deliver their product at prices attractive to industrial users. But cost reduction track records suggest that the dollar/watt metric will soon be disrupted. Telecom revenue bases bolster companies like JDSU and Bookham, providing wafer fab economy of scale and access to offshore assembly unavailable to the smaller industrial diode shops. As impressive as the latter's early offerings are, they perform well below commercialized telecom pump facet power densities, leaving room to improve performance while reducing cost. If the industrial marketplace's unquenchable appetite for lower dollar/watt snowballs into rapid-fire diode laser innovation alongside volume-driven cost reduction, the solid-state industrial laser market could see fireworks.

To see where a second wave of innovation might lead, let's extrapolate commercially available fiber-coupled 100 μ m aperture single-emitter diodes, now available at \$35/W in volume, at the rate of progress sustained by telecom 980 nm pumps over the last decade (see figure). Assuming operating power increases at 17.5% annually, with manufacturing efficiencies enabling dollar/watt prices to fall by 26%, the year 2016 may see a reliable 35 W fiber-coupled 100 μ m aperture single-emitter diode laser source selling for \$60, or <\$2/W. The curmudgeon in the thirteenth row will say that this falls short of the \$1/W Holy Grail, but I for one am betting on an increasingly bright future for solid-state lasers, and the pumps which enable them.

"The solid-state industrial laser market could see fireworks."



STOCKS AND SHARES

Emcore stock hits four-year high

Analyst raises Emcore's target price by 33% as the fiber-optic market bounces back to form and the commercial production of triple-junction solar cells for terrestrial applications begins in earnest.

You wouldn't say that the good times are rolling again at Emcore – not while it is still making a net loss – but for investors in the New Jersey company the signs are good. While the share prices of technology companies in general, and chip manufacturers in particular, have strengthened in recent months, Emcore has outperformed most in the field to register a four-year high.

Back in January 2002 Emcore's stock value plunged below the \$10 mark, and in October 2004 it was still bumping along at well under \$2. But since then, the only way has been up for the chip, module and materials supplier. As *Compound Semiconductor* went to press it was close to pushing back above \$10 in what could be seen as evidence of an impending boom across all sectors of the compound semiconductor business.

That's because Emcore is one of the few companies that straddles all the major III-V areas, and is something of a barometer for the industry. It sells wafers for RF applications, makes laser chips and modules for fiber-optic communications, triple-junction solar cells, and LEDs through Gelcore.

In the four years since the \$10 mark was last breached, Emcore has of course undergone some major reconstructive surgery. Most notable, from a compound semiconductor point of view, was the sale of its Turbodisc MOCVD equipment division – the very heart of the company – to Veeco Instruments back in late 2003.

John Lau, an analyst from investment house Jefferies and Company who covers Emcore's stock, now sees a big upside opportunity for investors. After the firm's positive results for the December quarter, where it beat revenue guidance estimates by nearly \$1 million, and an upbeat outlook, Lau revised his target price for the stock from \$9 to \$12. And it wasn't just Emcore's strong guidance for the current quarter that prompted this. For the first time it now appears that triple-junction solar cells based on III-V materials are set for serious commercial application on Earth. Until now, the application of those 36% efficiency cells has been stuck firmly in space, considered way too expensive for terrestrial consumption.

However, that all looks set to change: "Emcore announced that they have received their first order [for terrestrial solar-cell products] and have transferred it into production for initial revenue this quarter," said Lau. Not only is this one-quarter ahead of schedule, Emcore's CEO Reuben Richards says that three different customers are already lined up to make solar panels featuring Emcore's multi-junction cells. One is in Spain and two are in Asia, including one in Japan. Already with a \$44 million order backlog for its overall solar business, Emcore is expected to reveal more details of these terrestrial developments in its next quarterly update.

Mark O'Neill, president of the Texan solar-system specialist Entech Solar, says that engineers have made great strides in recent years to solve the optical and thermal problems associated with concentrator systems, so a multi-junction III-V system is now much more cost-



On the up: since bottoming out in late 2004, Emcore's share price rose three-fold to hit \$9 in February.

Emcore's growth by segment (source: Emcore/Jefferies & Co)

Business division	\$ million revenue (Dec 05 qtr)	% of total	% annual growth
Fiber-optics	25	62.7	42
Photovoltaics	10.7	26.8	44
Electronic materials and devices	4.2	10.5	128
Total	39.9	—	48

effective than one based on polycrystalline silicon – provided that it can be made in volume.

O'Neill estimates that systems featuring multi-junction concentrator cells could operate at an output of \$3/W – a figure Lau concurs with – compared with around \$6–7/W for polysilicon cells. With engineering issues now solved, Entech says that the only thing holding up wider deployment of the technology is to bring in some financing to support volume production of multi-junction solar systems. That may well be a problem restricted to the US, which has lagged behind the rest of the world in photovoltaics. But with positive noises emanating from the Bush administration on the solar energy front, even the US's political and economic pendulum could be set to swing in Emcore's favor.

Richards says that Emcore is ready to meet photovoltaic demand by adding manufacturing capacity for both front- and back-end processes. Capacity is for now limited mainly by a relative lack of back-end equipment, while additional epitaxy machines are expected to be installed as production begins to ramp up "in earnest". Within two years Richards expects to have 40% efficient solar cells available that could push the conversion cost as low as \$1.50/W. At that price the potential for terrestrial applications would be enormous – although don't expect to see GaAs-based systems on domestic rooftops just yet, as the bulky concentrators are suitable only for supplying the electrical grid, or at a push helping to top up the power requirements of a Wal-Mart store, perhaps.

Richards is in buoyant mood: "At the moment the company is hitting on all cylinders." Lau expects the strong growth to continue, reaching around \$225 million by 2007. Unsurprisingly, he's rating the company as a "buy".

"The company is hitting on all cylinders."

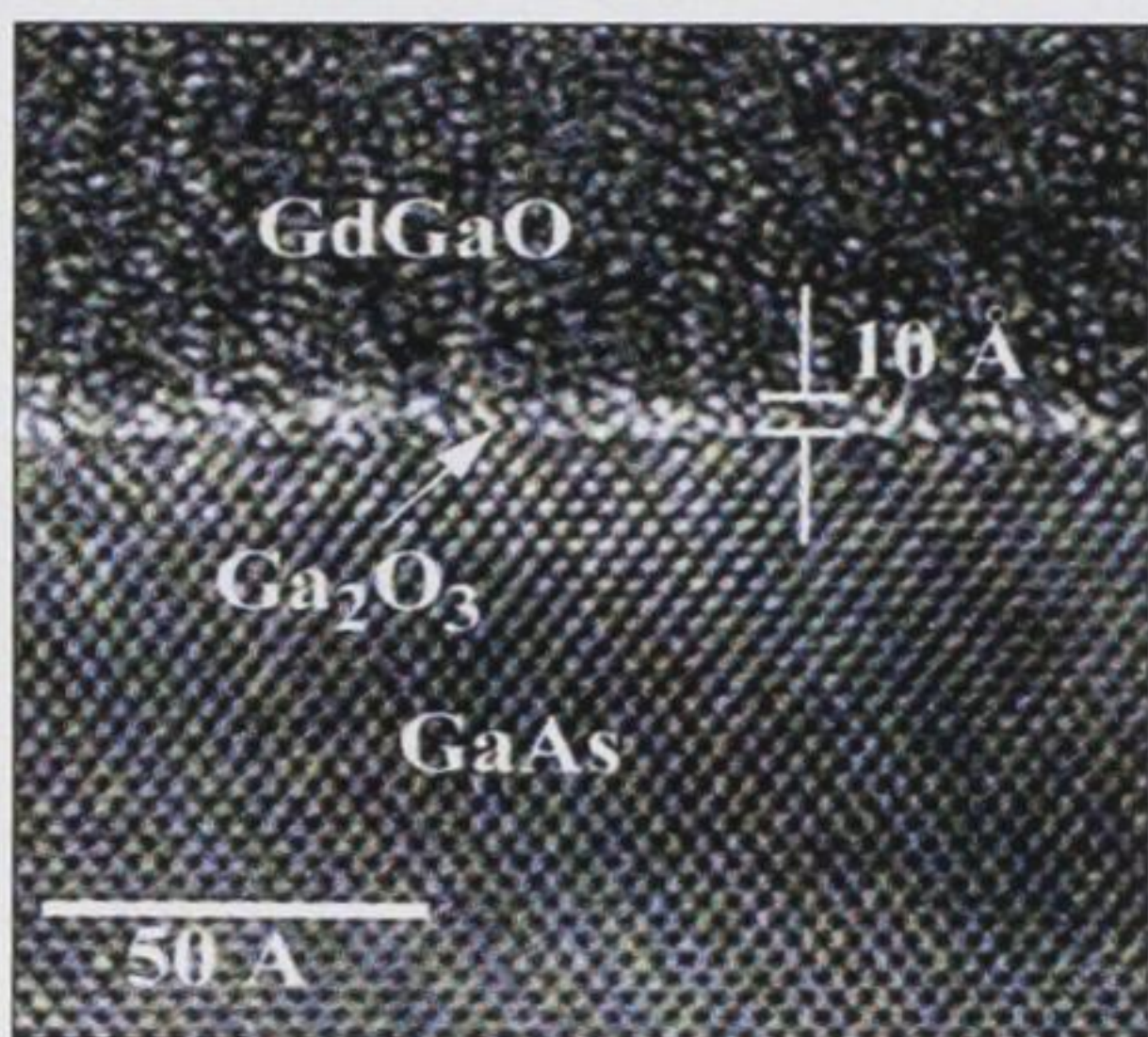
Reuben Richards
Emcore CEO



CONVERGENCE

Freescall puts MOSFETs on the map

Michael Hatcher hopes that Freescale's GaAs MOSFET development proves more fruitful than the Motorola spin-off's previous attempt to bring together silicon and III-V technology.



With a gate length of 1 μm and a 13 nm oxide layer, the Freescale MOSFET showed a transconductance of 80 mS/mm – far greater than that seen in previous GaAs MOSFET architectures.

Freescale Semiconductor's MOSFET development team appears to have made a genuine breakthrough in developing a device that could one day be scaled in much the same way as silicon CMOS technology.

If it does prove viable, the development could pave the way for a GaAs equivalent of Moore's law, by which the speed and size of transistors can be advanced rapidly through lithography and other standard processes.

Finding a compatible gate oxide material has turned out to be the key stumbling block in the past. And while Freescale's is not the first GaAs MOSFET to be developed (examples of such devices go as far back as 1965), the company does see it as the first such design to be commercially viable.

Matthias Passlack is a key member of Freescale's MOSFET project group based in Tempe, AZ. "All previously published enhancement-mode GaAs MOSFET data showed performance of less than 1%, with transconductance typically in the microSiemens per millimeter range," he explained. "There has been no progress over the last 30 years, and 1% devices are of no interest for commercial application. Our [80 mS/mm] technology provides a performance that shows promise for applications for the first time."

Passlack highlighted the high defectivity seen at the oxide/GaAs interface – something that causes Fermi-level pinning – as being the main problem with previous MOSFETs. Solving this difficulty was the first of two key breakthroughs that Passlack says were crucial to the development.

To unpin the Fermi level, the Freescale team deposited an amorphous Ga_2O_3 template by MBE. They then used an amorphous dielectric layer of GdGaO, which provides the required band offsets while neither disrupting the template nor creating a secondary interface. The second crucial part was a new enhancement-mode device concept, which provides the typical terminal behavior of inversion mode devices, but does not use surface inversion. "This allows one to take advantage of the intrinsically high mobility of III-V semiconductors in MOSFET channel layers," explained Passlack.

Freescale's senior executives are also raving over the development. "This remarkable achievement overturns industry assumptions," added Freescale's acting CTO Sumit Sadana. "[It] has the potential to fundamentally change the way high-performance semiconductors are designed, manufactured and deployed."

The biggest silicon house of them all – Intel – has already acknowledged the potential of III-Vs in its own technology roadmap, seeing GaAs as an option beyond the 22 nm node required around 2012. If III-V materials are ever going to cross over into the digital mainstream, then a high-k dielectric MOSFET is essential, as these are the only devices that are scalable to such small dimensions. "As far as I can tell," Passlack told *Compound Semiconductor*, "there is a consensus in the industry that III-V MOSFETs must be investigated for

future digital applications. Which channel material and device concept [will be used] is still hotly debated, although there is also a consensus that this must happen on a silicon platform."

That would present another difficulty – how to grow lattice-mismatched materials with low defectivity.

Another company that has experience in making GaAs MOSFET material and devices, and that worked with Freescale in the early stages of device development, is the Rochester-based MBE specialist Osemi.

Recognizing the importance of Freescale's breakthrough, Dave Braddock from Osemi says that the convergence of compounds and silicon as outlined in Intel's roadmap will fundamentally change the overall semiconductor industry, and that III-V MOSFETs in both GaAs and GaN flavors will open new doors in digital and mixed-circuit electronics.

Freescale says it now has plans to work in collaboration with other companies to develop products that make use of the high-speed computing performance enabled by GaAs MOSFETs. Karl Johnson from the company believes that digital conversion of analog or radio frequency signals would be almost instantaneous with a fully-functional GaAs MOSFET, offering to greatly simplify wireless architectures and improve talk and standby times in handsets.

While wireless power amplifiers are dominated by the GaAs HBT currently, these devices are not suited to front-end switching and power control. A GaAs MOSFET could combine the small-die advantages of the HBT and the efficiency of a PHEMT structure with its own intrinsic integration capability.

Back in 2001, Freescale (which was then simply known as Motorola's semiconductor products group) courted similar fanfare after announcing that it had developed GaAs-on-silicon wafers, which also promised to revolutionize microelectronics. Motorola even formed a separate spin-off company to exploit that technology, but the initial optimism proved groundless as problems with defects saw the hybrid approach shelved.

But the convergence of what have traditionally been seen as the very separate worlds of silicon and III-V semiconductors has remained a compelling topic, and Freescale's latest work will be widely applauded. As always, however, the proof of the pudding will be in the eating. Let's hope that the GaAs MOSFET proves to be a more satisfying meal than the previous attempt at 12 inch GaAs-on-silicon wafers, which left a rather disappointing taste in the mouth.

"Our technology provides a performance [that] shows promise for applications for the first time."

Matthias Passlack
Freescale

EPITAXIAL GROWTH

Motorola and IQE grow GaAs on large-area Si substrates

Researchers from Motorola and IQE have demonstrated the growth of gallium arsenide on large-area silicon substrates. This could open the way to low-cost GaAs device manufacturing and a multitude of integration possibilities. *By Marie Meyer*



Motorola has fabricated power amplifiers from the GaAs-on-Si wafers and incorporated them into mobile phones that have been used in live trials.

Motorola has fabricated power amplifiers from the GaAs-on-Si wafers and incorporated them into mobile phones that have been used in live trials.

The Motorola spin-off made similar headlines in late 2001 with GaAs-on-silicon technology.

Resonant-cavity LEDs fire

The plastic optical fiber networks that feature in many of today's cars have data transmission rates that are limited by LED switching speeds. This barrier can be overcome, though, says Firecomms' **John Lambkin**, if these light sources are replaced with resonant-cavity LEDs.

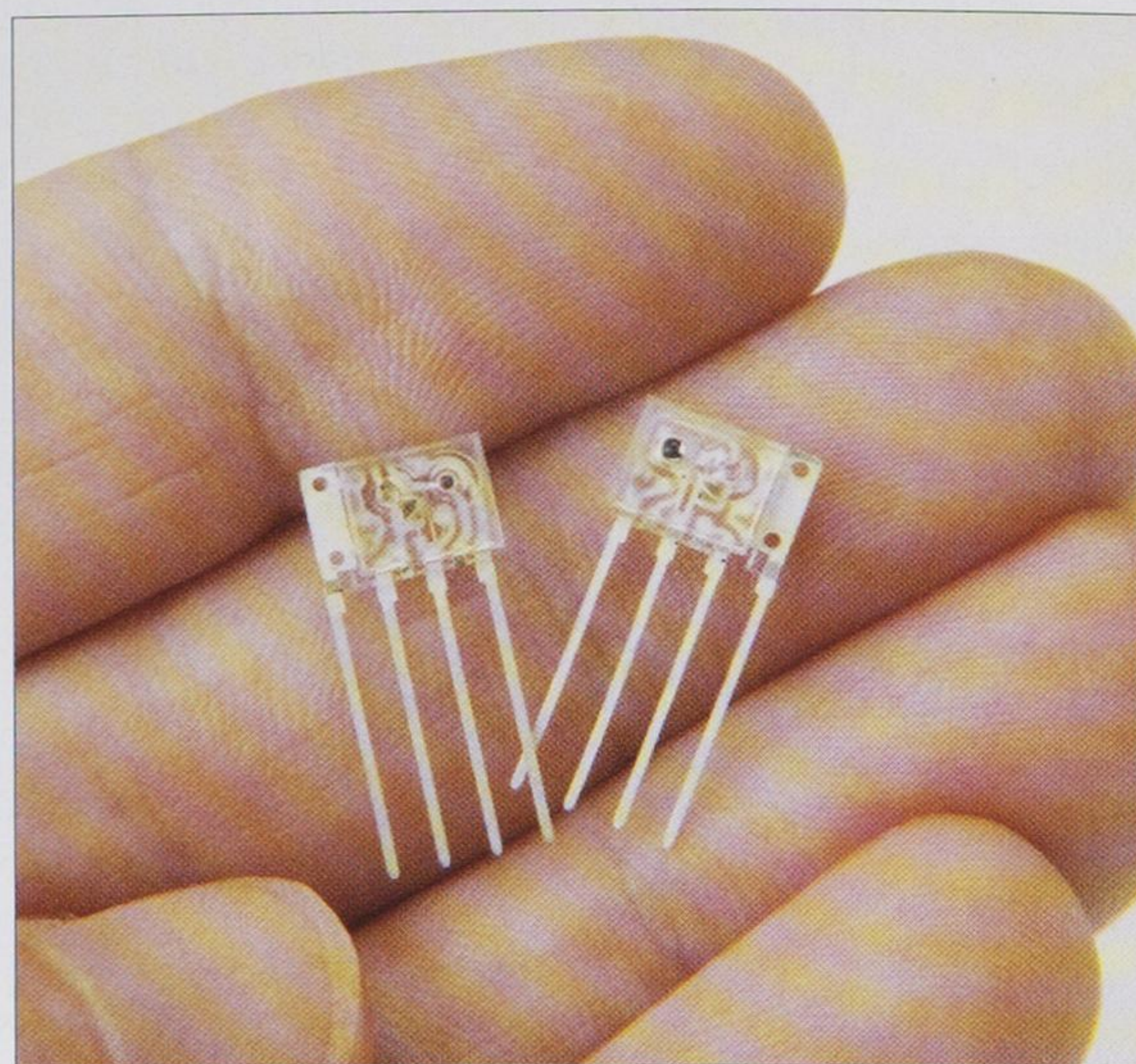
Today's car owners are demanding more from their vehicles than just good looks. They now want models offering greater levels of comfort, safety, fuel efficiency and reliability, along with features such as in-car navigation systems, GPS telephones, satellite radios, DVD players and Internet browsing facilities.

All of these features are implemented through the car's infotainment bus, which is a network of digital electronic devices operating at high data rates in an extremely harsh and electromagnetically noisy environment. Today these networks operate at 25 Mb/s, but car manufacturers are planning to migrate to 150 Mb/s, 200 Mb/s, 400 Mb/s and even 1 Gb/s speeds for real-time camera applications.

A copper-based wiring harness operating at these bit rates requires complex, heavy and expensive shielded cable assemblies, so the automotive industry has started to turn to cost-effective systems employing plastic optical fiber (POF). Largely immune from electromagnetic interference, POF offers several advantages over glass fiber, including easy termination and a high tolerance to mechanical vibration. These benefits have led to low-cost connectors and a rugged assembly process.

Many of today's cars already feature Media Oriented Systems Transport (MOST) POF-based multimedia buses (see "POF in-car network evolution" box). The key components of these systems are transmitter (Tx) and receiver (Rx) fiber-optic transceivers (FOTs), which are currently supplied by companies such as Infineon and Hamamatsu. The plastic-encapsulated FOTs are fully integrated and contain both the light source and detector, together with the controlling LED driver and limiting amplifier integrated circuits. These components form a digital transceiver that can be driven by standard transistor-transistor logic signals and operate between -40 and +95 °C for the full 15-year lifetime of the vehicle. These FOTs, although operating at relatively low data rates, are highly sophisticated optoelectronic devices that offer the car industry an excellent price-to-performance ratio.

The MOST bus was specifically designed to support higher data rates, and work is already underway to implement next-generation MOST systems operating at 150 Mb/s. This development will face competition from the IDB-1394, a rival optical standard



Late last year Firecomms launched the world's first resonant-cavity LED-based MOST 1.1 compliant fiber-optic transceiver, which features both the company's receivers and its 650 nm emitters.

operating at 200 Mb/s, which is based on the consumer multimedia IEEE 1394.b (FireWire) protocol. One of the advantages of this standard is that it allows products such as Apple's iPod and Sony's PlayStation Portable (PSP) to be directly connected into the multimedia bus. This bus is still to be deployed, but several automotive manufacturers are actively supporting the development of this standard in Europe and Japan.

Red's the color

POF requires 630–685 nm light sources, because these are the wavelengths where fiber attenuation is at its lowest. For the systems installed in today's cars, which operate below 50 Mb/s, conventional surface-emitting red LEDs are used for the transmitter. These devices are highly attractive as they have no threshold current and can consequently use simple drive circuits. In addition, they have good thermal stability. The LEDs are also intrinsically eye safe, and being red it is trivial to literally see optical signals during maintenance operations.

