

COMPOUND SEMICONDUCTOR

Three-Fives and Silicon Heterostructures

November 2003 Volume 9 Number 10



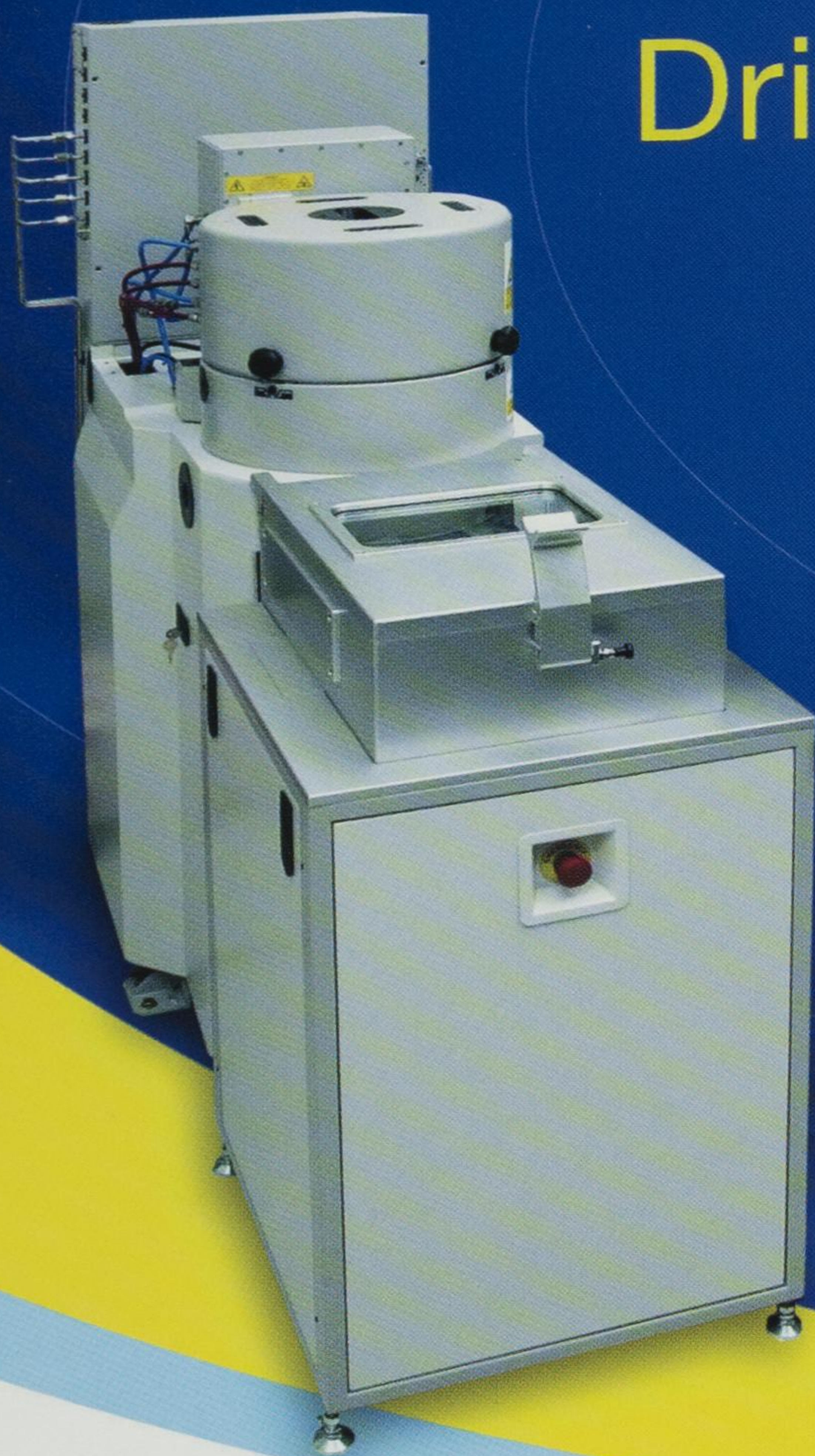
CONVERGENCE WITH SILICON
**Compounds industry adopts
silicon business concepts**

ALSO INSIDE

**Veeco bags Emcore
MOCVD business**

**III-V science tackles
 SiO_2 gate challenge**

**Solar cells: getting
back down to Earth**



Driving down the cost per die

Seeing is believing

MEMS Photonics Wireless

Advanced Packaging Data Storage

Delivering leading-edge process technology to our customers and driving down the cost-per-die of dry plasma processes has been the impetus behind the development of the new 'Pro' generation of equipment platforms from STS.

Key Features:

- Exceptional Process Capability
- Enhanced Reliability
- Reduced Maintenance
- Smaller Footprint
- Lower Cost of Ownership
- Faster Installation
- Remote Operation and Diagnostics
- Improved User Interface and Functionality
- Direct Manual Control
- Improved job scheduling

Completely re-engineered and re-packaged with the latest generation of SCADA/PLC control systems, the 'Pro' platforms provide uncompromising performance and exceptional reliability.