However, as the MOST standard upgrades to 150 Mb/s and IDB 1394 progresses to 200 Mb/s, the challenge is to find POF-compatible light sources that deliver these data rates while also meeting the car's arduous environmental operating conditions. Conventional surface-emitting LEDs are limited to speeds of up to 50 Mb/s. The devices are also inefficient because most of the light generated in the active region is internally reflected, and less than 4% is extracted (see figure 1a). High-bandwidth visible edge-emitting lasers can address these issues, but their threshold

up latest in-car networks

POF in-car network evolution

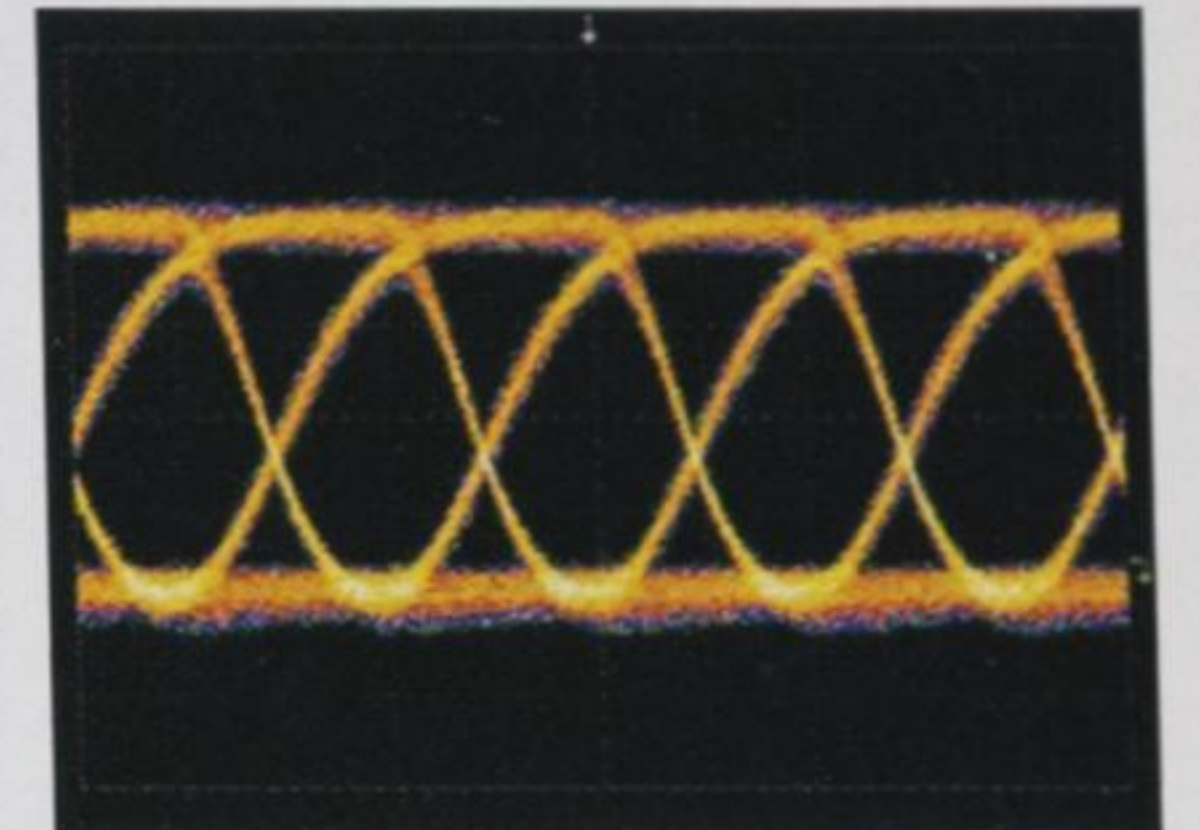
Plastic optical fiber (POF) was first used extensively in industrial field buses such as PROFIBUS, SERCOS and INTERBUS-S for controlling process equipment in rugged, electromagnetically noisy manufacturing environments, but in 1998 Daimler-Benz put the first POF bus into a serial production vehicle. This bus, called the Digital Domestic Bus (D²B), used 650 nm LEDs and standard step-index POF with a 1 mm core diameter. Operating at 5.6 Mb/s, this system transmitted signals for sound systems and speech recognition, and speech, audio and control data for phones. In 2001 BMW joined in, introducing the byteflight POF bus into its 7 Series vehicles for an airbag sensor deployment network capable of operating at 10 Mb/s.

Later that year the same company installed the first Media Oriented Systems Transport (MOST) POF-based multimedia bus in its 7 Series, which was a major milestone for POF-based automotive networks. Based largely on the same physical layer as the D²B network, the MOST bus operates at 22.6 Mb/s, which allows the transmission of compressed video data. Initially this system was introduced in top-of-the-range vehicles such as the 7 Series and the DaimlerChrysler E-Class, but now it



POF MOST networks first appeared in BMW's exclusive 7 Series, but they are now being deployed by a number of manufacturers in a wide range of cars, including the BMW 1 Series shown here.

is featuring in more than 30 different cars, including the BMW 1 Series, DaimlerChrysler smart car, Mitsubishi Colt, Volvo S40, Audi 6 and Peugeot 807. Last year 12 million POF nodes were installed into cars and this figure is expected to rise to 15 million in 2006.



This sharp optical "eye diagram" of a 650 nm RCLED at 250 Mb/s demonstrates its suitability for transmission at this data rate.

current characteristics and poor thermal behavior means that these emitters are awkward and costly devices to control compared with the simpler, more reliable and more temperature-stable LEDs.

We believe that more suitable sources for higher data rates are resonant-cavity LEDs (RCLEDs), which combine high extraction efficiencies with good spectral and modulation characteristics. Since 1992, significant effort has been directed towards the development of these devices – visible RCLEDs in particular – and today these emitters can meet the specifications and lifetime performance demanded by the automotive industry.

An RCLED consists of a thin quantum-well active region in a Fabry-Pérot cavity formed from metallic mirrors or distributed Bragg reflectors (DBRs). The RCLED cavity promotes emission into resonant modes within the LED's "escape cone", while suppressing emission into off-resonance modes. This means that the emission profile, which is significantly different from the isotropic nature of a standard LED, can substantially improve the device's extraction efficiency.

Firecomms' red RCLEDs contain an InGaP/AlGaInP quantum-well active region and AlGaAs-based DBR mirrors, and are grown by conventional MOVPE. The device structure is similar to that of a VCSEL, but the number of mirror pairs in the top

DBR is significantly smaller, normally less than 10. However, because the RCLED is a spontaneous emission device, the tolerances needed during growth and fabrication procedures are significantly relaxed in comparison with a VCSEL, leading to yields and production costs similar to those of conventional LEDs.

RCLEDs also have a higher bandwidth than conventional LEDs. This improvement comes from the use of thin quantum-well active regions and current-confining oxide apertures. These apertures, which are larger than those routinely used in VCSEL production, reduce the optical loss from below the wire-bond contacts. They also help to maintain higher carrier densities for a given current, which reduces the photon's spontaneous lifetime and increases the device's bandwidth.

With small diameter apertures of less than 50 μm , RCLEDs can produce remarkably high bit rates of 1.25 Gb/s, although internal heating effects limit the useful output power. Arguably more important, though, bit rates of 150 and 200 Mb/s, which are required for next-generation MOST and IDB 1394

"The aerospace industry is beginning to look at adopting POF-based technology."

Fig. 1. RCLEDs have significantly higher extraction efficiencies than LEDs because their design alters the emission profile from an isotropic one (a) to emission that is stronger in the directions below the critical angle, θ_c (b).

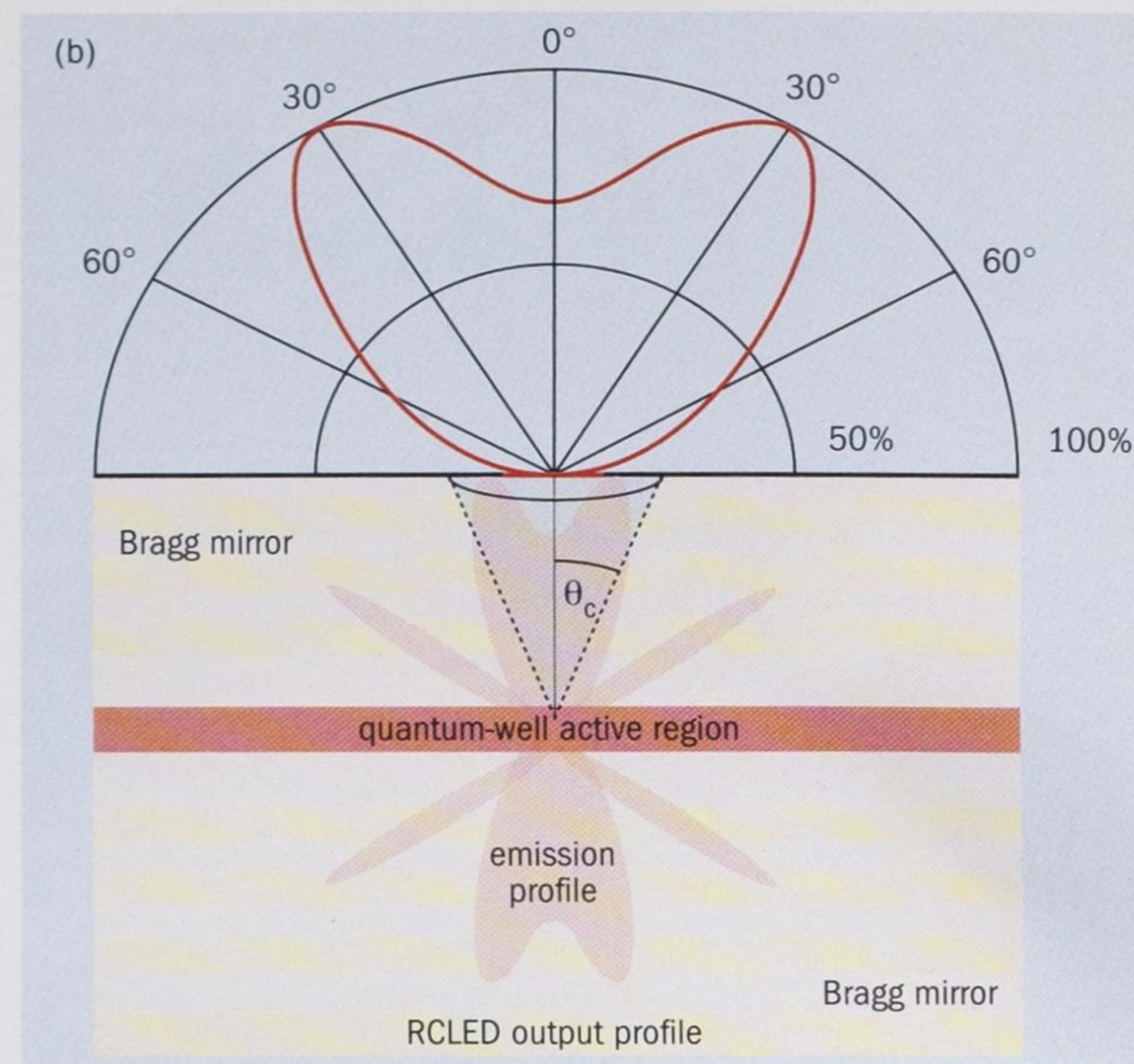
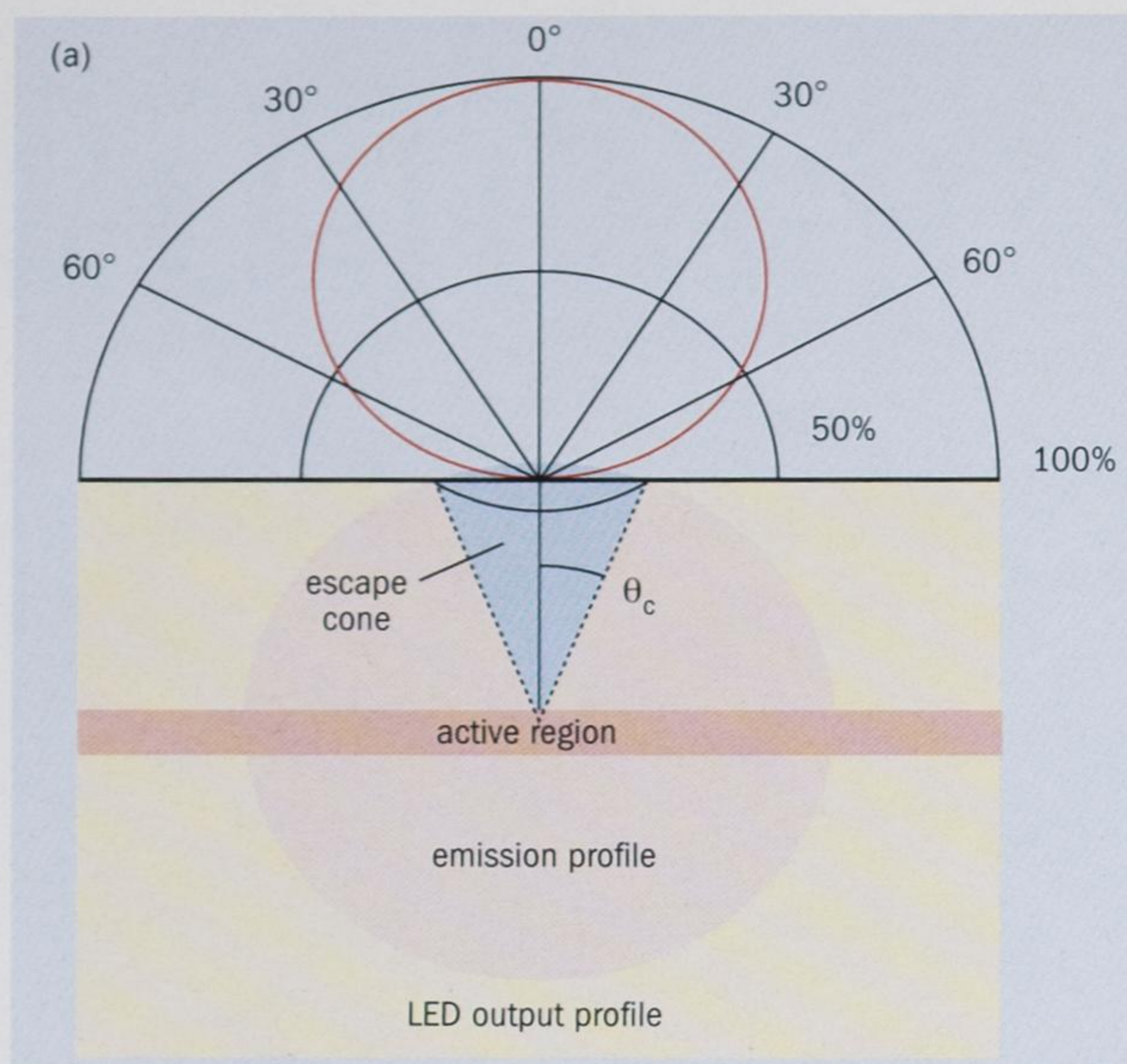
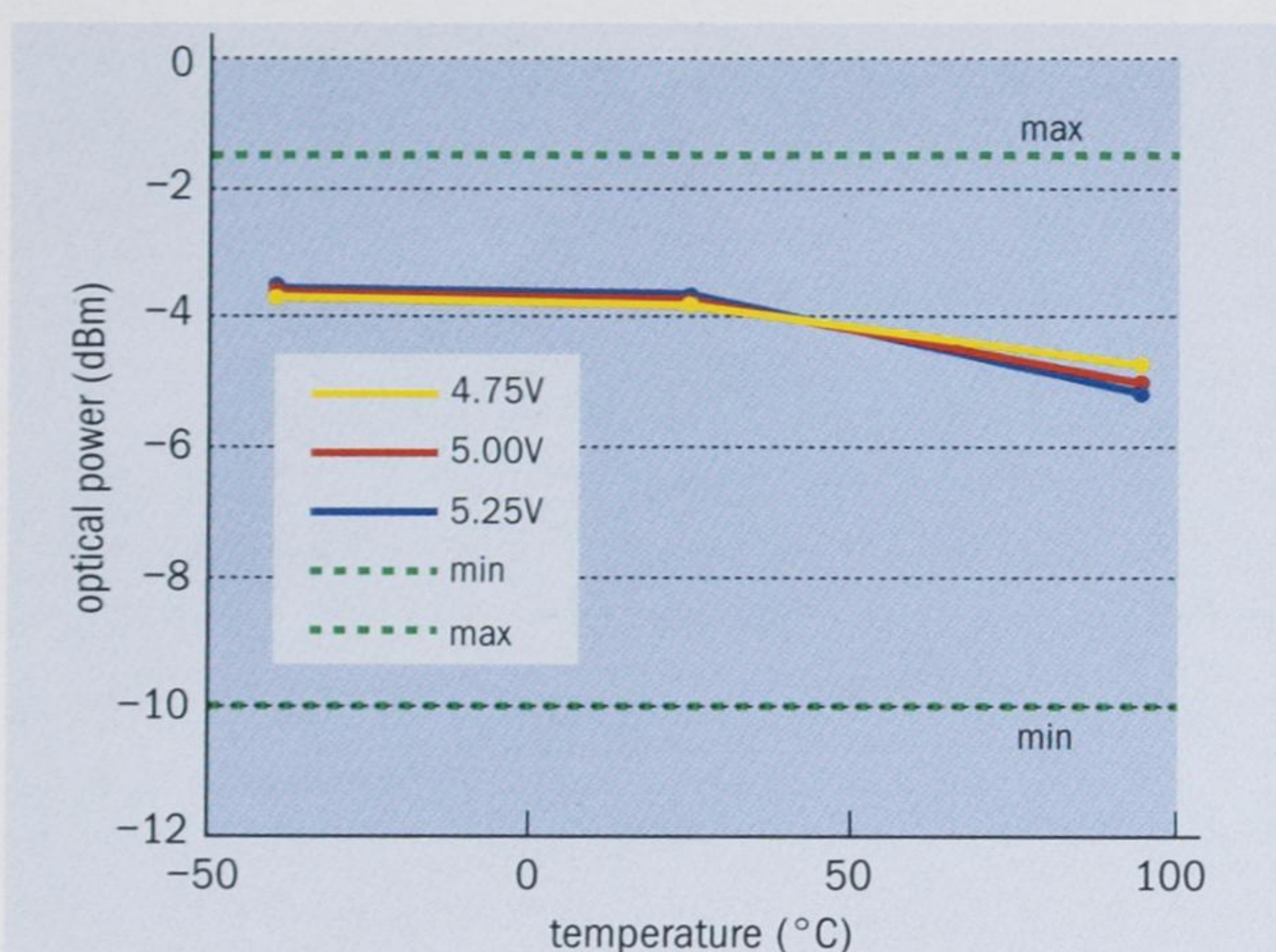


Fig. 2. The output of Firecomms' RCLED-based FOTs are only slightly affected by changes in temperature and operating voltage.



standards, can be easily achieved while still maintaining high output powers.

The RCLEDs' thermal behavior differs substantially from that of a conventional LED, but a highly stable output power can be produced by optimizing the RCLEDs' active region. Reliability is the other critical characteristic for automotive applications. At Firecomms headquarters in Ireland we have collected over 500,000 device hours of reliability data for RCLEDs in plastic-encapsulated FOT packages and on TO style headers, run in both DC and AC, at temperatures of -40, 85, 95, 110 and 140 °C. We recorded no device failures, which shows that RCLEDs can deliver the same high levels of reliability as their more conventional LED cousins.

The MOST 1.1 standard currently deployed in car manufacturing requires a maximum data rate of 50 Mb/s (including signalling overhead), so it may seem unnecessary to consider using RCLEDs in MOST FOTs. However, RCLEDs designed for automotive applications can deliver high fiber-coupled power, good temperature stability and a significant increase in the launched optical power, compared with the current MOST optical budget. In addition, this technology offers an evolutionary roadmap for MOST to

deliver 150 Mb/s data transfer over POF, and that allows car manufacturers to continue using the well-established POF harnesses.

First to market

At the MOST Interconnectivity Conference held in Japan late last year, we launched the world's first MOST 1.1 compliant FOT using RCLED technology. Through optimized design of the RCLED and associated driver IC, our MOST FOT can deliver a minimum fiber-coupled output power over operating temperature and life of -7 dBm, which is a 3 dB improvement over this standard's minimum power specification. The change in output power of our RCLEDs over temperature is as low as 2 dB (see figure 2), and the devices can maintain a full-width half-maximum of their emission below 25 nm across the entire temperature range, which reduces absorption loss within the fiber. Our corresponding receiver FOT has a -28 dBm sensitivity over operating temperature and life, which is a 5 dB improvement over the MOST standard requirement. This means that our system can deliver an additional 8 dB of margin over the MOST specification, which allows the POF harness to incorporate either an increased number of in-line connectors or tolerate higher bend losses in the fiber.

Today MOST FOTs in high volume have a \$2-3 target price per FOT pair, and this year fully digital FOTs meeting the 200 Mb/s IDB 1394 and IEEE 1394.b standards will be launched by several suppliers. Consequently, we expect that this automotive-driven technology will not only continue to impact the car industry, but migrate to non-automotive applications such as public audio/visual address systems, home entertainment networks and security-camera systems. The aerospace industry is also beginning to look at adopting POF-based technology for cabin-based multimedia systems. In all these cases we believe the combination of the POF fiber physical layer and the multimedia-oriented bus standards of MOST and IEEE 1394 will make for a reliable, cost-effective and high-performance optical system.



About the author

John Lambkin is Firecomms' chief technology officer and a founder of the company. E-mail: jlambkin@firecomms.com.



Ketecca Corporation with its Worldwide Offices is the Leading Manufacturer of **Dicing saw surfactant, Dispensing Systems, Dicing Blades and Print pads.**

- Provides standard and customized products.
- Fast manufacturing process to cater for immediate availability of products.

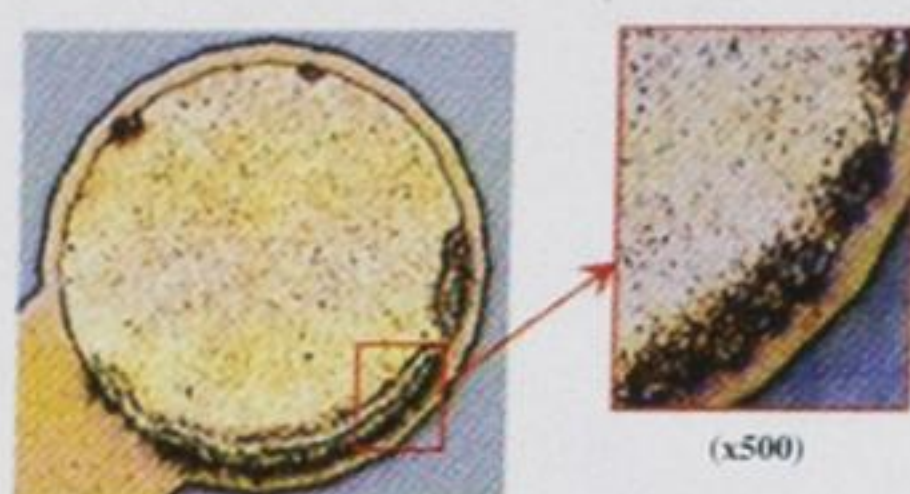
DIAMAFLOW Solutions for Wafer Dicing



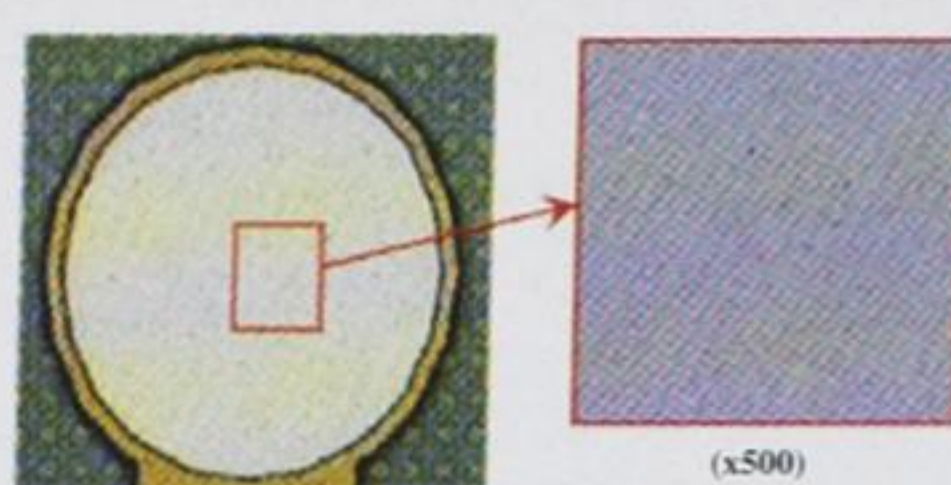
- Prevent Silicon Dust build-up on Bonding Pads
- Reduce heat and surface tension by 50%
- Prevent Galvanic corrosion
- Improve ball shear strength



Without Diamaflow With Diamaflow



Without Diamaflow



With Diamaflow

Distinctive Qualities of DIAMABLADE

- Stronger Blade
- Extended Wear Rate
- Best in delivery leadtime



With Manufacturing Plants in the USA and Singapore, we provide standard and customized Print pads to cater to different packages and application.