The Pro range is available in the following platform options:

- Multiplex^{Pro} - Single process chamber with carousel loadlock
- MACS^{Pro} - Single process chamber with atmospheric cassette handling system
- ASPECT^{Pro} - Production cluster platform configured with up to 2 vacuum cassette handlers and 4 process modules

www.stsystems.com

• MEMS • Photonics • Wireless • Advanced Packaging • Data Storage

Surface Technology Systems plc



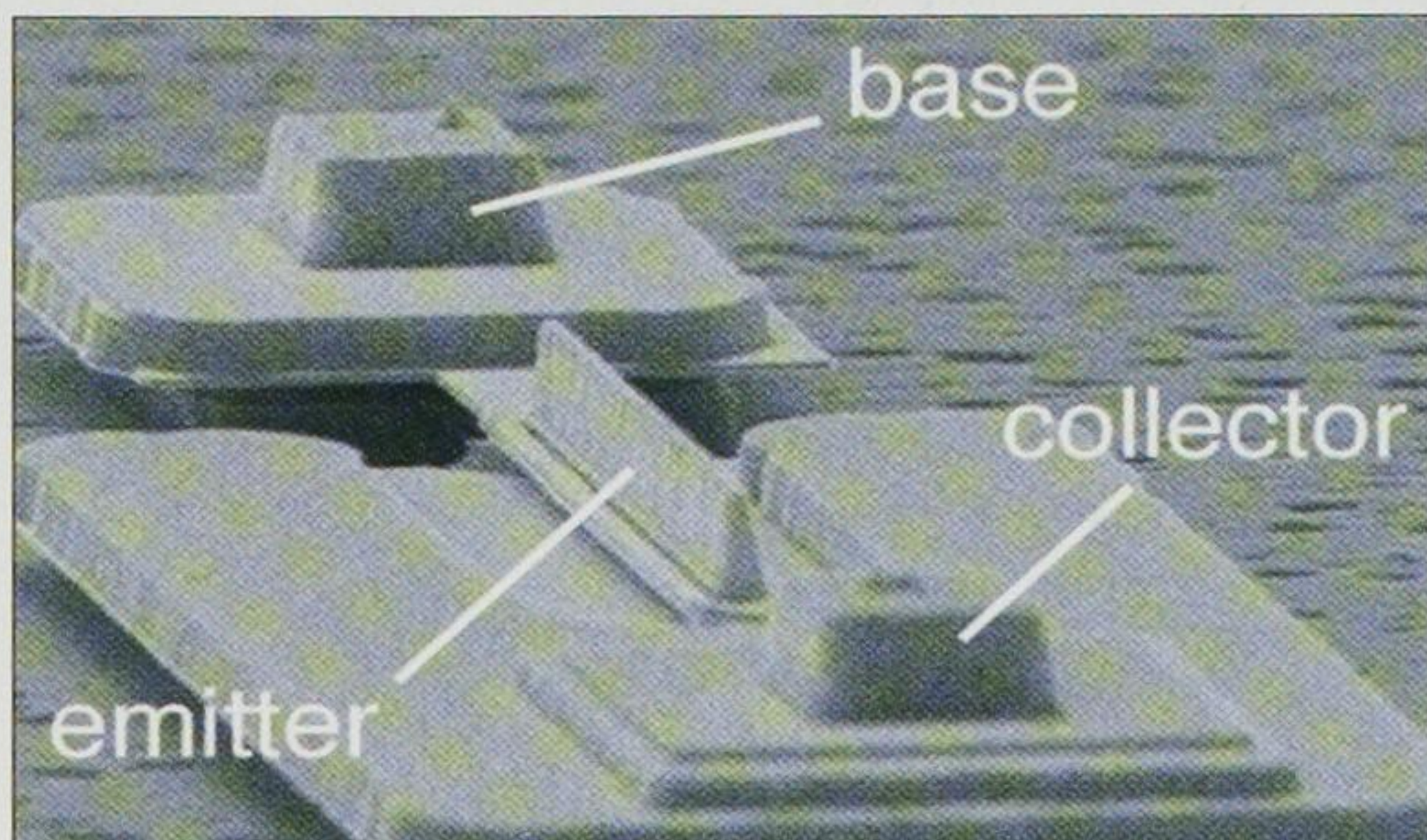
SURFACE TECHNOLOGY SYSTEMS

Imperial Park, Newport, NP10 8UJ, UK. Tel: +44 1633 652 400 Fax: +44 1633 652 405 email: Enquiries@stsystems.co.uk

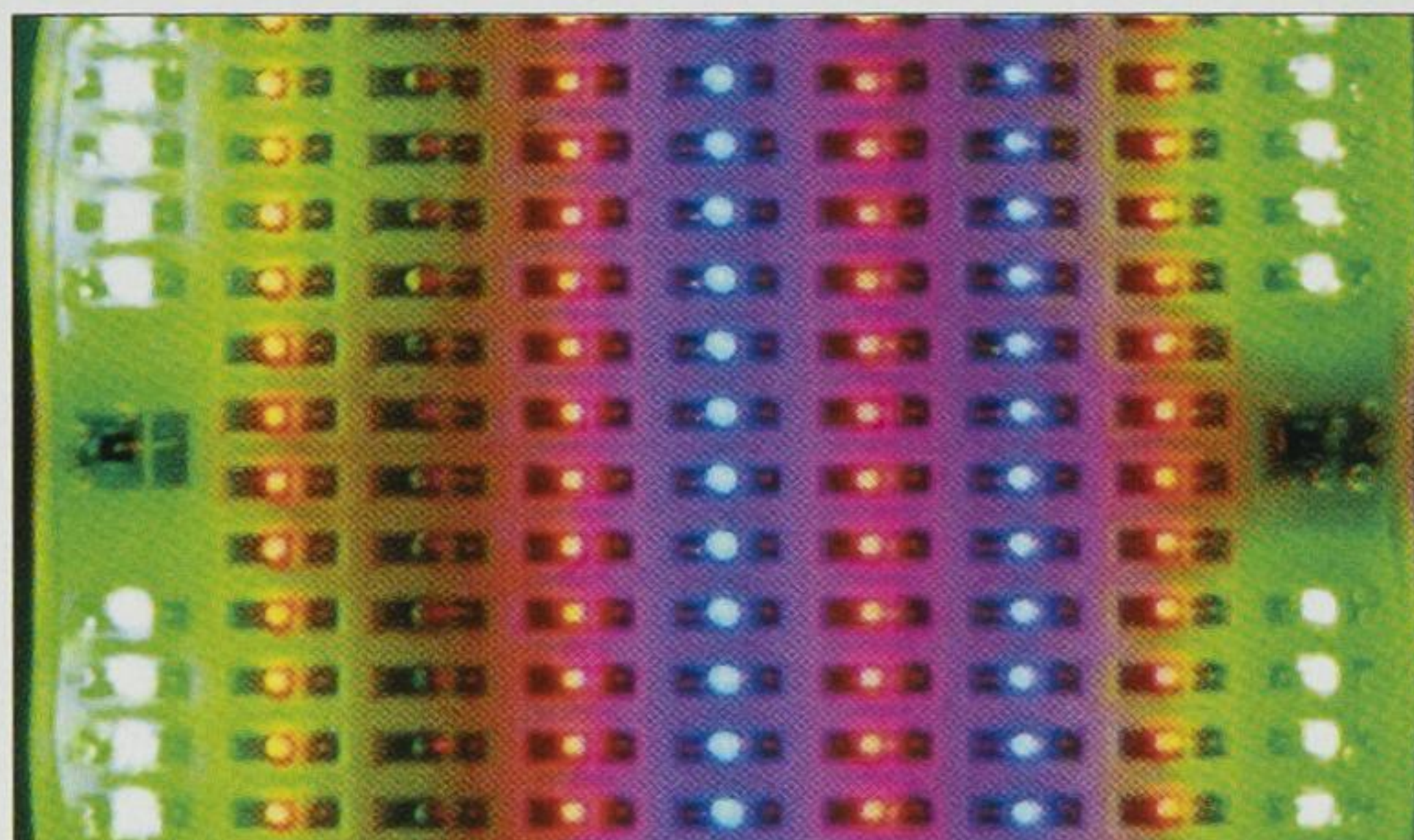
COMPOUND SEMICONDUCTOR

Three-Fives and Silicon Heterostructures

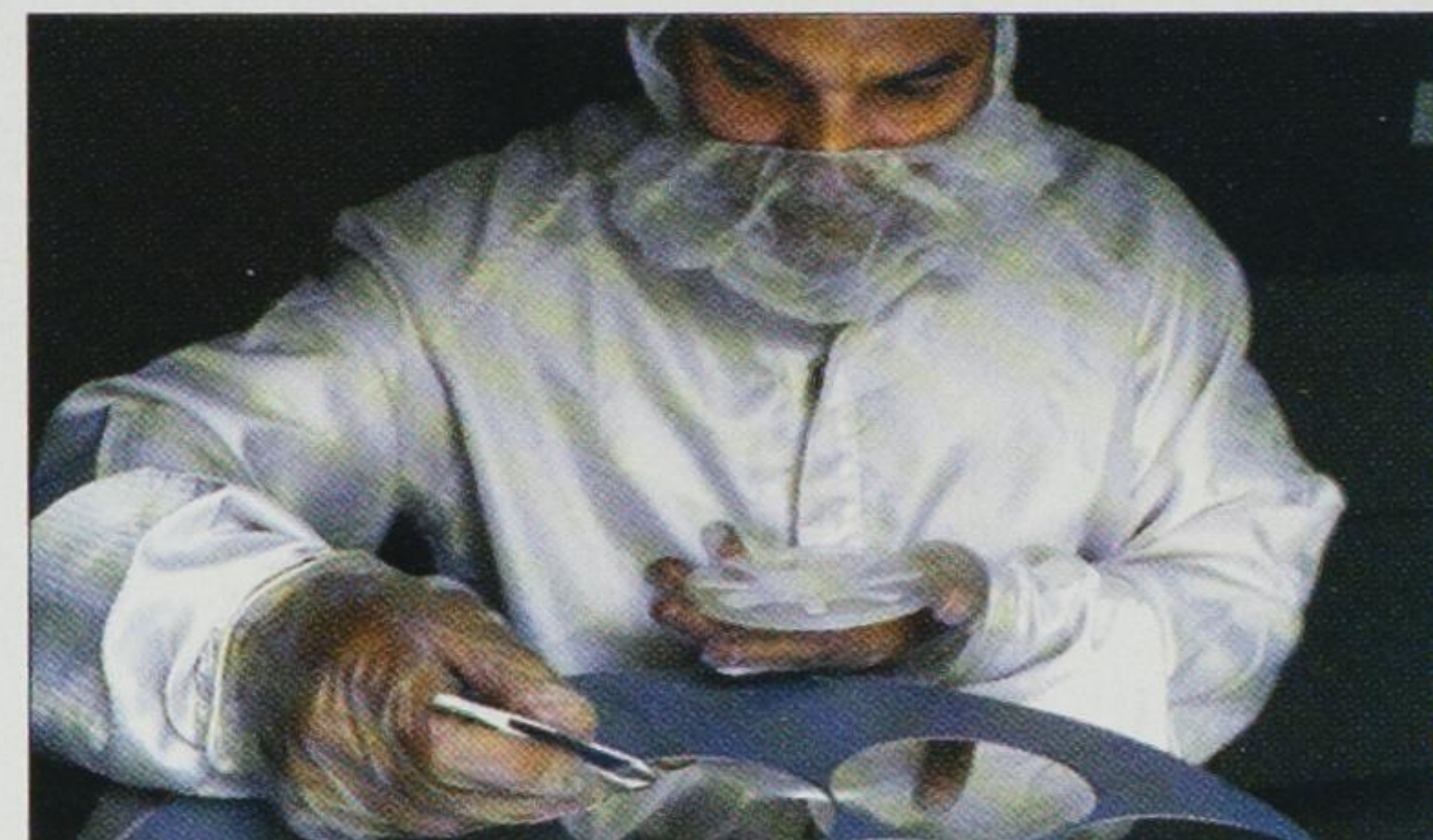
NOVEMBER 2003 VOLUME 9 NUMBER 10



A group from UIUC has broken the 500 GHz f_t barrier with an InP-based SHBT **p8**



NASA will use this Norlux HB-LED array aboard the International Space Station **p11**



Prospects for terrestrial energy sources based on III-V solar cells are looking up **p25**

NEWS

- 5** **Headline News** Raytheon sells commercial GaAs unit...AXT sells opto business, reports flat revenue
- 8** **GaAs News** InP/InGaAs HBTs break record with f_t of 500 GHz...Anadigics buys Celeritek's Tavanza unit
- 11** **LED News** More CyberLite custom for Kopin... Cree's LED sales top \$50 million for quarter
- 14** **Silicon Compounds** IBM demos SiGe transistor on SOI...Jazz signs up Chinese foundry
- 17** **Wide Bandgap News** Infineon SiC Schottky diodes made in Austria... II-VI and Semisouth develop SiC wafers
- 19** **Opto News** Alfalight project targets 80% efficiency lasers...Indigo InGaAs detector sees visible light
- 35** **Fiber News** Albis to focus on short-reach 10 Gbit/s datacoms...Emcore acquires 10 Gbit Ethernet business
- 35** **Materials & Equipment** Veeco buys MOCVD unit from Emcore

DEPARTMENTS

- 38** **Research Review** AlIn/GaN mirrors for GaN devices...SiGe VCOs target the automotive radar market
- 40** **Portfolio** Reversal of fortune complete as RFMD revenue beats JDSU

ADVERTISING SECTION

- 39** **Device Processing Equipment Suppliers Guide**

COVER STORY: CONVERGENCE WITH SILICON

20 Time for the compounds industry to adopt silicon concepts

The integration of silicon and non-silicon technologies is a crucial issue facing the entire semiconductor business. To create a successful hybrid industry, the compounds sector needs to adopt business models from its silicon counterpart while developing new technologies, as Michael Hatcher reports.

29 Epitaxy and the high- κ dielectric contest

The race is on to find a replacement for SiO_2 as a gate dielectric in CMOS. Jorg Osten describes the challenges faced, and how knowledge from III-V materials science will help.

FEATURES

25 Solar cell manufacturers come back down to Earth