USA & EUROPE

Ketecca USA Inc.
5525 West Latham St.
Phoenix AZ, 85043
Tel: 602 278-7789
Email: Jmanley@Ketecausa.com

ASIA

Ketecca Singapore (PTE) Ltd.
35 Tannery Road 07-06
Ruby Industrial Complex
Singapore 347740
Tel: 65-67493318
Website: www.ketecca.com

Semicon China Booth 1735, Hall W1

Semicon Singapore Booth, 1020

EPI NOVA

III-V EPITAXIAL SOLUTIONS

III-V epiwafers

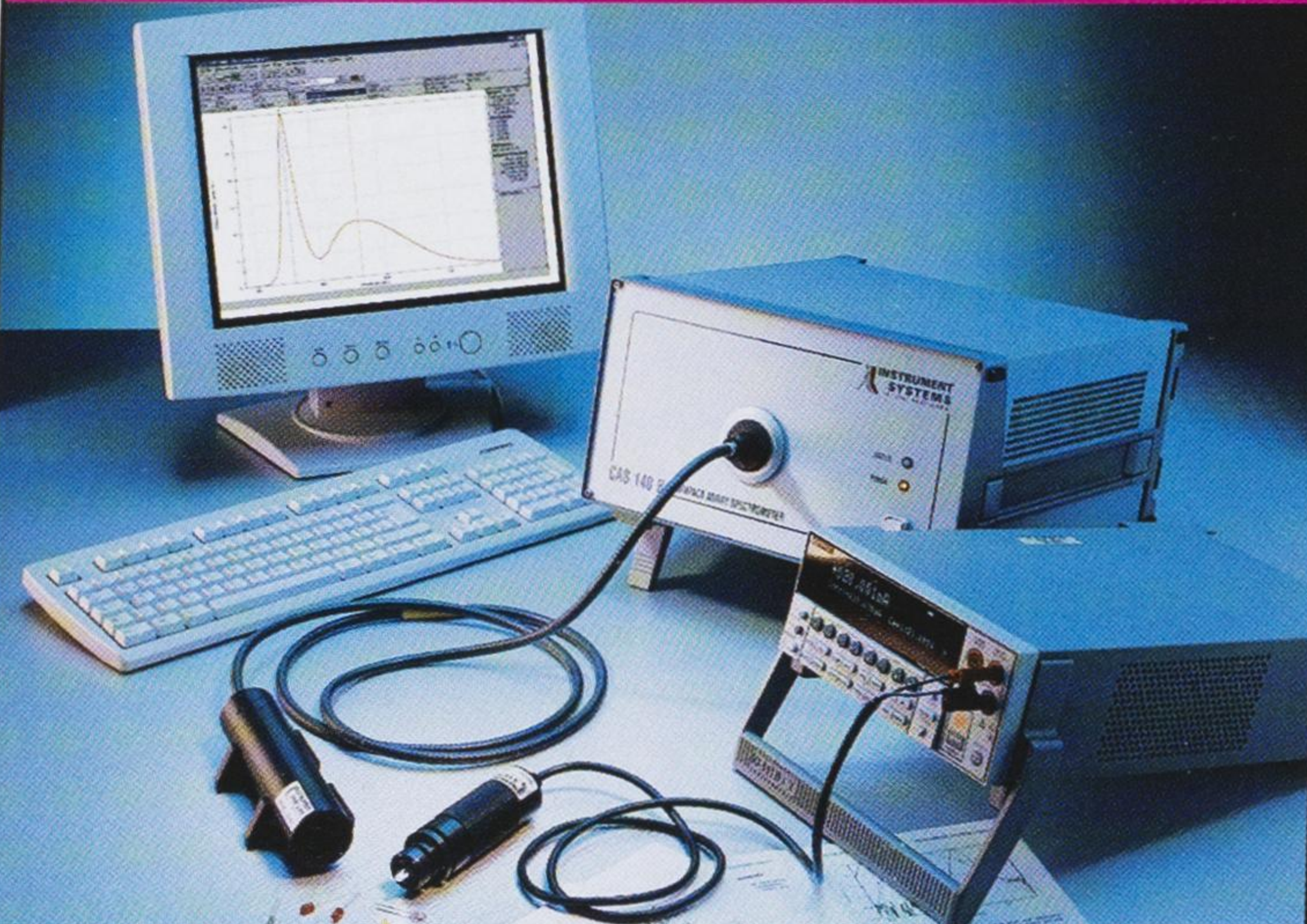
- Customized layer structures
- Highest quality
- Development and production
- Excellent long term reproducibility
- Short delivery time
- Scientific support

EpiNova
is bridging
the gap
between
ideas and
devices



www.epinova.de

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

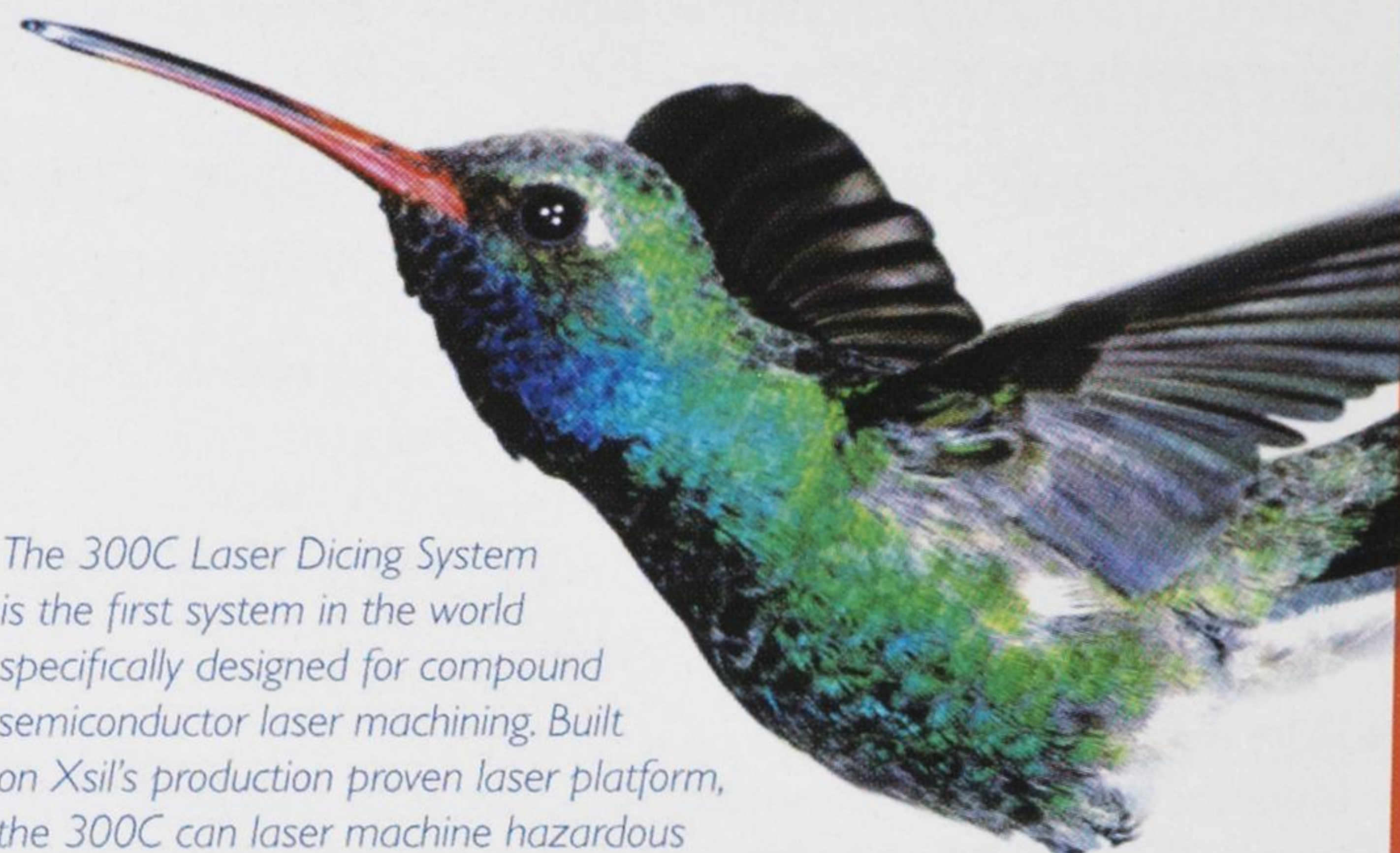
INSTRUMENT SYSTEMS
OPTISCHE MESSTECHNIK

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

WE BRING QUALITY TO LIGHT

When safety and precision
are of the highest priority...

Xsil's 300C Laser Dicing System



The 300C Laser Dicing System is the first system in the world specifically designed for compound semiconductor laser machining. Built on Xsil's production proven laser platform, the 300C can laser machine hazardous materials with precision and safety.

For more information please contact us on info@xsil.com

Now expanding: please check out www.xsil.com/careers



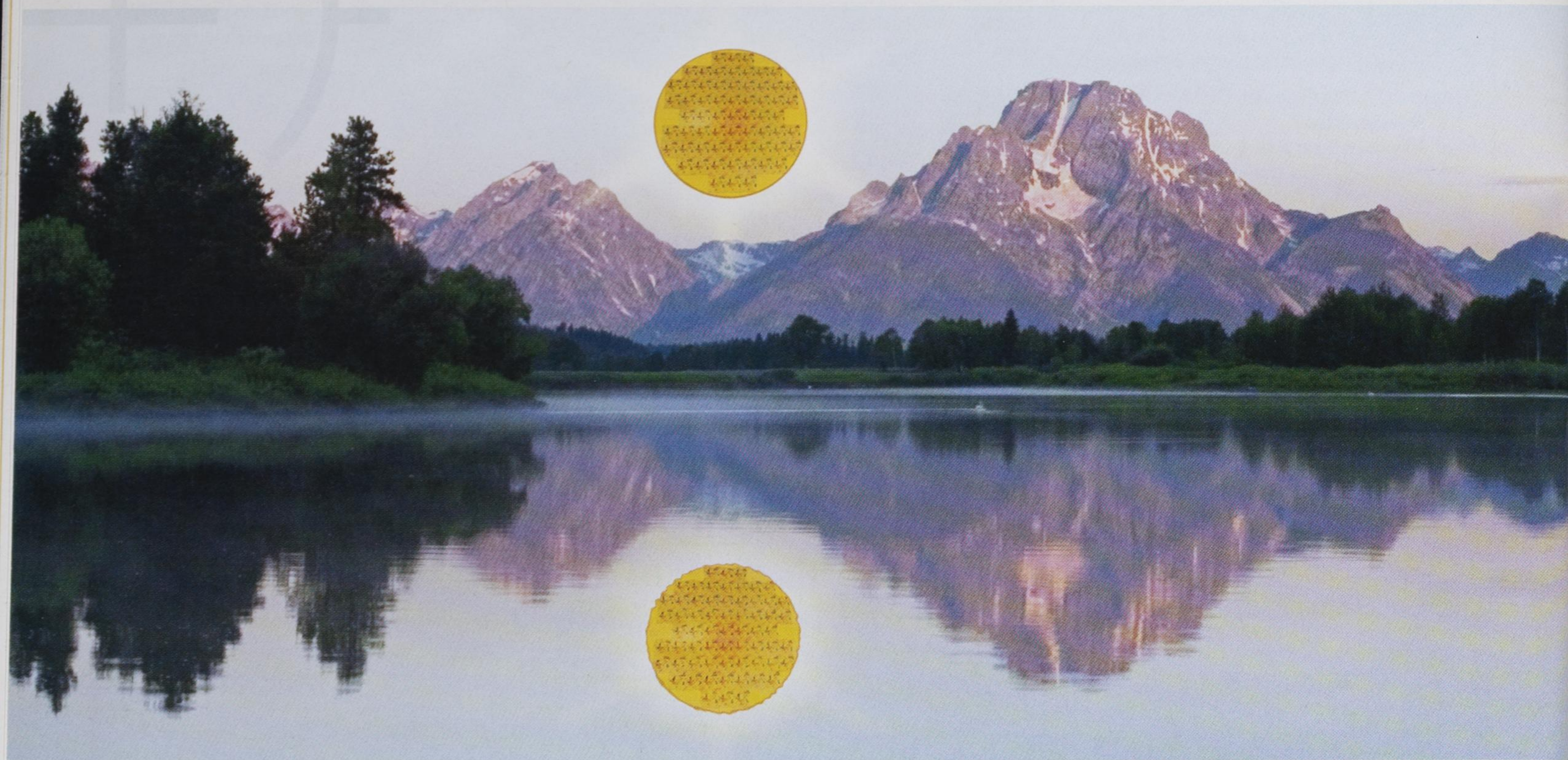
Headquarters:
Unit 3, Trinity Enterprise Centre
Pearse St., Dublin 2, Ireland
Tel: +353 1 245 7500
Fax: +353 1 245 7501
Web: www.xsil.com

Offices in:
USA, Japan, Taiwan & Singapore

XSIL
Enable

Application-Driven Wafer Bonding: The Dawning of a New Day

Unsurpassed Accuracy, Uniformity and Flexibility



FOR THE **VERY BEST** WAFER BONDER TURN TO SUSS

MST/MEMS/MOEMS

- Superior process performance enables precise production
- Laser pre-bonding enables a high yield post-bond accuracy of 1.0 μm for anodic applications
- IR Alignment enables sub-micron post-bond alignment

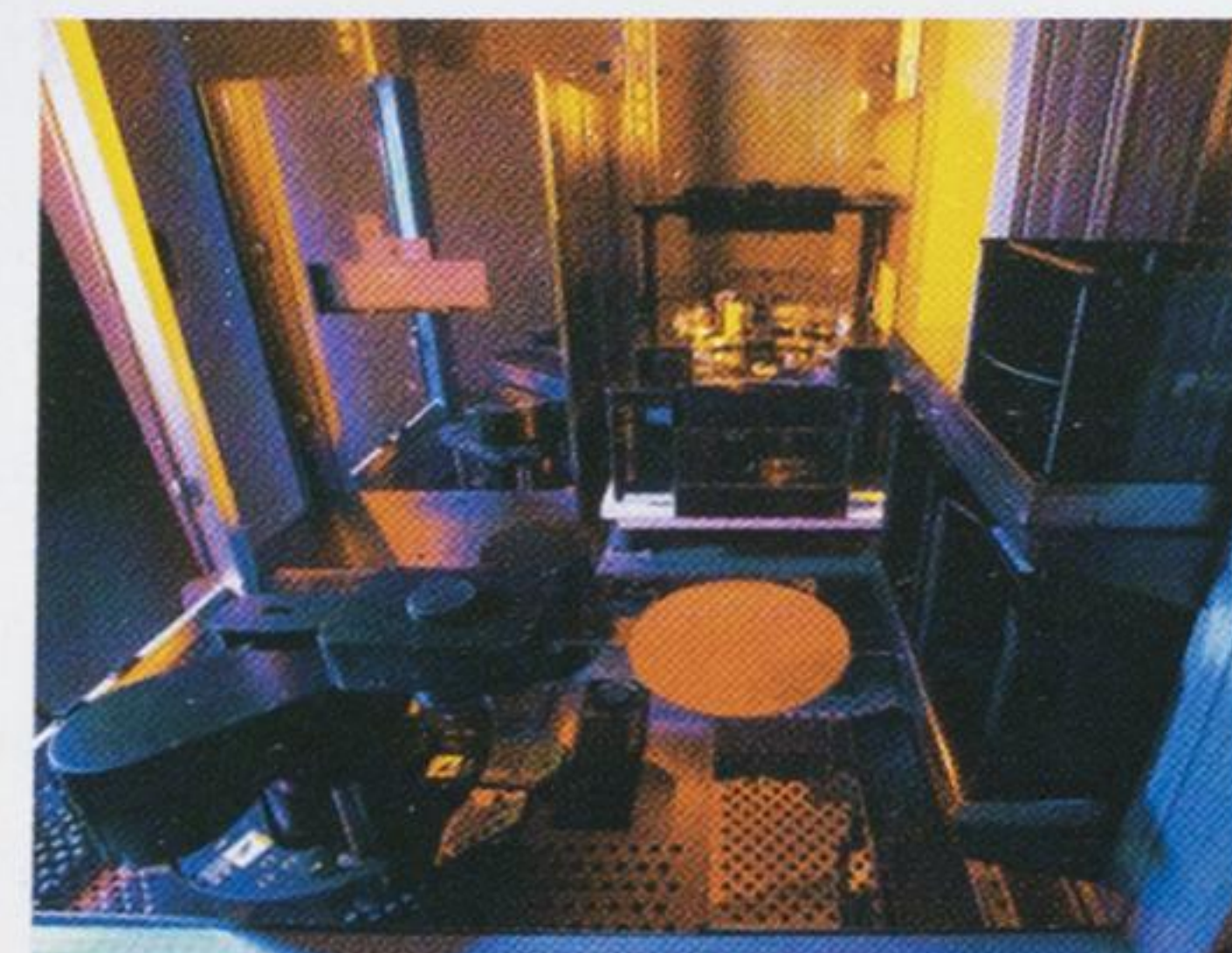
SOI/Layer Transfer

- nanoPrep plasma activation reduces anneal temperature to 200°C
- Innovative particle removal
- No wafer brushing

Post-Bond Metrology

- Real Time, In-line

Now Available:
New SB8e LED
Wafer Bonder



Every application is unique.

Let our team of experts help you find the solution to your bonding needs.

For more information visit www.suss.com/waferbonders

SUSS. Our Solutions Set Standards

SUSS MicroTec

POWER TRANSMISSION

SiC modules promise grid efficiency boost

Power inverters look like becoming a big application area for SiC chips, and ought to help the global movement to cut greenhouse gas emissions, writes **Michael Hatcher.**

We'd all be better off with a world economy that is less dependent on oil for power generation – even President Bush agrees, recently proposing a 22% increase in funding for clean energy research. While this includes nuclear energy, renewable sources like wind and solar power are of course central to the drive and will in time account for a much larger proportion of grid power.

This is all well and good, but saving the planet is clearly a complicated business and innovation at the lower-profile “nuts and bolts” level of the electrical grid is just as important. One difficulty with renewables such as wind and solar energy is that these sources produce a direct current, which then needs to be switched to the alternating current used by the grid. This power conversion requires inverter modules, which are currently based on silicon devices.

The problem with these inverters is that they operate at “only” 90–96% efficiency, depending on the application. While high, this can be further improved by SiC to between 95 and 98%. That might not sound like much, but across a grid it could make a huge impact.

A key proponent of SiC-based inverters is the utilities company Kansai Electric Power (KEPCO), which supplies electricity throughout much of Japan. As well as running dozens of conventional power stations and nuclear facilities, KEPCO is keen to develop renewables and has a 21% stake in the wind-power generator Eco Power. Yoshitaka Sugawara manages the SiC program at KEPCO. “Tremendous energy savings could be realized by switching from silicon to SiC inverters,” said the executive researcher.

Now, following an eight-year development program with SiC chipmaker Cree, KEPCO has built a three-phase inverter module rated at 100 kVA. Until recently, the best power rating that had been achieved by the team was just 12 kVA. “Typically, we need 300–600 kVA inverters,” Sugawara told *Compound Semiconductor*. “We can get to 300 kVA by connecting three 100 kVA inverters in parallel, but we will have to increase the output power of the inverter to reach 600 kVA.”

Each inverter module uses two SiC devices – a commutated gate turn-off thyristor (SiCGT) to act as a switch, and a *pin* diode. Thyristors, also known as silicon-controlled rectifiers, have an anode, a cathode and a gate. Usually, the gate current extracted from a thyristor is much smaller than the current flowing between its anode and cathode, but in the commutated device the two are equivalent. According to Sugawara, this means high-speed, low-power-loss switching.

The 100 kVA performance of the latest inverter was met by connecting six of these modules together, and it operated with a pulse-width modulation frequency of 2 kHz. The next step for the collaboration will be to scale up the power capability so that KEPCO can use SiC inverters in a wider range of commercial applications. “This will be done by increasing both the SiC device chip size and the current density,” explained Sugawara. Currently, the SiCGTs measure 8 × 8 mm, their large size



Eco-power: KEPCO's SiC power inverter (inset) can slash the transmission losses that are normally incurred when a DC renewable source such as wind energy is hooked up to the grid.

having been enabled by a major reduction in SiC crystal defect density and improved epitaxy. Increasing the chip area will require further defect reduction and a more homogenous flow of current.

Although additional development is required, Cree's John Palmour says that the technology is moving closer to the point at which – if deployed widely – it should significantly reduce the need for new power stations and, in turn, decrease carbon dioxide emissions.

Palmour added that demand for Cree's SiC Schottky diodes for inverter designs was already being fielded by a number of European customers. “A few are DC for battery storage, but most are grid-connected,” he said. The European demand stems largely from a European Union directive that pays around half a euro per kilowatt hour for solar-generated power.

Though these solar designs have a much smaller power requirement than the KEPCO inverters, larger systems can be built by connecting modules in parallel. These systems boost the variable voltage input to the grid that the solar panels produce, with the SiC Schottky diodes again yielding greater power efficiency than their silicon equivalents.

Although Palmour won't make a prediction on what the total addressable market for SiC-based inverters could amount to, he does believe that the market for power devices based on the wide-bandgap material will be “very large”. Schottkys from the likes of Cree and Infineon, which is soon to release a new version of its SiC diodes, are already widely used for power factor correction in computer server switch-mode power supplies.

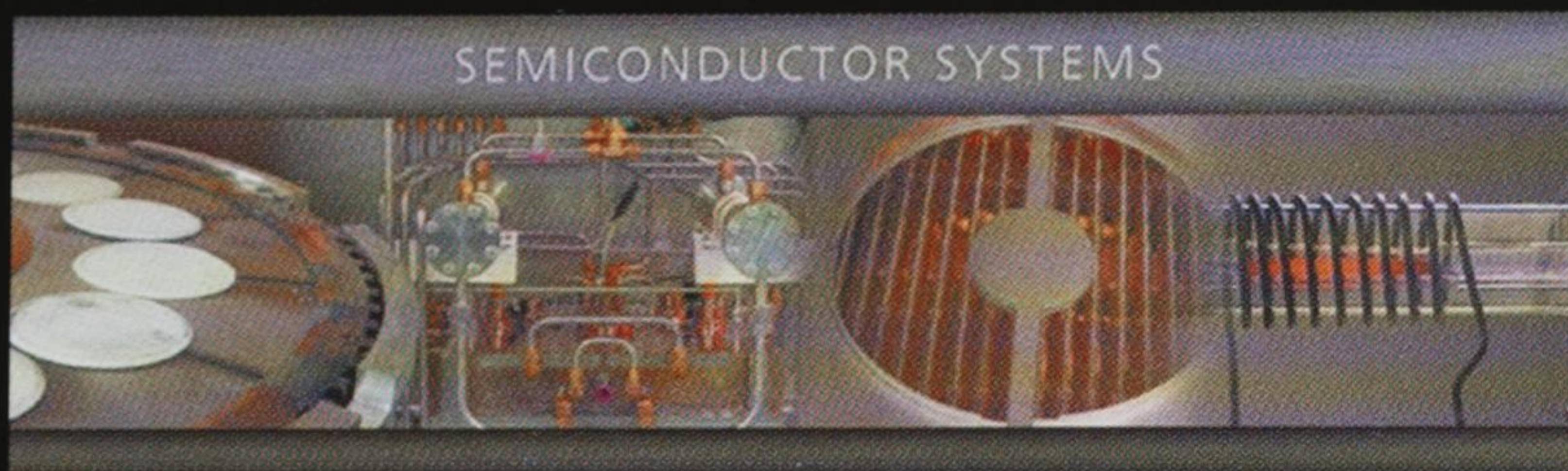
While wide-bandgap materials have received a lot of funding to exploit their potential in military applications, the knock-on effect promises to be altogether more environmentally friendly. And any reduction in oil dependency must be encouraged on both environmental and political grounds. Just ask George W Bush.

“Tremendous energy savings could be realized by switching to SiC inverters.”

Yoshitaka Sugawara
KEPCO



EMF
Semiconductor
Systems



SEMICONDUCTOR SYSTEMS

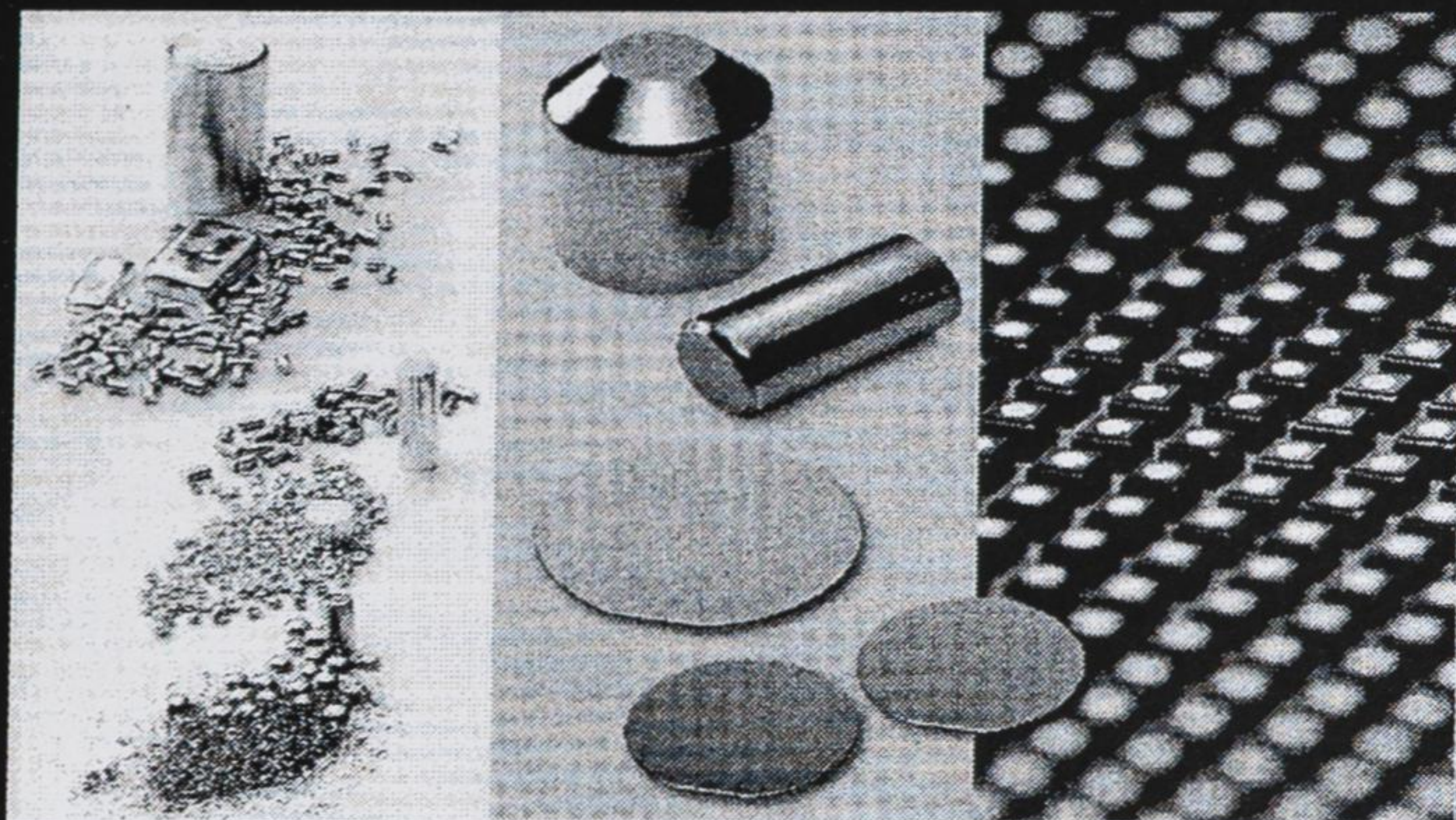
EMF - the next logical step in MOCVD innovation

Predictive, dynamic, closed loop control MOCVD tools for GaN, AlGaIn, InGaIn, ZnO, SiC and custom growth solutions.

Unit 5, Chesterton Mill, French's Road, Cambridge, United Kingdom.
Tel: +44 (0) 1223 352244 Fax: +44 (0) 1223 352444
E-mail: sales@emf.co.uk Web: www.emf.co.uk

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 Epiwafer

- ◆ AlN on Sapphire: 2 inch
- ◆ AlGaIn 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

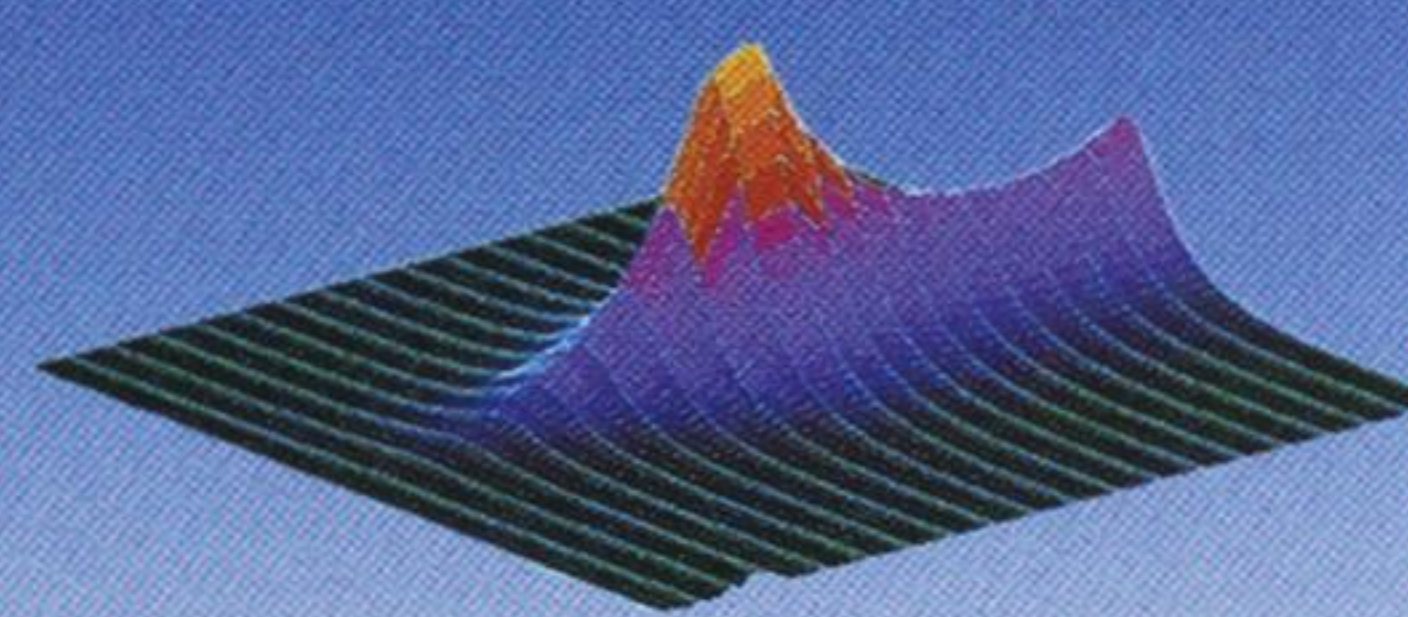
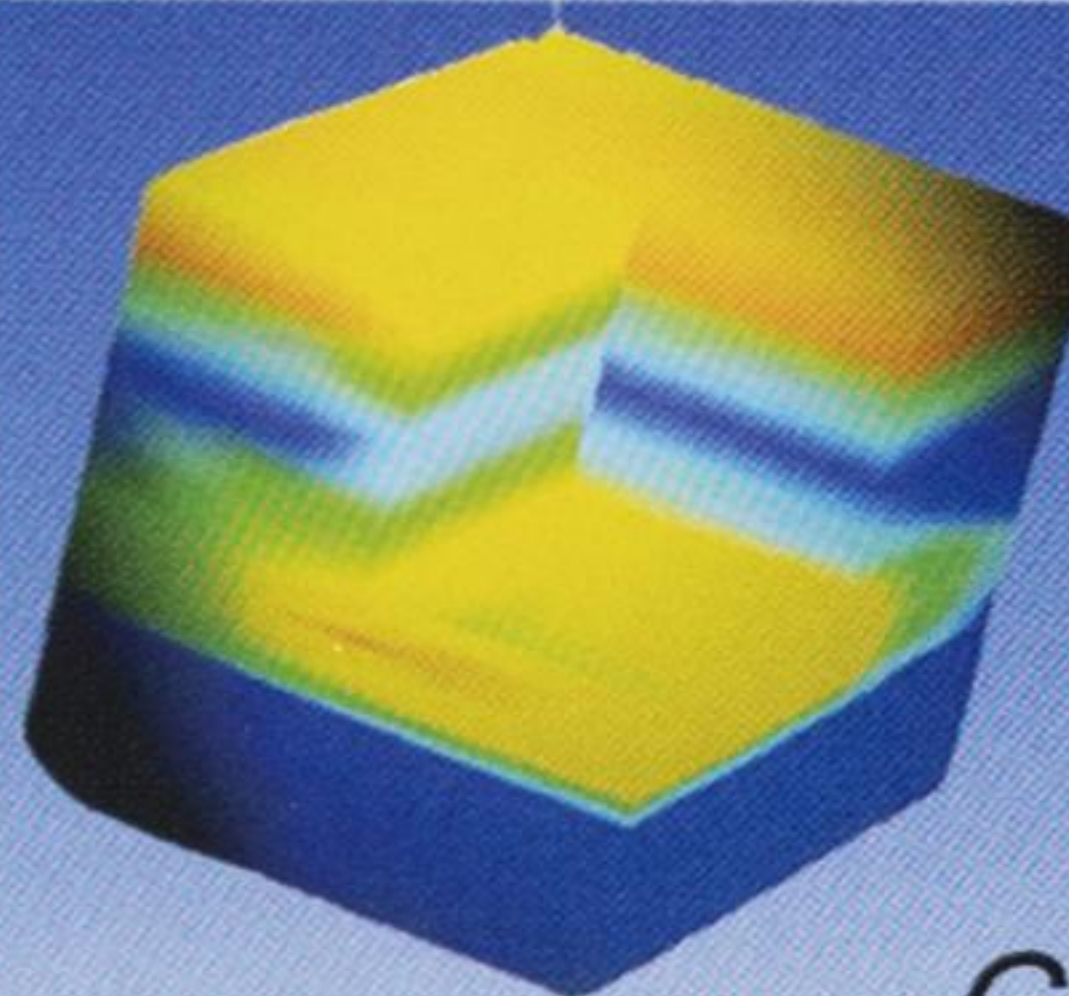
2/3D DEVICE/PROCESS SIMULATION SOFTWARE FOR COMPOUND SEMICONDUCTOR DEVICES

APSYS: Device simulator for LED (with 2/3D ray tracing), HEMT, HFET, HBT, APD, PIN, RTD, etc.

PICS3D/LASTIP: Specialized simulator for Laser Diode, VCSEL, SOA and Waveguide PD.

CSUPREM: Silicon/GaAs process simulation. Standford's code fully extend to 3D.

PROCOM: MOCVD reactor simulation software for binary/ternary/quaternary compounds



CROSSLIGHT
Software Inc.

Creators of award winning software offer state-of-the-art physical models such as intraband/interband quantum tunneling, hot carrier transport, 8x8 k.p band structure for zincblende materials, and 6x6 k.p theory for wurtzite structures.

206-3993 HENNING DR.
BURNABY BC V5C 6P7 CANADA
TEL: (604) 320-1704 FAX: (604) 320-1734
www.crosslight.com

Compound semiconductor MEMS community targets new applications

Today's III-V MEMS community is producing a wide variety of devices for applications as diverse as gas sensing, monitoring sugar levels in water, detecting explosives and reducing pollution from diesel engines.

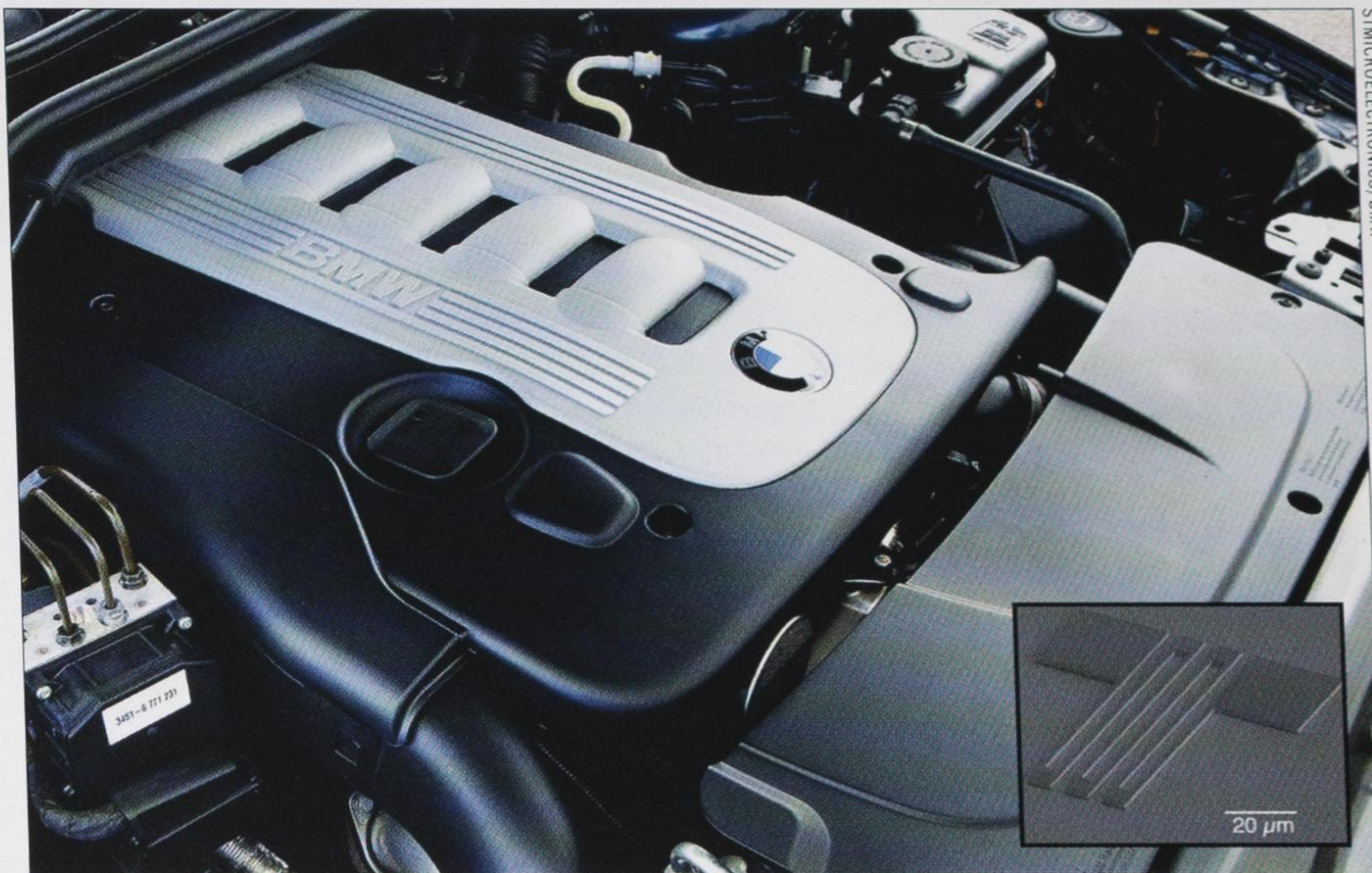
Richard Stevenson reports.

The multi-billion-dollar market for micro-electro-mechanical systems (MEMS) – devices containing micron-sized moving parts produced by photolithographic processes – is overwhelmingly dominated by silicon. However, this material is not suitable for the fabrication of certain devices, and academic institutions and company research labs are using various compound semiconductor materials to produce MEMS-based devices, including VCSELs, tunable filters, optical amplifiers, mechanical detectors and pressure sensors.

The last few years have seen growth in the development of wider bandgap semiconductor MEMS sensors for the relatively harsh automobile and aeronautical environments. French market analyst company Yole Développement predicts that this market could be worth about \$100 million for components manufacturers this year and \$300 million in 2010. The only factors expected to halt this revenue growth are a lack of progress relating to device metallization and packaging, or unexpectedly slow improvements to the SiC and GaN substrate cost and performance.

One company that is using SiC for MEMS devices is STMicroelectronics. The Switzerland-based semiconductor giant has developed a sensor that can help to reduce pollution from cars by monitoring the pressure within a diesel engine. Piezoelectric sensors incorporating resistors are arranged in a Wheatstone bridge configuration and then integrated within 4H SiC material, with a 100 μm thick membrane used to improve the device's sensitivity. Pressure changes deform the membrane, putting strain on the resistors, which modifies their resistance and leads to an unbalanced bridge that produces an output voltage.

Salvo Coffa, the research director of STMicroelectronics' soft computing, silicon optics and post-silicon technologies group, explained that SiC was selected for constructing the sensor because it can withstand high temperatures from both a mechanical and electrical perspective. He revealed that the company

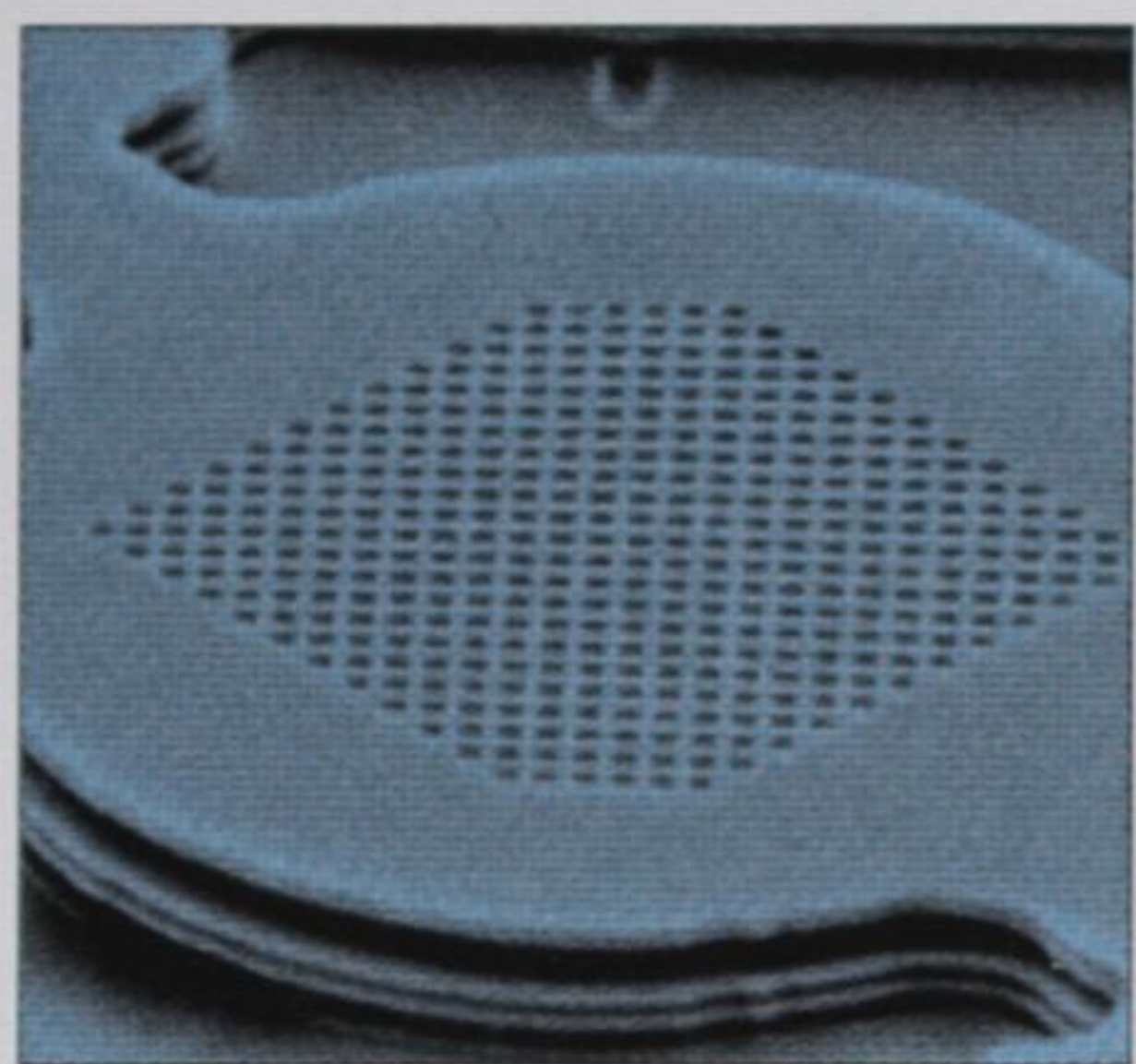


also had to develop a metallization process for the sensor to produce contacts capable of operating at 800 °C, and an electrochemical etching process for SiC, because this material doesn't react with acids.

When the sensor is used in a "closed loop" configuration engine pollution is reduced because pressure measurements allow the timing of the ignition to be adjusted to ensure that all the fuel is burnt. Today the device is used as a lab sensor to provide information on the combustion of a specific engine, but the target of the project is to have it installed in cars. Although the device is competing against other pressure sensors that can be used in diesel engines, it is the only sensor that can be directly exposed to the environment. "Rival products require local cooling, which is expensive and limits their use to the research lab, or they need a transducer that removes the temperature from the sensor, but this approach reduces sensitivity and dynamic range," explained Coffa.