For III-V solar cell manufacturers, it is Earth rather than space that represents the final frontier. However, recent advances in the performance of cells and high-concentration optical modules suggest that multi-junction photovoltaics can infiltrate the silicon-dominated terrestrial energy market, as Michael Hatcher reports.



Compound Semiconductor's circulation figures are audited by BPA International

On the cover: Veeco Instruments is emulating business models widely used in the silicon industry at its new Process Integration Center (PIC) – see p20.

COMPOUND SEMICONDUCTOR

Three-Fives and Silicon Heterostructures

Editor Tim Whitaker
tim.whitaker@iop.org
Tel: +44 117 930 1233; Fax: +44 117 925 1942

Technology editor Jon Newey
jon.newey@iop.org
Tel: +44 117 930 1192

Associate editor Michael Hatcher
michael.hatcher@iop.org
Tel: +44 117 930 1013

Commercial manager Rebecca Griffiths
rebecca.griffiths@iop.org
Tel: +44 117 930 1030; Fax: +44 117 930 1178

Sales executive Luke Neel
luke.neel@iop.org
Tel: +44 117 930 1264; Fax: +44 117 930 1178

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

Senior production editor Kerry Bristow
Ad production Jackie Cooke/Joanne Derrick
Circulation Jackie King
Art director Andrew Giaquinto
Technical illustrator Alison Tovey
Publishing director Richard Roe
Managing editor Marie Meyer

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 \$132 US/€142; library \$300 US/€335. Orders to Compound Semiconductor, WDIS, Units 12 & 13, Cranleigh Gardens Industrial Estate, Southall, Middlesex UB1 2DB, UK. Tel: +44 208 606 7516; Fax: +44 208 606 7303. General enquiries: compoundsemi@iop.org.



8476 total qualified circulation*
*May 2003 BPA audit statement

Editorial board

Mayank Bulsara AmberWave Systems (USA);
Andrew Carter Bookham Technology (UK);
Jacob Tarn Epistar/Gigacomm (Taiwan); **Ian Ferguson** Georgia Institute of Technology (USA);
Toby Strite JDS Uniphase (Switzerland); **Mark Wilson** Motorola (USA); **Dwight Streit** Northrop Grumman (USA); **Joseph Smart** RF Micro Devices (USA); **Colombo Bolognesi** Simon Fraser University (Canada); **Shuji Nakamura** University of California at Santa Barbara (USA)

©2003 IOP Publishing Ltd. All rights reserved.