SiC pressure sensor development started three years ago. The first measurements on diesel engines were carried out last year, and Coffa expects that the devices will start appearing in cars within a couple of years. Although the current cost of these devices is roughly three times too high for mass deployment, Coffa says that the price is dominated by SiC substrate costs, and that the price of this material is falling substantially. According to him, the product's success will also depend on future European legislation regarding the permitted emission levels from cars, and the tightening of these laws could drive the uptake of these sensors.

STMicroelectronics has produced SiC-based MEMS pressure sensors (see inset) that can help reduce pollution levels by optimizing a diesel engine's combustion cycle.



Researchers in Lyon, France, have added a photonic bandgap structure to their tunable filters to make devices that can produce directive optical sources.

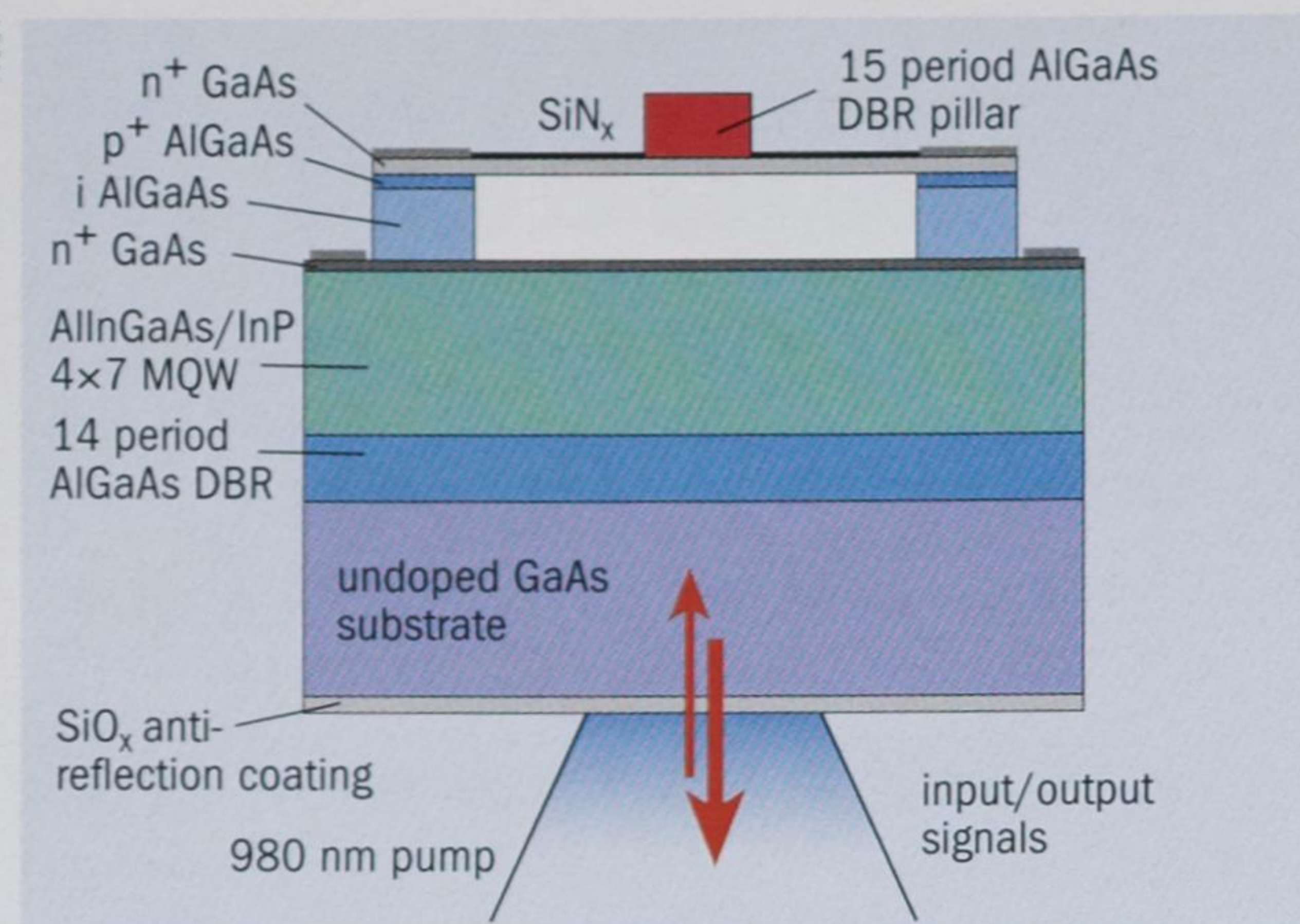


Fig. 1. The University of California, Santa Barbara's MEMS-tunable vertical-cavity semiconductor optical amplifiers have the potential to be deployed as wavelength-selective amplifiers in fiber and free-space networks. The devices are formed by bonding an active region containing four sets of seven 0.85% compressively strained AlInGaAs multiple quantum wells (MQW) grown by MOCVD on an InP wafer, to two distinct AlGaAs distributed Bragg reflector (DBR) mirrors grown by MBE on GaAs substrates. The top mirror is designed to have a reflectivity as close to 100% as possible and the bottom mirror targets 94% reflectivity. By pumping the amplifier with a 980 nm laser, 12 dB of on-chip gain can be produced over a 21 nm wavelength range.

Selective amplification

At the University of California, Santa Barbara (UCSB), John Bowers' group is producing MEMS-based vertical-cavity semiconductor optical amplifiers (VCISOAs) that deliver simultaneous optical amplification and tunable filtering (see figure 1). This property makes the devices suitable for wavelength-selective amplification in fiber-based networks, and free-space communication systems.

According to Garrett Cole, a former researcher in the group who is now heading tunable VCISOA development at start-up Aeries Photonics, the VCISOAs face competition from fiber-based optical parametric amplifiers (OPAs), which can also combine tunable filtering and amplification. However, Cole says that the MEMS VCISOAs offer several advantages, including low pump and tuning powers, and straightforward integration with components such as lasers and detectors. "OPAs have extremely high gain, as well as continuous and very wide wavelength tuning ranges of nearly 200 nm, but these devices require extremely high pump power and a tunable pump laser to realize the wide wavelength tuning range of the gain spectrum." OPAs have other drawbacks too because they require the use of long lengths of specialty optical fiber, while MEMS-based VCISOAs have the potential to be produced as single-chip two-dimensional arrays.

UCSB's optical amplifier operates in reflection mode, with the input signal entering through a mirror with reduced reflectivity, and the amplified output exiting from the same side of the device. A circulator or coupler is required to separate the ingoing and outgoing light, and an optical source is needed to pump the cavity and enable amplification.

The researchers are still to determine what data rates

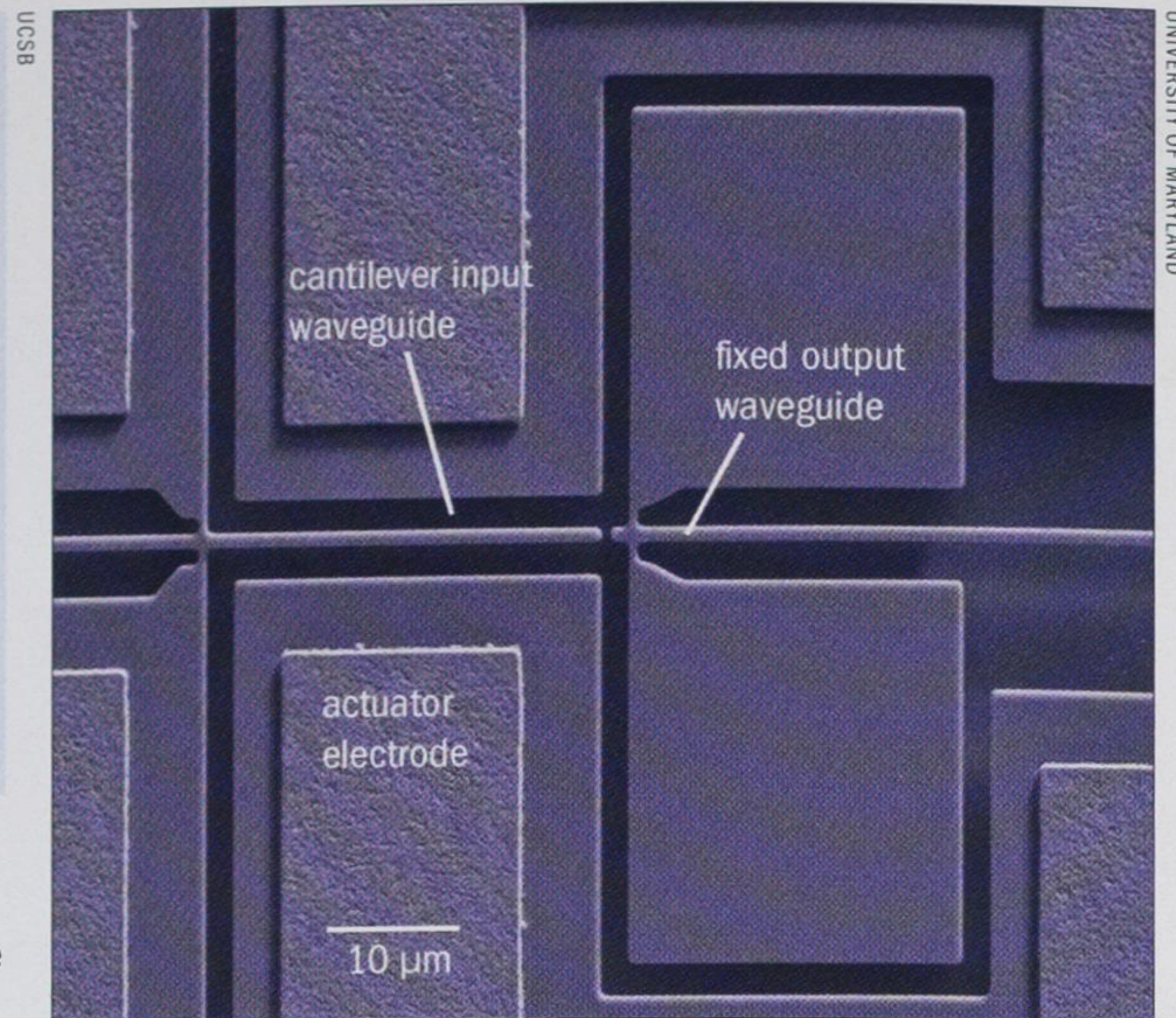


Fig. 2. The MEMS Sensors and Actuators Lab at the University of Maryland is developing cantilevers offering on-chip detection of explosive materials by monitoring the light transmitted between the cantilever and the fixed-output waveguide. The cantilever is coated with a thin chemically sensitive material that interacts with the material to be detected, leading to an increase in the cantilever's mass and a shift in its resonant frequency.

are possible with their MEMS VCISOA. However, they are optimistic that it will be capable of operating at high data rates because the device's structure is almost identical to the fixed-wavelength SOAs that the team has built in the past, which could operate at 20 Gb/s.

UCSB and Aeries are continuing MEMS-based VCISOA development, with efforts being directed at producing electrically-injected devices, and counterparts that operate in transmission mode and are more suitable for network deployment. Both teams are also investigating the integration of VCISOAs with optical detectors in order to create integrated preamplifier receiver modules.

US universities are also responsible for producing the first InP optical waveguide MEMS switch, which came from Reza Ghodssi's group in the MEMS Sensors and Actuators Lab at the University of Maryland. Although these devices have insufficient switching speeds to route packets over optical networks, Ghodssi says that they are ideal for use in network restoration applications, where switching speeds are less stringent. The devices also offer lower static power consumption than traditional detector/emitter switches for these redundancy applications.

At present, though, the group is building InP MEMS environmental sensors with on-chip detection that share the same technology platform as the optical switches, but feature a cantilever coated with a thin chemically sensitive material and a fixed optical waveguide (see figure 2). Absorption of agents is revealed by a resonance frequency shift resulting from an increase in the mass of the cantilever, which can be identified by measuring the modulated optical power at the output waveguide.

"There has been a recent push to design devices that

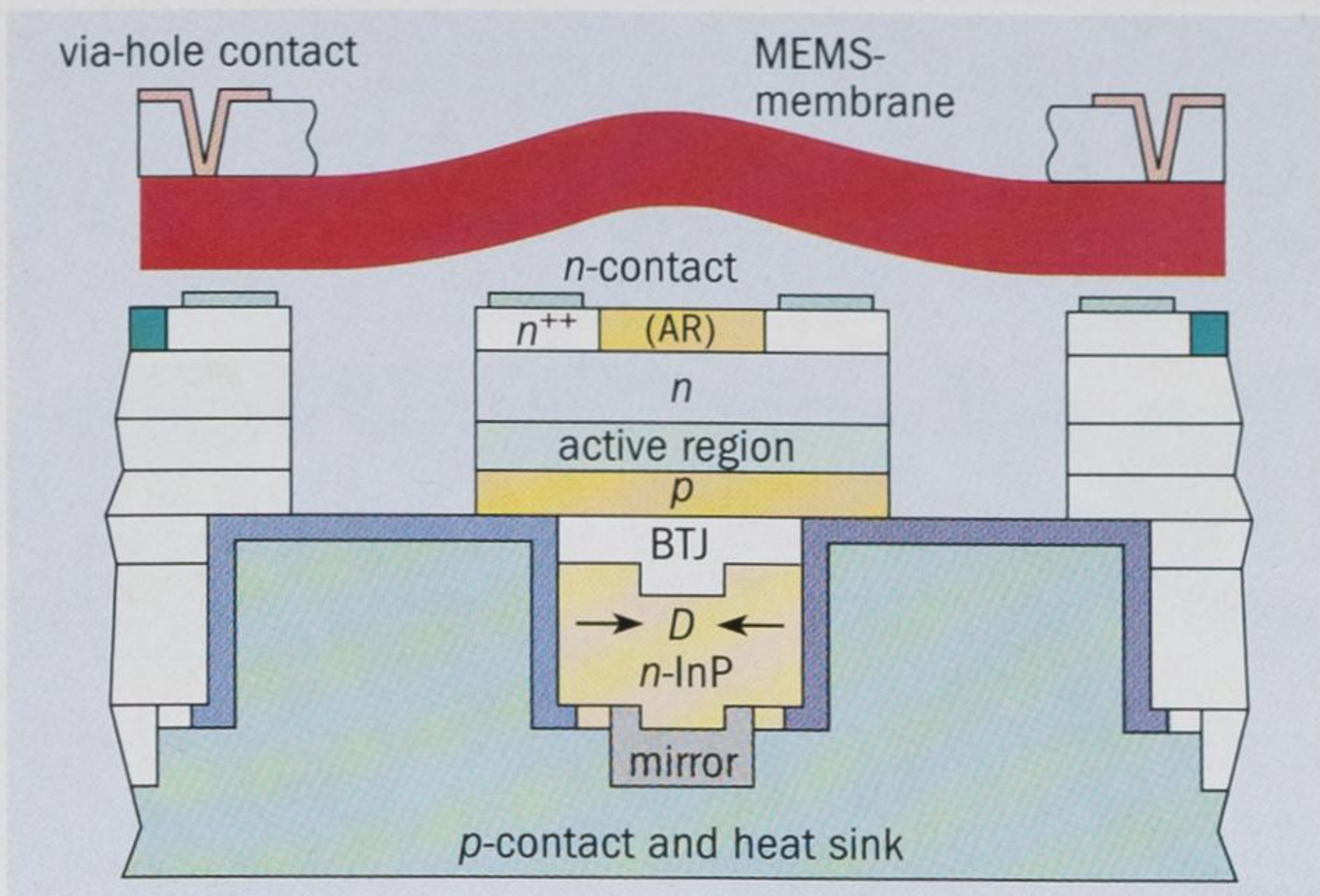


Fig. 3. The Walter Schottky Institute's tunable VCSELs can deliver an output of 1.7 mW. They are fabricated by bonding an active region grown on an InP substrate to a GaAs chip containing a distributed Bragg reflector mirror. The latest version also features an aluminum oxide anti-reflection (AR) layer, which has increased the tuning range from 43 to 60 nm. Tuning is achieved by injecting a current into the membrane through the via hole contacts, which causes thermal expansion of the material and changes the cavity's dimension. The laterally structured buried tunnel junction (BTJ) provides effective current confinement to the diameter (D).

can be placed in places such as airports to detect the presence of explosive material, bioagents, and other dangerous materials," remarked Ghodssi. According to him, various chemicals are known to react in a predictable way with these harmful substances, and the cantilever is coated with these reactive agents.

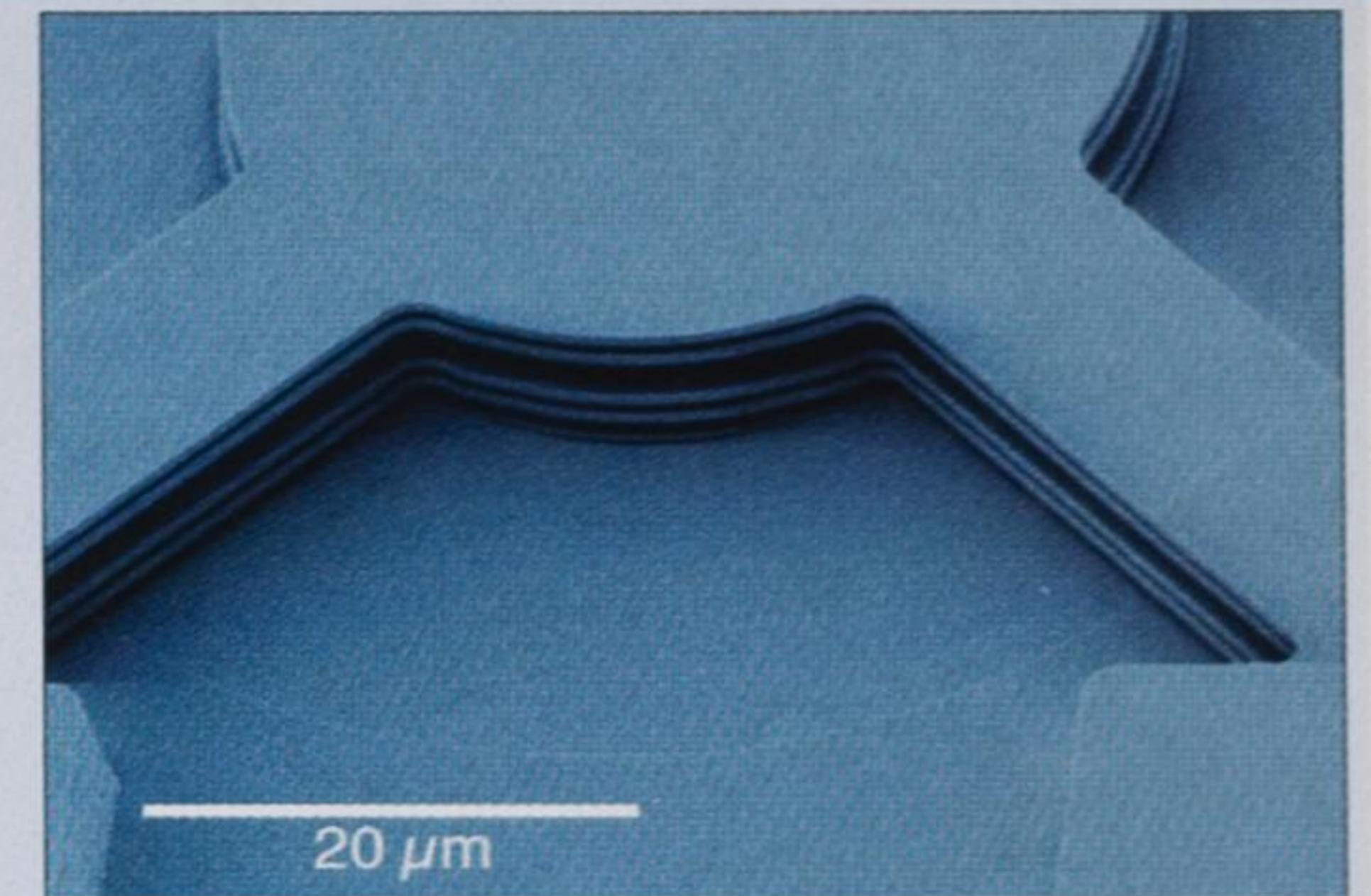
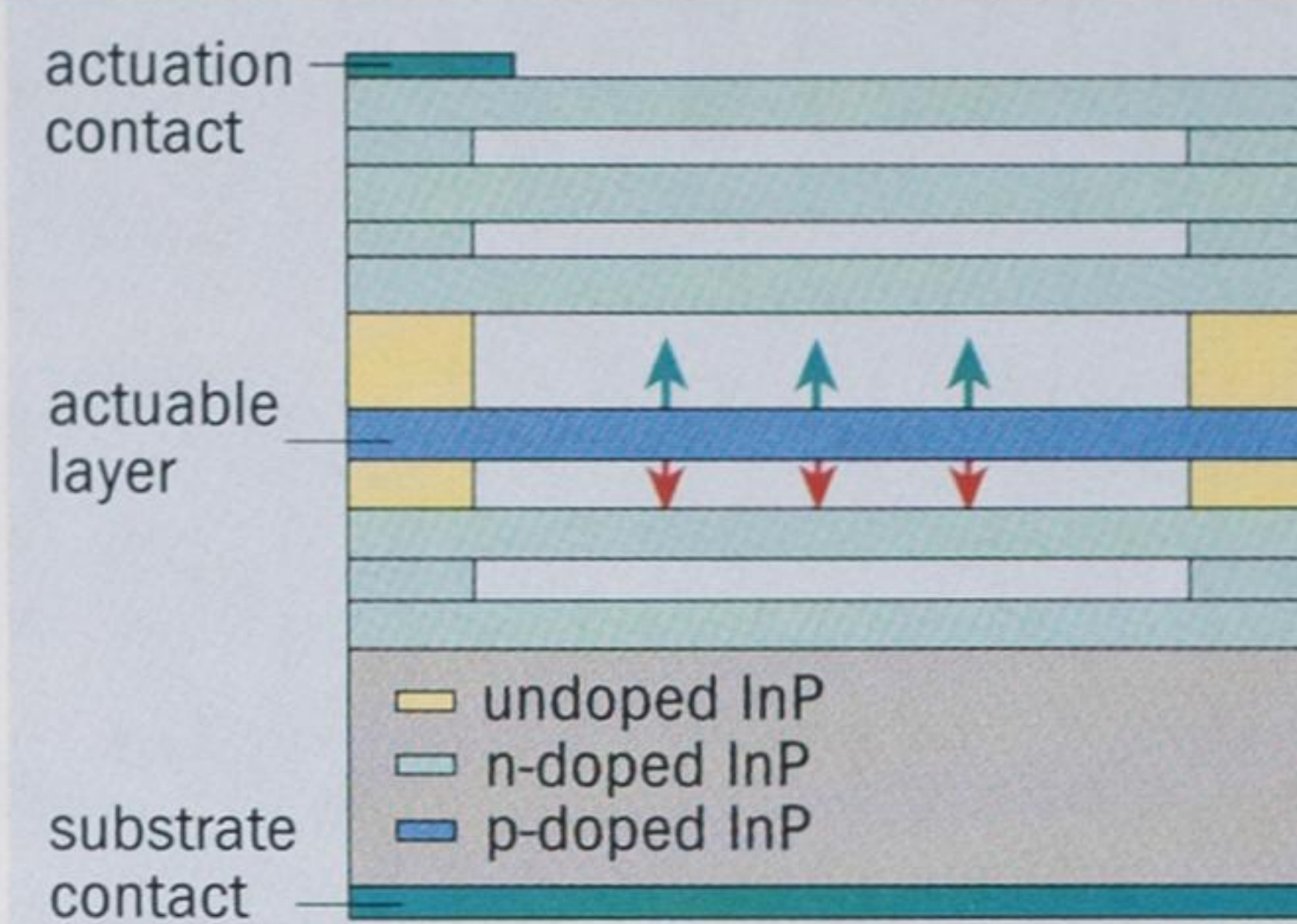
Tunable VCSEL progress

In Europe two companies, Switzerland-based Beam Express and Germany-based Vertilas, have recently developed InP MEMS tunable VCSELs that can be pumped electrically. These products are more mature than those made by the optically-pumped MEMS-tunable VCSEL company Coretek, which was bought by Nortel Networks in early 2000 for a staggering \$1.43 billion, and discarded two years later. Although the telecom market is not currently interested in buying these products, they offer an impressive collection of specifications. Unlike JDSU and Bookham's tunable edge-emitters that deliver a discrete set of wavelengths, these VCSELs offer wavelength tuning, highly efficient light coupling into a fiber and direct light modulation.

Markus-Christian Amann, chairman of the Semiconductor Technology Group at the Walter Schottky Institute in Garching, Germany, claims that the VCSELs, which have been developed in collaboration with Vertilas and the Technical University of Darmstadt, deliver the most advanced device performance in terms of tuning range and output power (see figure 3). "The VCSELs have a tuning range of up to 60 nm and operate at room temperature with single-mode performance," he said.

The VCSELs are still under development and have not been released for sampling. Although they are suitable for telecom applications, they can also play a role in gas sensing. The broad tuning range would allow a

LEOM's filters target sugar monitoring



The device shown on the left contains two back-to-back PIN junctions, enabling the actuated membrane layer to be displaced both upwards and downwards. Devices based on this design had a minimum linewidth ranging from 0.15 to 10 nm, depending on the number of membranes, and a typical tuning range of greater than 100 nm.

The latest tunable filters from the French government's optoelectronic, semiconductor and microsystems laboratory in Lyon are suitable for applications such as the detection of sugar levels in water (see above). The filters are constructed by growing an InP-InGaAs epitaxial structure by MOCVD, and then polishing the wafer's backside, fabricating ohmic contacts for actuation, vertically patterning the structure by reactive ion etching and selectively etching the InGaAs layers to produce suspended InP membranes.

mixture of gases to be monitored with just one MEMS VCSEL, says Amann, although he concedes that this may not be a cost-effective solution.

The French government's optoelectronic, semiconductor and microsystems laboratory (LEOM) in Lyon is also targeting non-telecoms applications. Senior scientist Michel Garrigues explained that the institute had previously worked on tunable VCSEL and filter development for telecom networks, but it is now developing tunable InP MEMS filters and detectors operating in the infrared region that could be used in spectrometers for chemical detection (see "LEOM's filters target sugar monitoring" box, above).

Garrigues explained that the laboratory has just started work on a project funded by the French National Research Agency that will aid the agricultural industry by developing an instrument containing tunable filters that can determine the sugar level in fruits or waste water. LEOM will be responsible for the design and micromachining process, the Alcatel-Thales III-V Lab will perform the epitaxy, SEM Datalink will construct the measurement system, and CEMAGREF, a public agricultural and environmental research institute, will build the analysis software and test the system.

The breadth of development of MEMS products, and the different markets that they serve, shows that these devices could feature in many of tomorrow's products. However, in many cases they are competing against rivals using alternative technologies, and it is this battleground that will determine the future revenue for the MEMS compound semiconductor industry. ●

"There has been a push towards devices that can detect explosives."

Engis

Optimized Surface Preparation

Higher levels of precision control are now achievable in the planarization, delayering and polishing of advanced materials and substrates for compound semiconductors, thanks to the new MPC surface preparation system from Engis-Microtech. Incorporated into the MPC's integral machine design is a 6-Sigma capability for material removal, flatness and surface finish generation. The menu-driven microprocessor controls enable operators to fully optimize any polishing, delayering or planarization



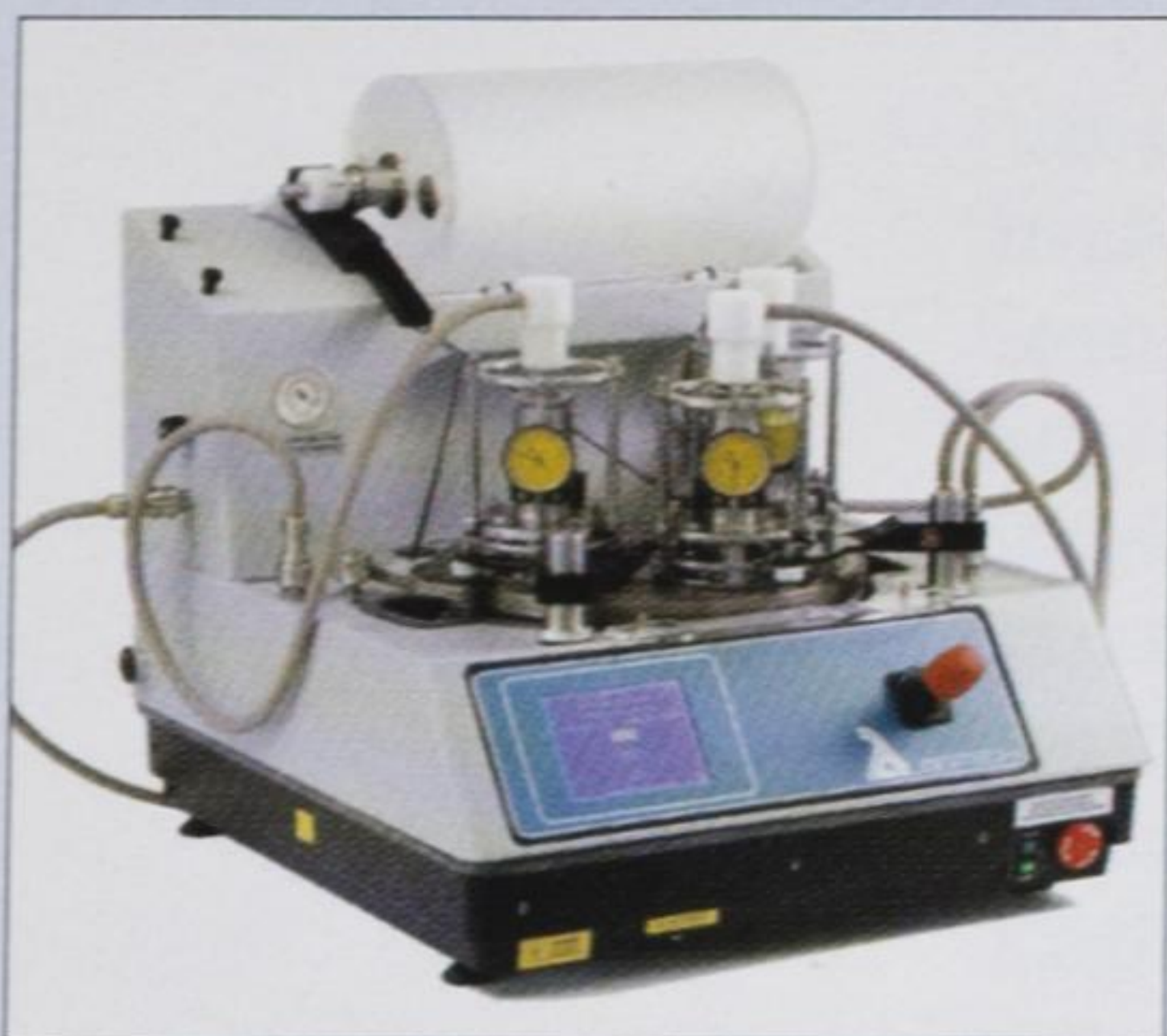
process. Plus, the MPC's oscillation system provides 3-axis motion for true CMP kinematics.

Contact: Engis Corporation,
105 W HINTZ Rd, Wheeling,
IL 60090 USA
Tel: +1 847 808 9400
Fax: +1 847 808 9430
E-mail: microtech@engis.com
Web: www.engismicrotech.com

Precision lap and polish systems

Logitech Limited

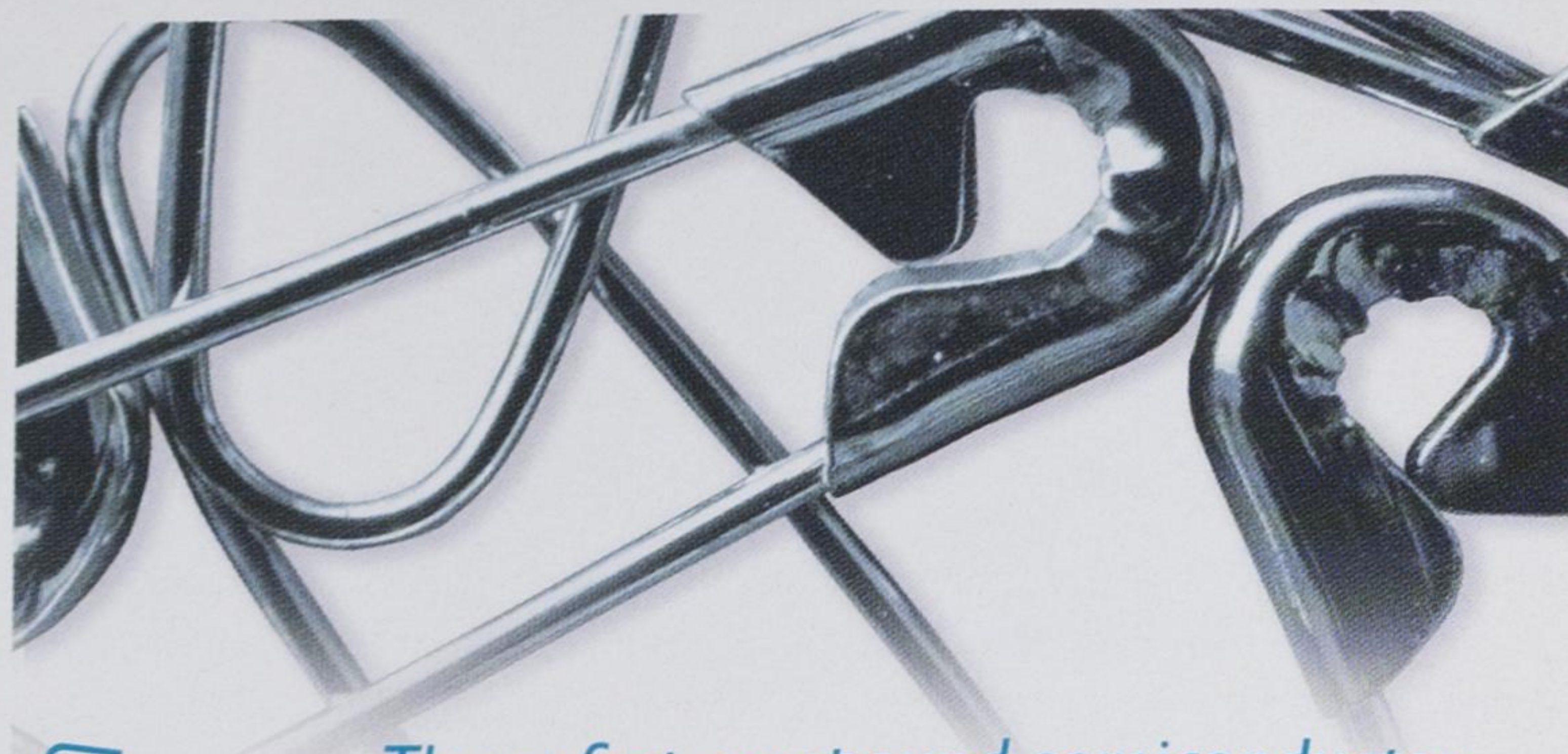
The PM5 and LP50 Precision Lap and Polish Systems from Logitech Ltd (Semicon Europa, booth A1-010) are ideal for processing wafers up to 6" in diameter or individual devices of III-V materials. Recently upgraded with new system controls, both the PM5 and LP50 offer automated plate flatness control to help ensure sample repeatability and a typical surface roughness of 3 nm. Standard results of ± 2 microns can be expected for final wafer



parallelism and thickness control. The new panel introduces an LCD menu system with joystick controls to help facilitate process set-up.

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

To advertise in the NEW classified section of *Compound Semiconductor*, contact **David Iddon** on tel: +44 117 930 1032, or e-mail: david.iddon@iop.org.



The safest compound semiconductor laser machining system in the world

Xsil's 300C Laser Dicing System

The 300C Laser Dicing System is the first system in the world specifically designed for compound semiconductor laser machining. Built on Xsil's production proven laser platform, the 300C can laser machine hazardous materials with precision and safety.

For more information please contact us on info@xsil.com

Now expanding: please check out www.xsil.com/careers

www.xsil.com



Headquarters: Dublin, Ireland

Offices in: USA, Japan, Taiwan & Singapore

Looking for further information on new products and jobs?

Why not visit compoundsemiconductor.net and view the Buyer's Guide too?

For more information go to
<http://compoundsemiconductor.net/buyers/>

COMPOUND IOP
SEMICONDUCTOR
Be part of your community

Modified photodiodes advance quantum communications

Princeton Lightwave has commercialized a single-photon avalanche photodiode that is targeting quantum cryptography applications. **Mark Itzler** describes some of the benefits offered by the device's design, and explains how it could provide uncrackable communications.

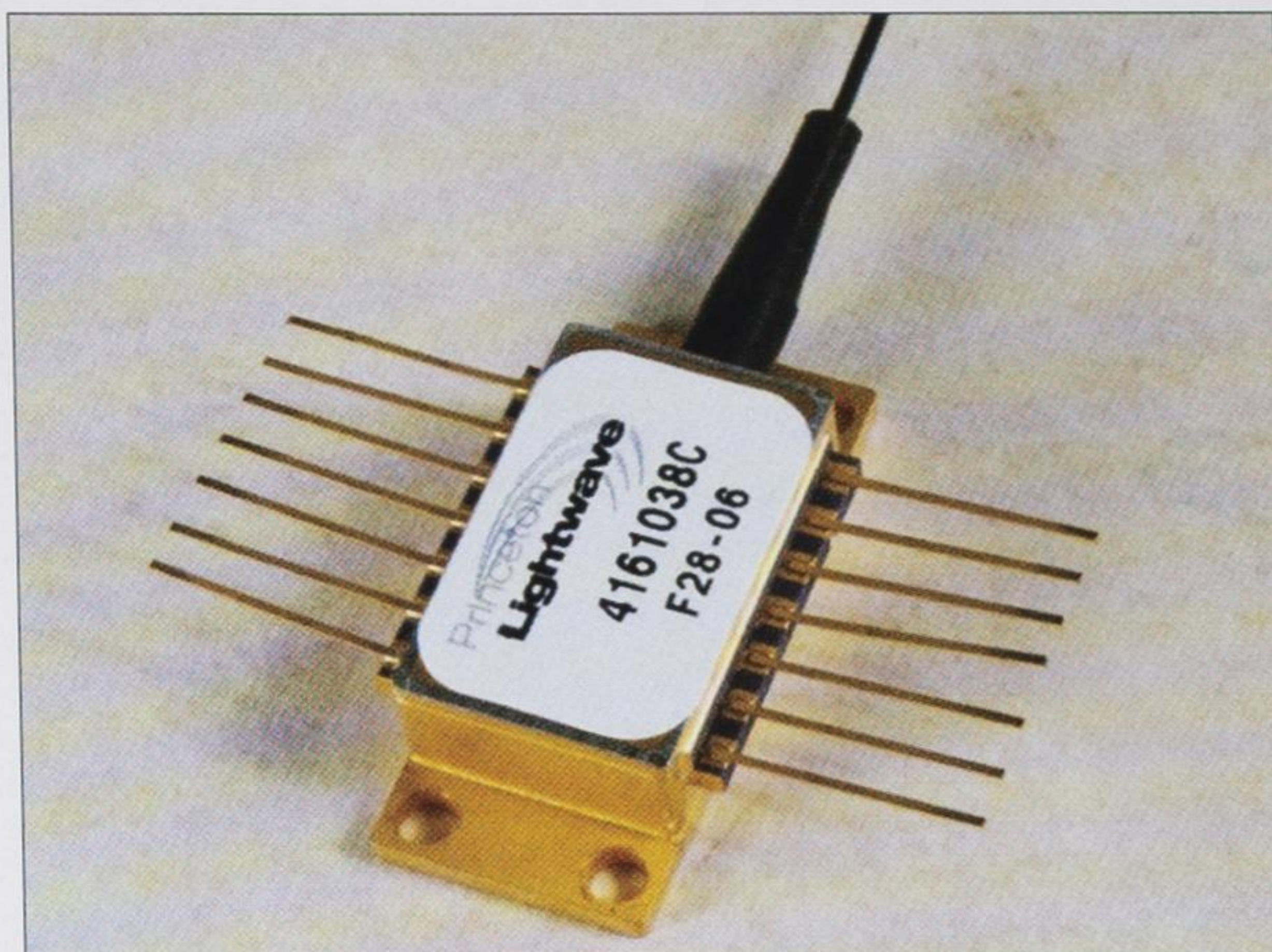
The advent of public network encryption has revolutionized secure information exchange. This modern method, based on algorithms, involves one party providing a public key that allows any other party to encrypt a message, but decryption can only be performed with a separate, private key held by the first party. This scheme does have a weakness, though, because it relies on computational complexity. Although breaking the key is exceedingly difficult today, this data encryption approach could be compromised in the foreseeable future through advances in computational power and the mathematics associated with code breaking.

However, the future for secure communication is not under threat because a truly unbreakable digital data encryption method also exists, which has been developed over the last 20 years and exploits the quantum mechanical properties of photons (see "Quantum key distribution systems" box, p28). Recently, commercial point-to-point secure links using quantum key distribution (QKD)-based encryption techniques have been launched by a handful of start-up companies, including idQuantique in Switzerland and MagiQ Technologies in the US. In addition, several large Japanese corporations, including Mitsubishi, NEC and Toshiba, have product-oriented programs for QKD system development.

These QKD systems are similar to traditional optical communications systems, and contain optical sources and detectors. However, QKD systems require single-photon transmission and detection, and the transmission of single photons currently limits QKD implementation to single-span point-to-point links, because single-photon repeaters that faithfully maintain the photon's quantum mechanical properties are not available.

Single-photon detectors

Another obstacle that restricts the performance of current QKD links is the lack of available high-quality single-photon detectors. To meet this need, at Princeton Lightwave we have recently developed the first commercially available InGaAs/InP-based single-photon avalanche diode (SPAD), which is also used in our single-photon benchtop receiver and incorporates the



Princeton Lightwave's single-photon avalanche diode-based receivers have to combine a high level of performance with accommodation for the optical, thermal and electrical interfaces. To provide high coupling efficiency with single-mode fiber, the design aligns fiber with sub-micron precision to small active-area devices that are thermoelectrically cooled and housed in a standard 14 pin butterfly-type package.

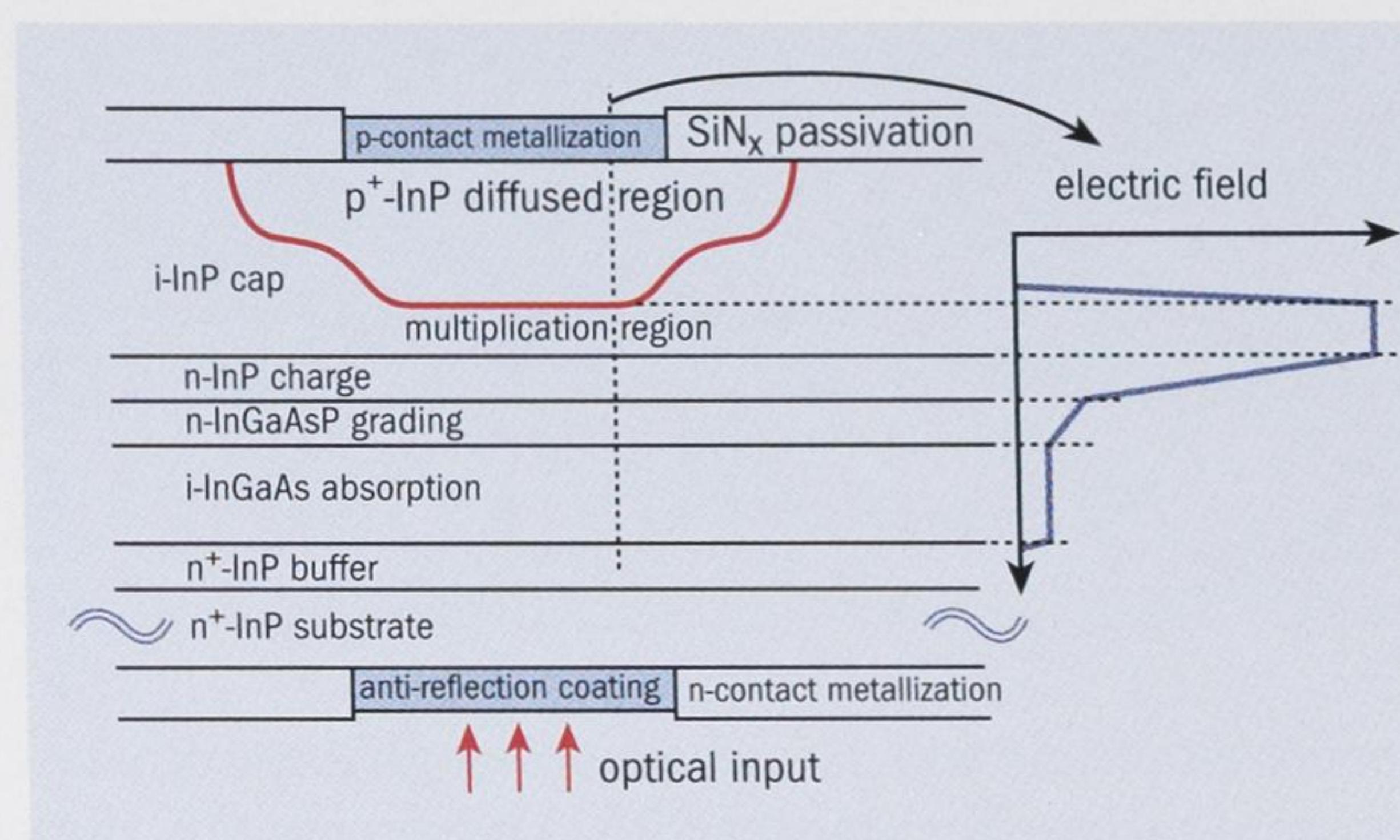


Fig. 1. Princeton Lightwave's single-photon avalanche diodes, like linear-mode avalanche photodiodes, use a doped charge layer to maintain a high field, which generates the avalanche gain in the multiplication region while keeping a sufficiently low field in the absorption region to minimize field-induced leakage currents.