US mailing information: *Compound Semiconductor* (ISSN 1096-598X) is published 11 times a year for \$132 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.

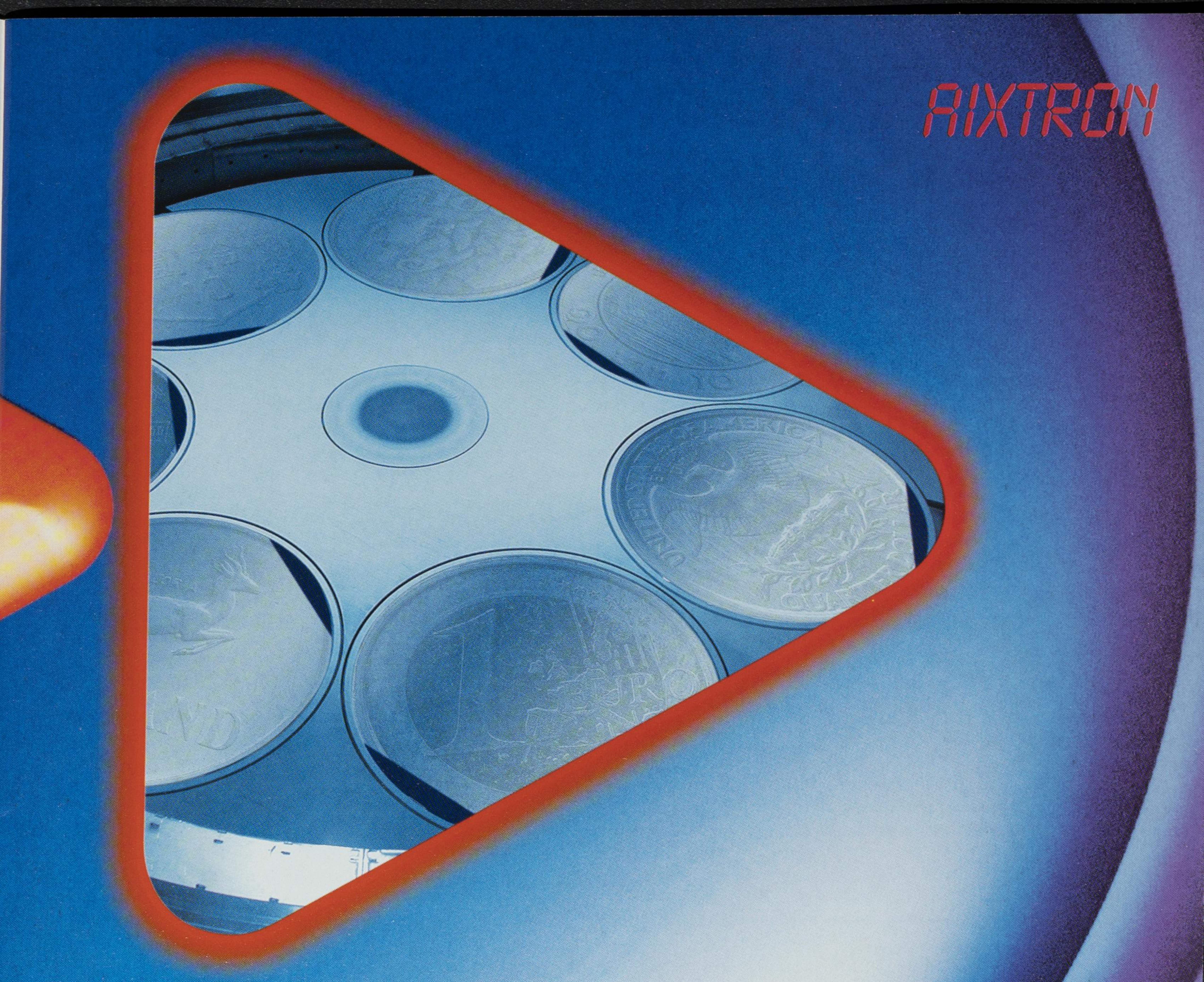
Institute of Physics PUBLISHING

Organization Index

II-VI Inc	18	Lumileds	11
Aeronex	37	Motorola	8
Albany Nanotech	20	Mykrolis	37
Alfalight	19	Nanosemiconductor	6
ALSI	36	National Renewable Energy Lab	25
Anadigics	9, 40	Nichia	12
Applied Materials	20	Nokia	8
Atmel	14	Osemi	29
ATMI	40	Osram Opto	5
Avanex	40	Raytheon	5
AXT	6, 40	RF Micro Devices	8, 40
Bell Labs	36	Riber	40
Bookham Technology	40	Rockwell Scientific	17
Celeritek	9, 40	Rohm	18
Communicant	14	Ruhr University	38
Cree	12, 40	Semi South	18
Crystal IS	18	Sirenza Microdevices	40
Emcore	25, 35	Skyworks Solutions	40
Endwave	40	Soitec	40
Everlight	5	Spectrolab	25
Fairchild Semiconductor	5	Strategy Analytics	8
FEI	36	Surface Technology Systems	37
GELcore	35	Swedish Royal Institute	38
Hannover University	29	Tavanza	9
IBM	14	Trikon	40
Indigo	19	TriQuint	8, 38, 40
Infineon	17, 38	Unaxis	40
Jazz Semiconductor	14	University of California San Diego	36
JDS Uniphase	40	University of Illinois	8
Kopin	11, 40	University of South Carolina	38
Kyma	18	Veeco	20, 35, 36, 40