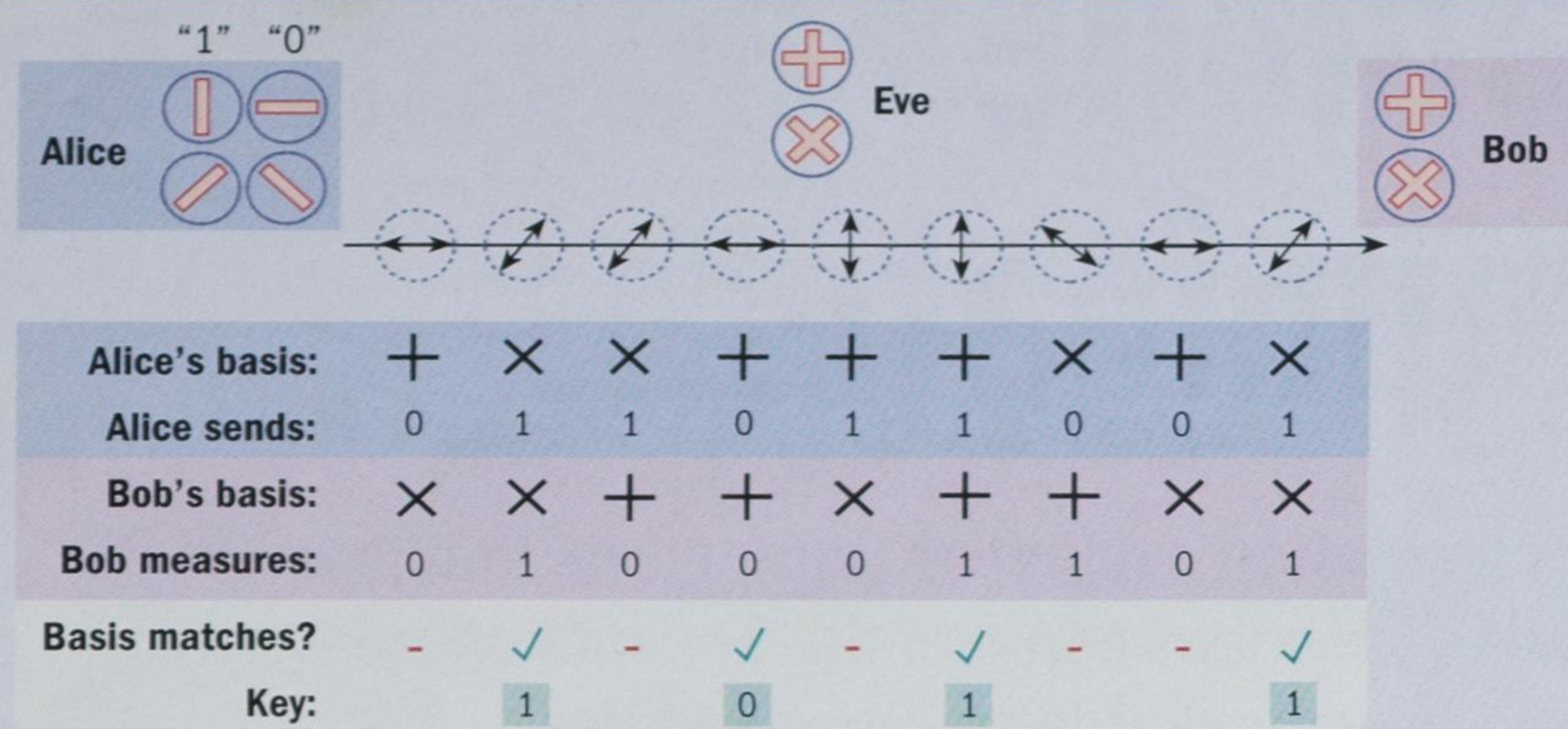
necessary electronic control circuitry.

Our detector outperforms photomultiplier tubes for QKD applications because these devices have a single-photon detection efficiency of only around 1%. It is also more suitable for QKD than the commercial linear-mode avalanche photodiodes (APDs) that detect between 0.3 and 1.6 μm and are used as SPADs by many of today's photon-counting practitioners.

These APDs can deliver single-photon counting performance when biased above the breakdown voltage, V_{br} , because a single photoexcited carrier can induce a runaway avalanche that leads to an easily detectable

"We have developed the first commercial InGaAs/InP SPADs."

Quantum key distribution systems



In quantum key distribution systems each data bit is represented by a single photon assigned a value using a quantum mechanical variable such as polarization. In the example above, this allows Alice and Bob to communicate by choosing a particular value for the polarization of each bit, using values taken from one of two randomly chosen quantum mechanical “bases”, represented by horizontal/vertical polarizations and $+45^\circ/-45^\circ$ polarizations. In each basis, one polarization direction corresponds to a digital “1” and the other to a “0”.

Alice, the sender, prepares a photon with the correct polarization for her first bit value (1 or 0). If Bob’s randomly chosen basis matches Alice’s, he measures the correct bit value. However, if he chooses the wrong basis, quantum mechanics dictates that there is a 50% chance he will measure the intended bit value and a 50% chance he measures the wrong value. After receiving all the information, Bob informs Alice via an insecure channel which basis he has used to measure each photon. Alice responds by telling Bob for which bits his basis choice was correct, and these bits are used as the encryption key.

This method is absolutely secure because it is impossible for an eavesdropper, known as the nefarious Eve to cryptographers everywhere, to intercept the key. To try and break the code she has to randomly choose a polarization basis for each photon measurement, just as Bob does, but even if she monitors Alice and Bob’s public discussion concerning their choices of basis, her random basis choices differ from Bob’s.

Eve’s situation is further disadvantaged because she can not intercept photons during the key distribution process without being detected. Even if she attempts to replace intercepted single photons, her incorrect polarization bases will mean that her replacement photons are not equivalent to Alice’s. Eve’s meddling is exposed when Alice and Bob check the validity of their transmitted key through error checking procedures, and the corrupted key is discarded.

macroscopic current. However, although these devices occasionally offer a good SPAD performance, they usually behave rather poorly because they are not designed for this application. They also have tremendous performance variations when used as SPADs, such as dark count rates (DCRs) that differ by several orders of magnitude.

APD design similarities...

Our SPADs share many device design elements with linear-mode APDs (see figure 1). For example, they incorporate an $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ layer that provides an acceptable absorption up to $1.65\ \mu\text{m}$ at room temperature and a wider bandgap InP multiplication region, because it is not possible to deliver high-field avalanche gain in InGaAs without also generating large leakage currents. Inserted between these is an InP field control layer, which enables the device to maintain high and low fields in the multiplication and absorp-

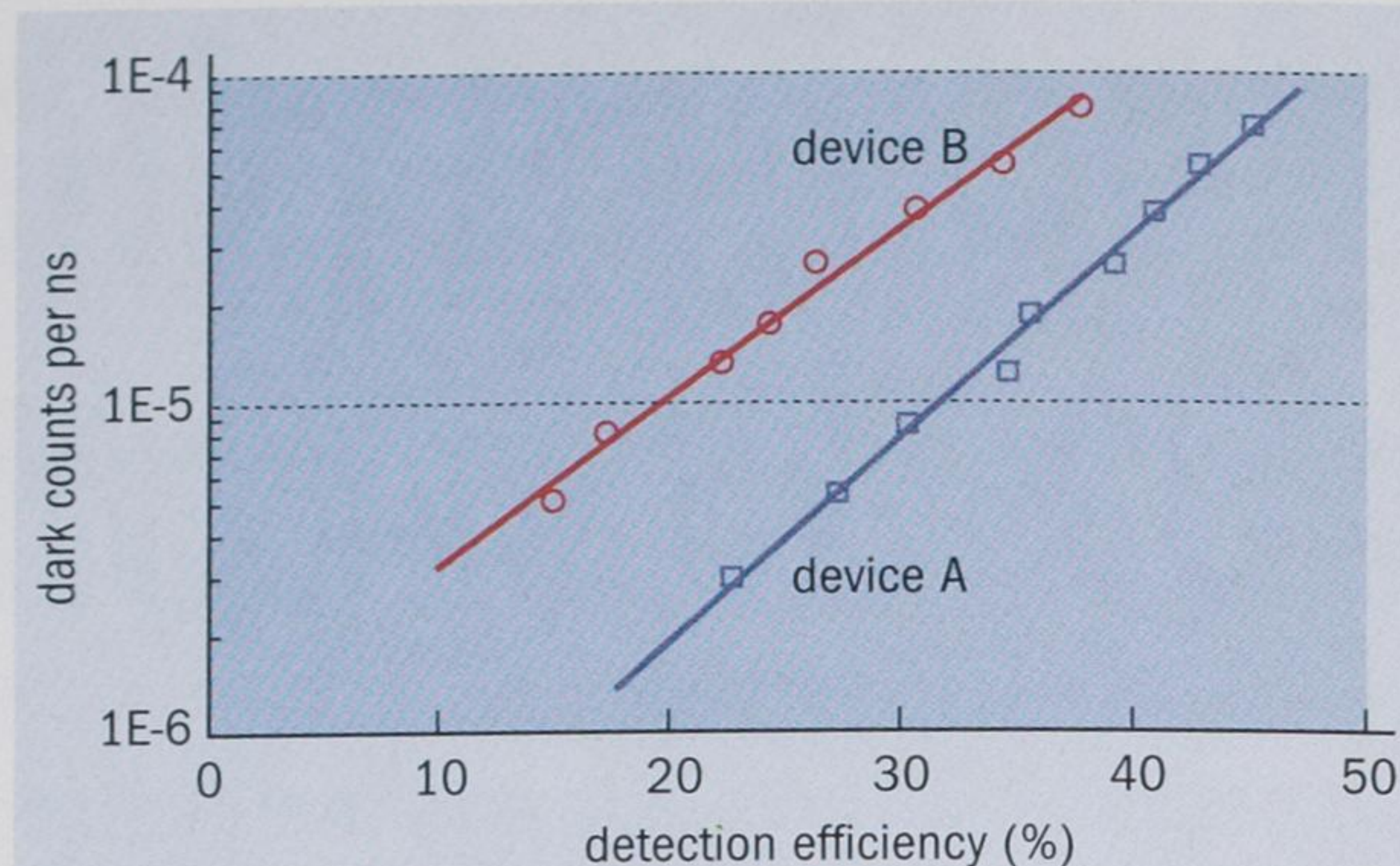


Fig. 2. Two of Princeton Lightwave’s devices that have a $25\ \mu\text{m}$ diameter active area show the expected trade-off between dark count rate (DCR) and detection efficiency. Device A has a lower DCR at a given single-photon detection efficiency than device B, but at the expense of higher timing jitter. For device A, a lower electric field in the absorption region leads to a lower DCR value due to reduced tunneling, but this also adversely impacts the carrier dynamics, which leads to a higher timing jitter. Both devices were operated at 200 K with active quenching and a 10 kHz gate repetition rate.

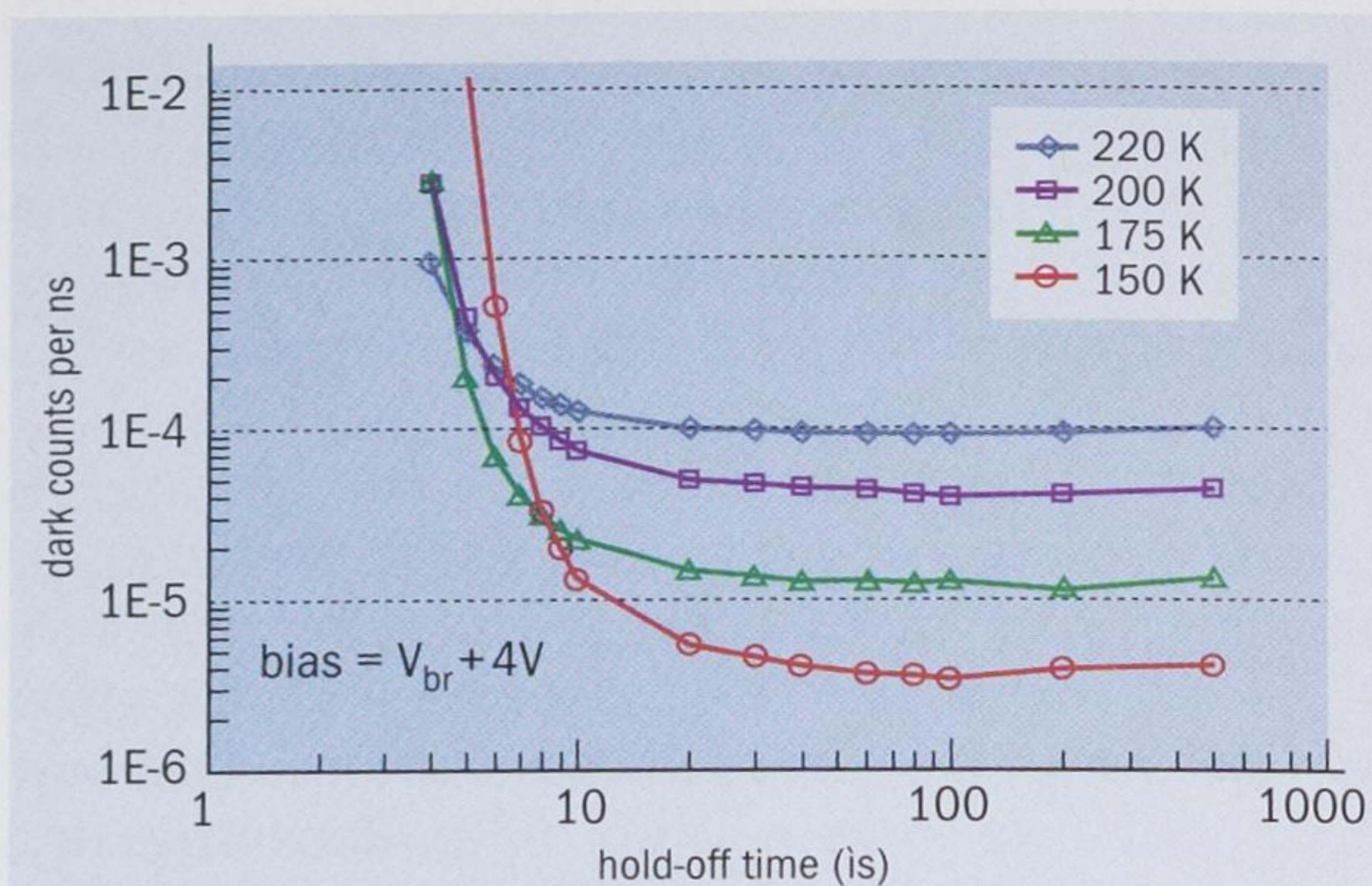


Fig. 3. The dark count rates of Princeton Lightwave’s $40\ \mu\text{m}$ diameter SPADs illustrate the adverse effects of short hold-off times that lead to afterpulsing effects. These devices were operated with 20 ns gate time, gated quenching and an operating bias 4 V above the breakdown voltage.

tion regions, respectively. Since a direct InGaAs/InP interface can trap carriers, a grading layer is added to smooth this interface.

...and differences

Despite the structural similarities, SPADs and linear-mode APDs do differ significantly. APDs require thin multiplication regions to reduce linear-mode APD noise and produce a more deterministic linear-mode avalanche process, while SPADs benefit from thicker multiplication regions that increase the probability of generating self-sustaining avalanches. SPAD designs must also be compatible with -60°C or lower operating temperatures, which reduce the dark count rate. Lastly, the design has to reflect the device’s detection process – linear-mode APDs are used as analog devices, but SPADs trigger a digital threshold circuit.

For linear-mode APDs the quantum efficiency is determined by the proportion of the photons that are

absorbed and then create photoexcited carriers. For SPADs, though, the carriers must also induce a detectable runaway avalanche, and it is the product of the probabilities of these two processes that determines the single-photon detection efficiency (SPDE).

The SPAD performance can be degraded by “dark counts” caused by processes other than photoexcitation, such as thermal excitation and the field-mediated creation of free carriers. To minimize these effects the devices are usually operated in gated mode. The detector is biased just below V_{br} , and a gate pulse is then applied to bring the detector bias above breakdown for typically 1–100 ns. After the avalanche is initiated and detected, it is quenched to allow the SPAD to be reset to its armed state with another gate pulse.

Effective QKD systems also demand minimal variation in the time taken for photon detection. The main contribution to the timing jitter for single-photon detection is a fluctuation in the way a runaway avalanche spreads laterally across the active area of a SPAD, but this variation can be reduced by using a higher bias voltage. SPADs also suffer from an afterpulsing effect that occurs when carriers created during an avalanche are trapped by defects in the multiplication region, and freed later through processes such as thermal emission, which contribute to the dark count. However, this unwanted effect can be compensated for by increasing the “hold-off” time before the next gate.

Working devices

The SPADs we have fabricated at Princeton Lightwave show that there is a trade-off between two important parameters, the SPDE and the DCR (see figure 2). While the SPDE improves linearly with increasing bias above V_{br} , the DCR also increases exponentially with increasing bias. The DCR can be reduced by cooling the device, but the required hold-off time increases (see figure 3).

At the system level this means that faster repetition rates are only possible at higher DCR. However, this is not a current concern for QKD systems as many of today’s secure point-to-point links use manual key distribution with timeframes of weeks or even months between key updates, while commercial QKD systems already provide new encryption keys with absolute security in just a fraction of a second.

We expect QKD deployment to continue to grow as the relevant component technologies mature, with SPADs playing a key role in improving system performance. We will focus on device performance improvements that raise the SPDE and lower the DCR because we believe that the QKD link reach is currently limited by SPAD’s DCR performance and that the single-photon transmission rate is restricted by the SPDE. ●

● Thanks to Radu Ispasoiu and Sergio Cova for device characterization and insightful discussions.



About the author

Mark Itzler is chief technical officer at Princeton Lightwave. He previously held the equivalent role at the EPITAXX division of JDS Uniphase.



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

If you would like to advertise in future issues, contact **David Iddon** (tel: +44 117 930 1032, fax: +44 117 920 0977, e-mail: david.iddon@iop.org).

Company name	Web address	Telephone number	Contact	GaN or SiC epiwafers for electronic devices	SiGe and Si epiwafers	Substrate preparation and polishing	Abrasives and chemicals	Characterization test and measurement
Accent Optical Technologies	accentopto.com	+44 1904 715 500	Dale Page					
Bandwidth Semiconductor LLC	bandwidthsemi.com	+1 603 689 1226	Edward D Gagnon					
CrySTec GmbH	crystec.de	+49 30 6566 09 66	Knut Peters					
Dow Corning	dowcorning.com	+1 989 496 6000	Cindy Esler					
EpiNova GmbH	epinova.de	+49 761 5569 7160	Sigrid Walker					
Innovative Organics	innovativeorganics.com	+1 714 701 3900	James Millar					
INTRINSIC Semiconductor	intrinsicsemi.com	+1 703 437 4000	Katya Tsvetkov					
IQE/Wafer Technology	iqep.com	+44 29 2083 9400	Kara Skinner					
Lake Shore Cryotronics, Inc	lakeshore.com	+1 614 891 2244	Shane Hritz					
NL Nanosemiconductor	nanosemiconductor.com	+49 231 47730 211	Guido Vogel					
Picogiga International SAS	picogiga.com	+33 1 69 31 61 30	Jean-Luc Ledys					
POWDEC	powdec.co.jp	+81 467 84 6080	Hiroji Kawai					
Rubicon Technology Inc	rubicon-es2.com	+1 847 295 7000	Gerhard Hoog					