Advertisers' Index

Addon	37	k-Space Associates	15
Aixtron	3	LayTec	18
Akzo Nobel	17	Loomis Industries	4
ASML	33	Nanosemiconductor	27
ATMI	36	ORS	15
AXT	23	Praxair Electronics	10
Bandwidth Semiconductor	27	Raboutet	19
Bruker	28	Riber	IBC
DCA Instruments	16	Schwarzkopf Technologies	11
Emcore	7	Strategies in Light 2004	34
Epichem	13	Surface Technology Systems	IFC
EpiNova	9	Thomas Swan Scientific Equipment	22
Freiberger Compound Materials	15	Umicore Electro Optic Materials	24
Integrated Systems Engineering	9	Unaxis	31
JPSA	12	Veeco	OBC



AIXTRON

TECHNOLOGY

PRODUCTIVITY

SERVICE

PURE PLAY

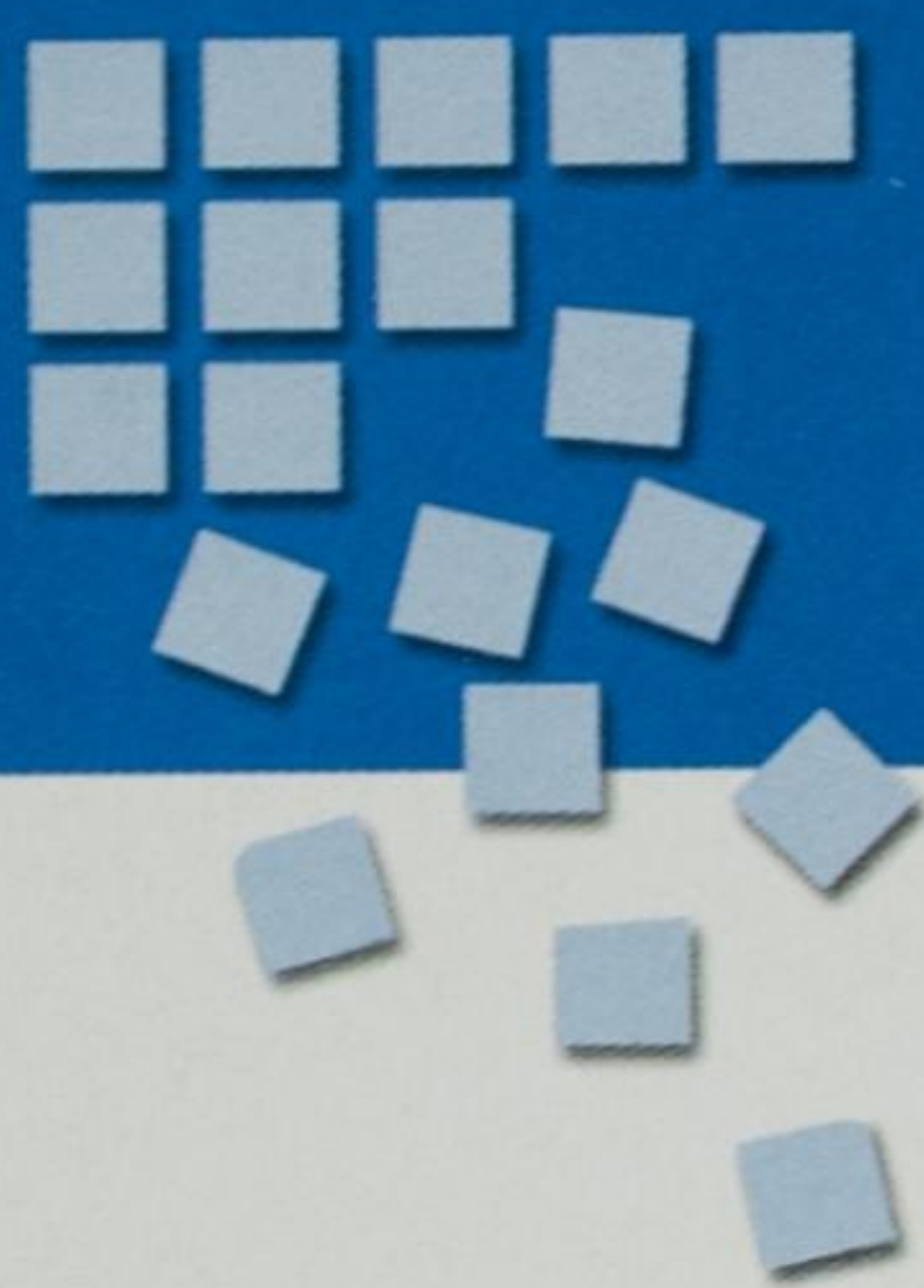
One of your best investments won't come from a banker.