INTRINSIC
SEMICONDUCTOR

Rubicon Technology
Evolving Science. Evolving Solutions.™



SAINT-GOBAIN
GRAINS & POWDERS
SURFACE CONDITIONING GROUP

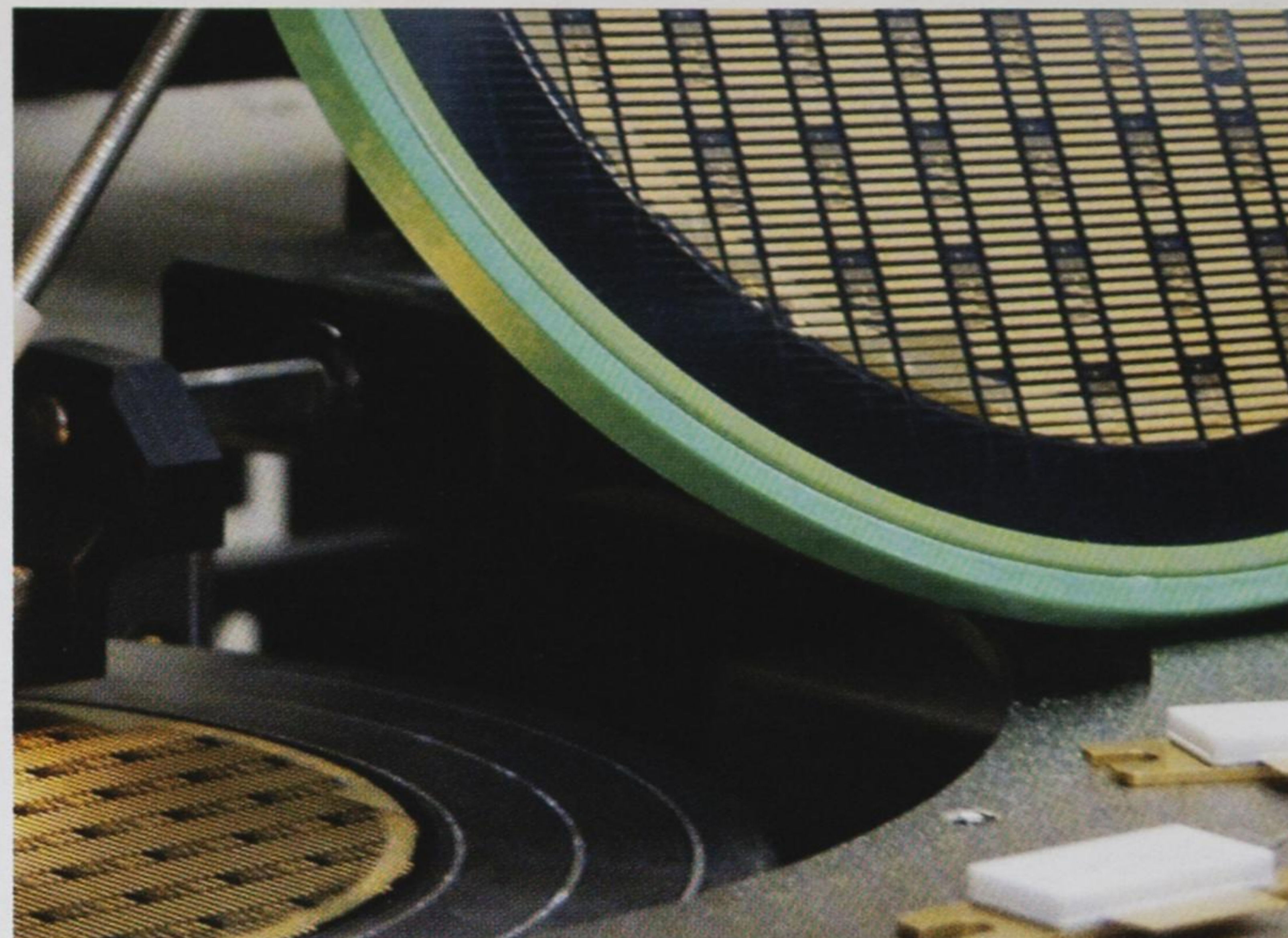
BANDWIDTH
SEMICONDUCTOR
EPITAXY & FOUNDRY SERVICES

Picogiga
A Soltec Group Company International

EPINOVA

III-V EPITAXIAL SOLUTIONS

nano
semiconductor



Technologytracking
Competitive intelligence on emerging technologies

Emerging Markets for GaN Electronics

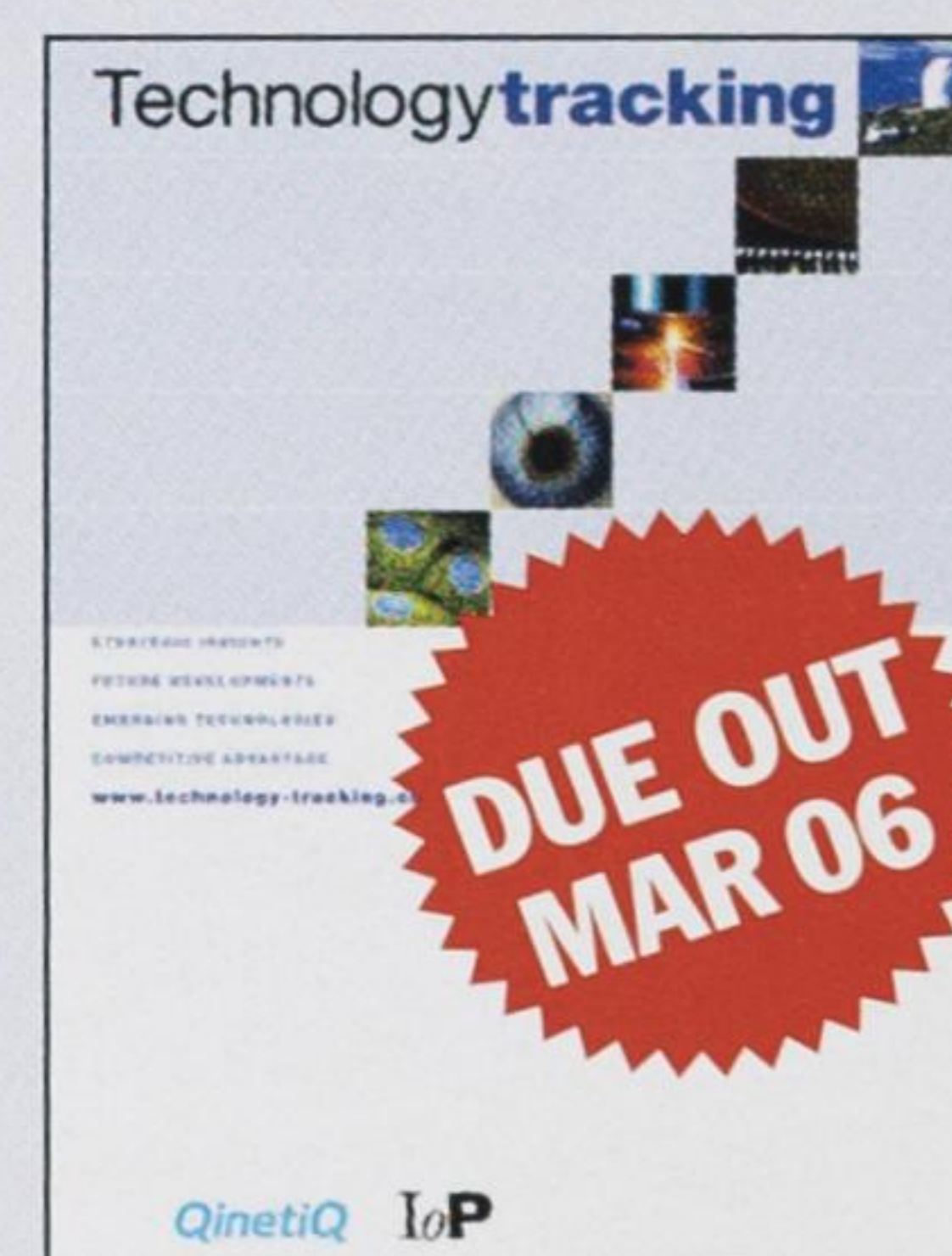
Electronic devices based on gallium nitride promise to deliver unrivalled power and thermal performance for RF applications, but widespread adoption of the technology depends on whether manufacturers can produce high-performance devices at low cost.

This new Technology Tracking report, from the publishers of *Compound Semiconductor*, analyses the challenges facing GaN device makers as they seek to develop commercial products that can compete effectively with existing RF technologies.

The report includes critical information in each of the following areas:

- Addressable markets
- Material choices
- Key metrics
- Reliability
- Market evolution
- Organizations

For more information, see
www.technology-tracking.com



Email: techtracking@iop.org
Tel: +44 (0)117 930 1034
Fax: +44 (0)117 930 1178



GaN SUBSTRATES

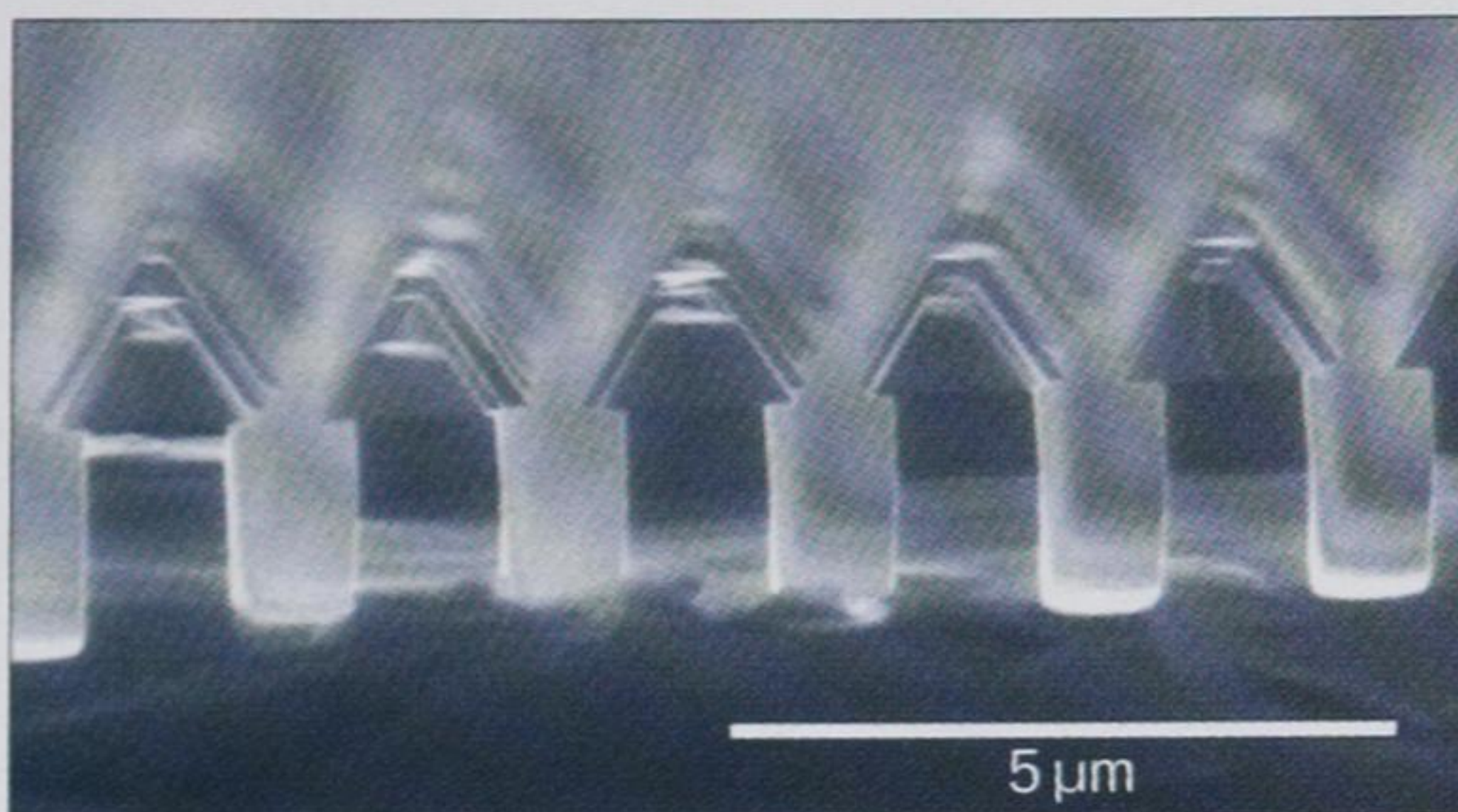
Patterned wafers cut dislocation density

Researchers from Japan's Toyota Central R&D Lab have produced the lowest threading dislocation density GaN-on-silicon (111) films from an uninterrupted process.

The dislocation density, which is substantially lower than that obtained with other uninterrupted processes involving inserting additional layers, doping with silicon, or using an *in situ* mask, should help to improve GaN-on-silicon optoelectronic and power electronic device performance and reliability.

The team produced the low dislocation density films by placing the substrate into an MOCVD reactor and using reactive ion etching to define a 1 μm wide stripe pattern into the silicon. This was followed by depositing a 20 nm thick AlN buffer layer at 750 °C, GaN growth along the facets at a higher, unspecified temperature, and then further GaN growth to form a flat layer at 1030 °C (see figure).

TEM images of the 1.3 μm thick GaN epi-



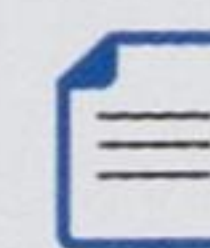
The Japanese team from the Toyota Central R&D labs produce GaN-on-silicon films with an uninterrupted process that involves etching 1 μm wide stripes into the silicon substrates, before depositing GaN by MOCVD. This scanning electron microscopy image shows the patterned substrate after 9 min of GaN growth at 1030 °C.

layer showed that the defects were mainly pure screw type dislocations and/or mixed type dislocations, and that the threading dislocation density was $1.0 \times 10^8 \text{ cm}^{-2}$. AFM measurements

suggested that the threading dislocation density is slightly higher, at $1.7 \times 10^8 \text{ cm}^{-2}$, and that the surface has "arranged steps" 0.31 nm high.

The team's GaN dislocation density is lower than that produced by similar techniques, but it is comparable to two-step processes that can also deliver densities of 10^8 cm^{-2} . However, the Toyota researchers argue that their process is simpler and avoids the impurities associated with the two-step process, in which a GaN template is grown on a planar, unmasked substrate, followed by *ex situ* deposition of a dielectric mask and re-growth.

Toyota's Tsutomu Uesugi told *Compound Semiconductor* that the team is still to fabricate devices using the GaN-on-silicon wafers, but he expects that their substrates will produce good device characteristics.



Journal reference

X Chen et al. 2006 *Appl. Phys. Lett.* **88** 031916.

QUANTUM CASCADE LASERS

Record terahertz output from QCL powers up astrophysics research

Users of heterodyne receivers are set to benefit from the record output power of quantum cascade lasers (QCLs) built by Massachusetts Institute of Technology (MIT) and Sandia National Laboratory.

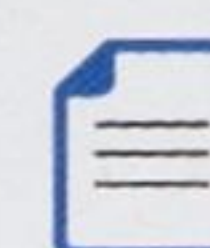
The US team's laser is both more powerful and smaller than the conventional sources

used for the local oscillators of heterodyne receivers, harmonic multipliers and molecular gas lasers. It could improve the performance of these receivers, which are used by astronomers to detect molecular, atomic and ionic lines in the interstellar dust.

The research team's MBE-grown AlGaAs/GaAs laser was 198 μm wide, 1.21 mm long, emitted at 4.4 THz, and produced a peak power of 248 mW in pulsed mode at 5 K. When operated in continuous-wave mode, the device produced up to 138 mW and lased at temperatures of up to 35 K.

The MIT-Sandia team is now focusing on increasing the operating temperature of its

QCLs. "The primary reason for the performance roll-off with temperature is the thermal activation of nonradiative scattering mechanisms that reduce the population inversion," explained Benjamin Williams from MIT, who added that this issue was best addressed by using quantum-well designs that are less sensitive to these effects. He also pointed out that many of the team's lasers can already operate well above liquid-nitrogen temperature, which makes them suitable for use outside of the lab environment.



Journal reference

B S Williams et al. 2006 *Electron. Lett.* **42** 89.

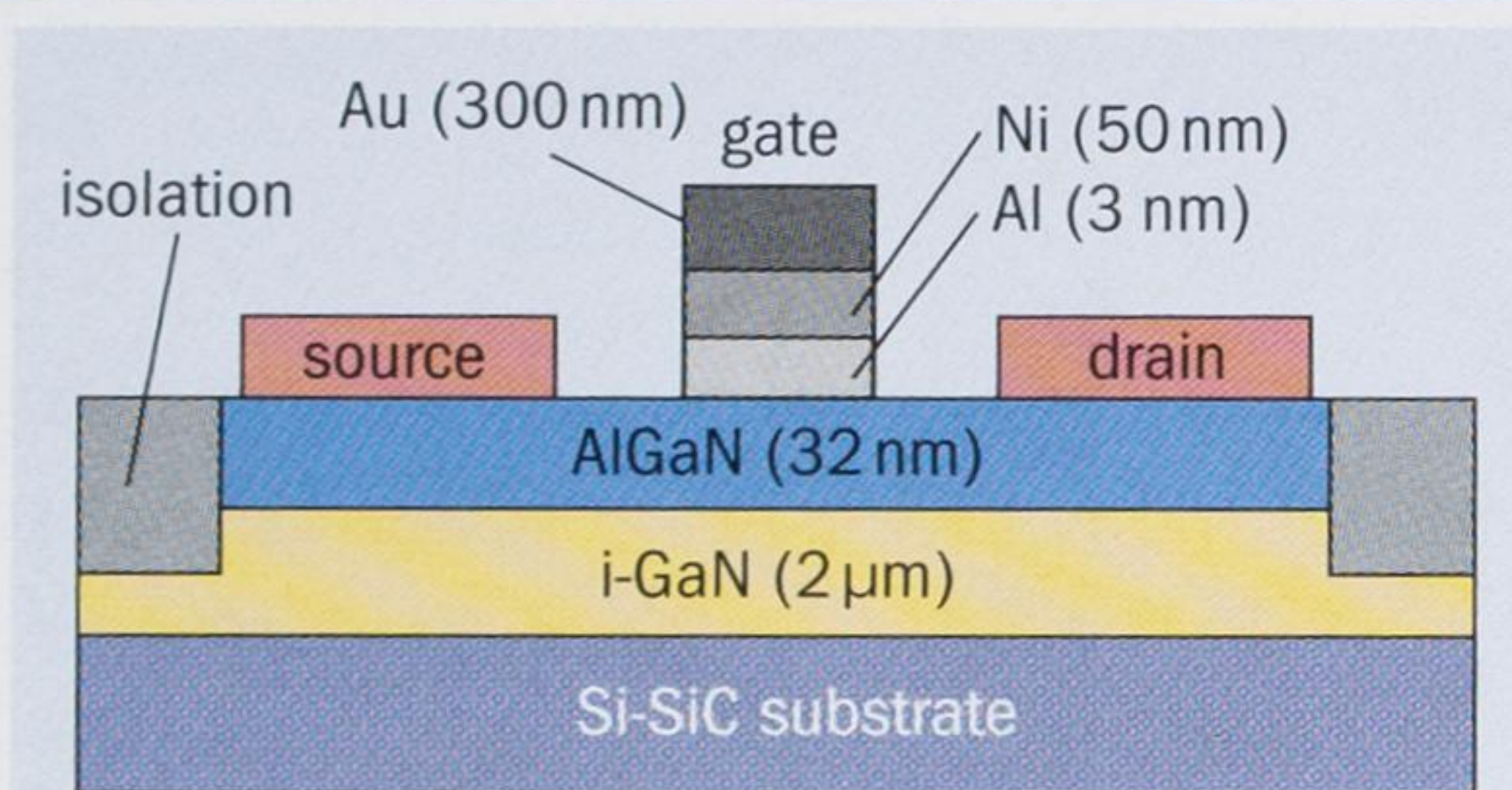
GaN MICROELECTRONICS

AlN interlayer boosts HEMT performance

Researchers at Mitsubishi Electric Corporation in Japan have fabricated GaN HEMTs that feature an additional aluminum layer and are claimed to deliver significant improvements in capacitance-voltage characteristics and a drastic reduction in gate leakage current.

The team says that the improvements could aid GaN HEMT development for high-power and high-frequency applications, because today's devices suffer from high gate leakage currents that deteriorate the low-frequency noise performance and breakdown voltage.

The HEMTs, which feature a 3 nm thick aluminum layer that is inserted between the



Mitsubishi researchers say that the addition of a 3 nm thick aluminum layer has dramatically improved the HEMT's capacitance-gate voltage characteristics and drastically reduced its gate leakage current.

AlGaAs barrier layer and gate contact (see figure), are said to show hardly any increase in capacitance until they are operated at frequencies as low as 1 kHz. The Japanese team believes that this characteristic indicates that

the insertion of the aluminum layer reduces the oxygen-related trap density.

The transistors also produced leakage currents at a -10 V gate bias of less than 0.01 mA/cm^2 , which is four orders of magnitude below the currents produced by equivalent devices built without the aluminum layer.

Mitsubishi's devices were grown by MOCVD on SiC substrates, with device isolation performed by Zn^+ implantation, and the 3 nm thick aluminum layer added by electron beam evaporation.

Researcher Takuma Nanjo says that the Mitsubishi team is still to investigate the lifetime of its devices, but he expects that the transistors will benefit from the reduction in oxygen traps and gate current leakage.



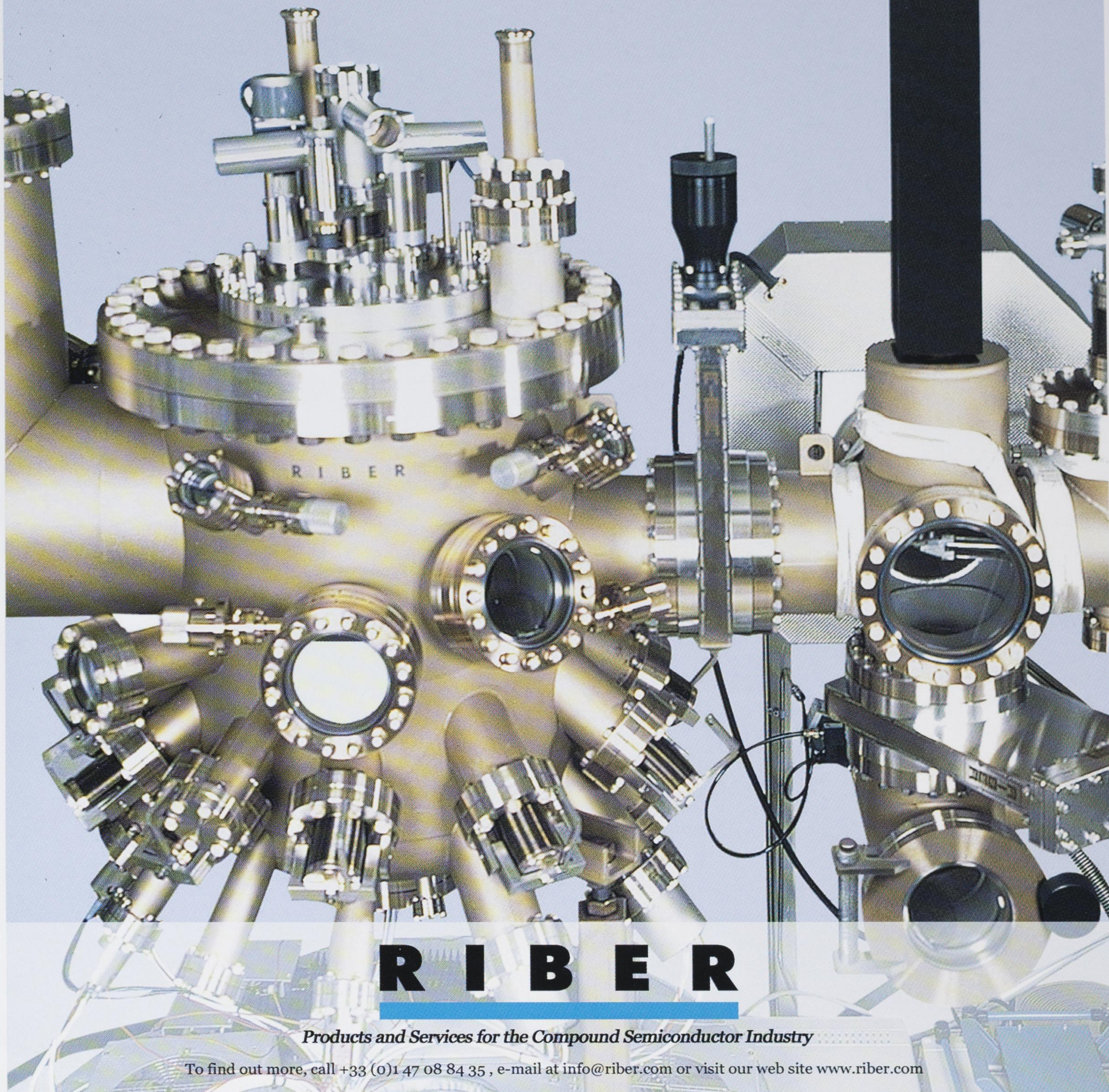
Journal reference

T Nanjo et al. 2006 *Appl. Phys. Lett.* **88** 043503.

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



Photo of Veeco Silicon-Style Cluster Tool.

Advance your MBE research and production—even while you sleep



The new Veeco GEN20: application specific designs, optional unattended operation.

For research and pilot-production, there's no better system than the Veeco GEN20. Incorporating industry-leading attributes from the GEN II and the GEN200, this all-new model, in a proven platform, manufactures wafers up to 4" with multi-chamber processing capabilities. It seamlessly integrates application-specific design features for both existing and emerging materials, including nitrides and oxides. Available either in automated cluster tool or manual models, the GEN20 is the best fit for you, providing flexibility to meet a wide range of budgets. For more information, visit www.veeco.com/gen20 or call 1.888.24.VEECO.

Compound Semiconductor Solutions

MBE, MOCVD, PVD, IBE
AFM and Optical Metrology
Process Integration Center

Solutions for a nanoscale world.™

Veeco