Performance stems from productivity. And with your investment in AIXTRON technology, you get a top quality CVD production system. Leading technology that fits your individual requirements. The aim of our work with you is to get the best out of the wafer: qualitatively and economically. For us, productivity is at the heart of all we do, leaving you free to concentrate on competing with the best products. Call us! And count on us. After all, the best return on your investment is at stake.

push your



PERFORMANCE

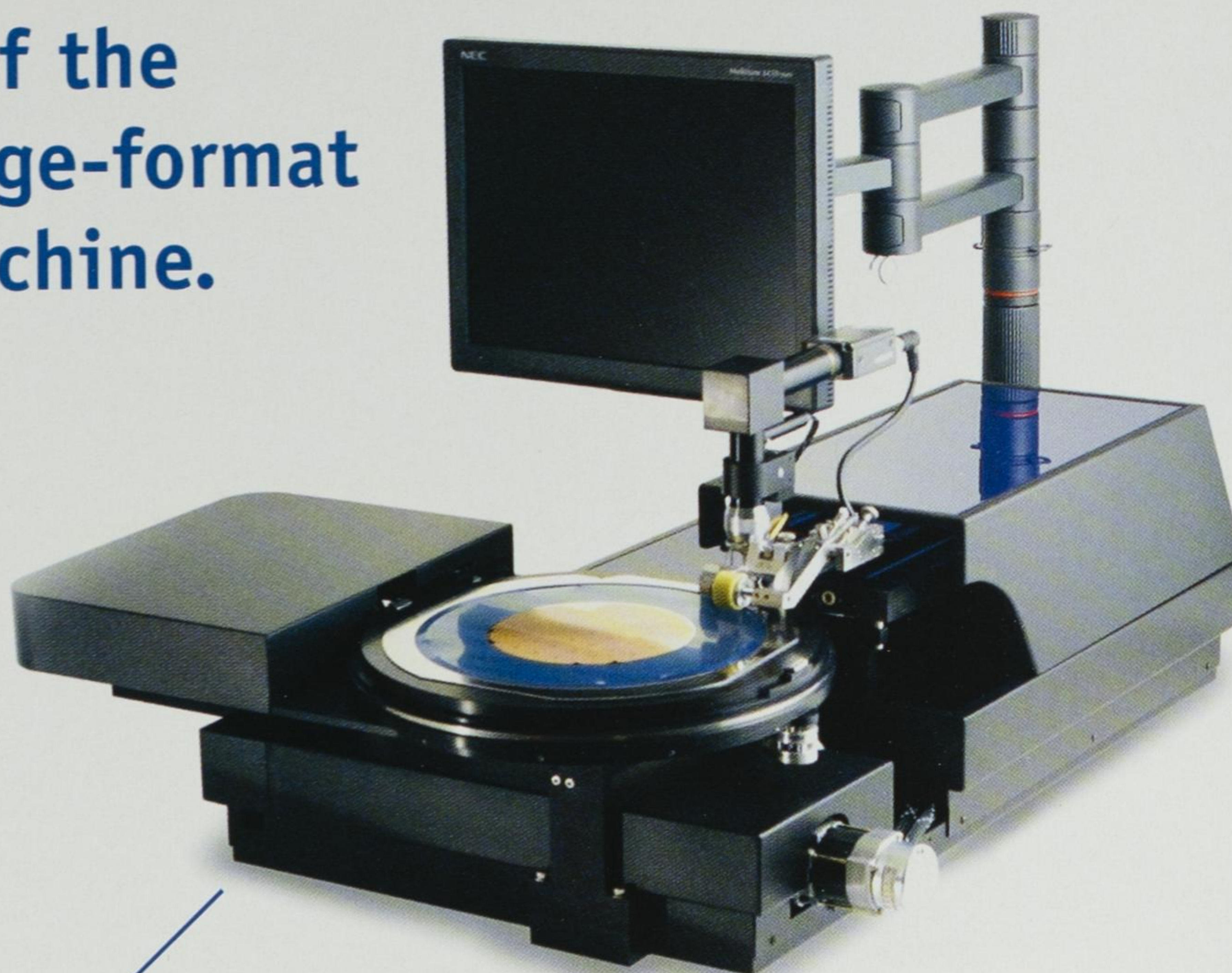


LOOMIS

Patented Scribe and Break Dicing Technology

www.loomisinc.com

A quick review of the new LSD-200 large-format scribe dicing machine.



FEATURES:

- Yadda yadda yadda
- Blahbitty blah-blah
- Yackety yack yack
- ZZzzzzzzzz...

BENEFITS:

- Pays for itself

You buy equipment based on fiscal realities. And your goal for any dicing system is obvious - fixed, manageable costs and the highest possible reliable yields. Thanks to two years of exhaustive research and field-testing, the LSD-200 offers your company both.

New technologies are exciting, even inspirational. Still, the smart company invests its money in capital equipment for one reason - to make more money. With minimal up-front investment and maximum throughput and yields, the LSD-200 is not just economically feasible - it's an economic necessity.

For a complete list of the LSD-200's bells and whistles and flexible financing options call us at **(707) 963-4111** – or visit us online at **www.loomisinc.com**.

LOOMIS

Patented Scribe and Break Dicing Technology

Raytheon sells commercial GaAs unit

Chip manufacturer Fairchild has bought the commercial unit of Raytheon's RF Components division. The purchase provides Fairchild with an immediate entry into applications that include wireless LANs and cell phone handset PAs.

The agreement adds GaAs MMICs to Fairchild's portfolio of compound semiconductor devices, which also includes LEDs and optocouplers. Financial details of the agreement were not disclosed.

Raytheon will continue to operate its 4 inch GaAs fab in Andover, MA, which serves internal Raytheon requirements for defense-related products (*Compound Semiconductor* October 2003 p23). However, the deal provides

Fairchild with access to foundry and support services at the Raytheon facility. Fairchild has also acquired Raytheon's foundry partnership agreement with WIN Semiconductors, as well as an equity stake in the Taiwanese company, which operates a 6 inch GaAs wafer fab.

Products and devices covered by the deal include transmit and receive modules, HBT and PHEMT PAs, and LNAs for handsets, as well as components for wireless base stations, data and space-based communications systems, and millimeter-wave systems.

Fairchild's new RF business will report to its Power Discrete Group, led by executive VP and general manager Izak Bencuya. "The addition of RF PAs to our current power prod-

uct offering strengthens Fairchild's presence in the wireless communications market, while enabling expanded design opportunities in the areas of wireless LANs and handsets," said Bencuya. "The total market size for GaAs PAs is projected by Strategy Analytics to grow to between \$770 million and \$1.2 billion by 2006, with a CAGR of 16%. We expect that [our new RF components] business should ramp to revenues of more than \$5 million per quarter towards the latter half of 2004."

More than 30 Raytheon designers, test engineers and business development employees will join Fairchild. Russ Wagner, former Raytheon RF Components VP of business development, will lead the group.

Everlight gains LED license from Osram...

By Tim Whitaker

German lighting company Osram has signed a patent licensing agreement with Everlight Electronics, a Taiwanese LED packaging company, under which Everlight will manufacture and sell a number of LED products based on Osram's patents.

Specifically, Osram has granted Everlight a royalty license to make and sell surface mountable (SMT) LEDs emitting white and colored light. Osram holds patents for several mounting forms and packages for SMT LEDs.

Everlight will also be free to manufacture white LEDs based around conversion technology, in which blue InGaN chips are combined with a suitable fluorescent converter. Again, Osram holds patents in these areas. Typical applications include backlighting for cell phone and car radio displays.

"Over the years, we have built up a very strong position and have a good deal of intellectual property at our disposal," explained Ruediger Mueller, CEO of Osram Opto Semiconductors. "We are willing to grant

licenses to other companies."

Mueller also said that the demand for SMT LEDs and white LEDs is growing so quickly that, for capacity reasons, Osram Opto Semiconductors "is not able to provide all the products the market is calling for".

Last year, Osram licensed its white LED manufacturing technology to Rohm and also signed a patent cross-licensing agreement with Nichia. The agreement with Everlight marks the first time that Osram has entered into a contract with a company from Taiwan.

...and is hit by preliminary injunction from Nichia

Japanese LED manufacturer Nichia has been awarded a preliminary injunction order against Everlight to prevent the Taiwanese company from using blue LED chips supplied by a third-party Taiwanese company. The chips have the part numbers ES-CEBH712:A3 and ES-CEBH712:A4, and are said to infringe on Nichia's Taiwan patent no. 160,722.

The part numbers correspond to chips manufactured by Epistar, an LED maker that has been hit by a separate injunction in favor of Nichia which is related to the same patent (*Compound Semiconductor* October 2003 p5). It seems that Nichia's case against Everlight is an extension of its attempt to prevent Epistar from selling products that allegedly use Nichia's patented technology.

A brief statement from Nichia said that the preliminary injunction order "may" prevent

Everlight from using the chips in question, and that Nichia "is currently evaluating whether to enforce the order, and whether further legal action will be instigated against other assembly manufacturers that use products infringing Nichia's patent(s)". It appears that Nichia is using its intellectual property muscle to force packaging companies such as Everlight to stop using Epistar's products.

However, Epistar says in a statement on its website that the injunction against it is related to one specific product only – the ES-CEBH712:A3 chip – and that demand for this chip is limited. The company has informed its major customers of the situation and expects the injunction to have "little effect" on its business operation.

Also, Epistar disputes Nichia's allegations against it. "Epistar values its own intellectual

property and at the same time respects the intellectual property rights of others," said the statement, which went on to claim that the product in question is in fact protected by Epistar's own patents. "Independent analysis by an outside expert has concluded that Epistar's product does not infringe on Nichia's patent," added the statement.

**Veeco buys
MOCVD unit
from Emcore –
see p35**

AXT sells opto business, reports flat revenue

AXT has sold its loss-making optoelectronics business to Lumei Optoelectronics for the equivalent of \$9.6 million in Chinese currency. The company announced its decision to stop manufacturing nitride LEDs, as well as VCSELs and edge-emitting lasers, back in June 2003. Following the sale, AXT used \$7.4 million of the proceeds to pay off its outstanding equipment-related leases and loans.

AXT will lease space to Lumei Optoelectronics in California and China for up to one year. Lumei has hired several of AXT Optoelectronics' key employees, including its president Gordon Lui. AXT has retained its building located in Monterey Park, CA, which it expects to sell in 2004. Lumei was set up specifically to acquire AXT's optoelectron-

ics assets and technology, with backing from several Chinese investors, and will continue the same product lines.

"Our decision to discontinue the optoelectronics business was difficult, but it was the best decision for the company," said Morris Young, AXT's president and CEO. "Now we can focus all of our efforts on growing and improving the performance of our core substrate business."

For its ongoing business, now devoted entirely to substrates, AXT reported revenue of \$8.5 million in the September quarter, the same figure as for the previous quarter. Sales of GaAs substrates amounted to \$6.9 million, with InP sales at just under \$500,000.

The company made a net loss of \$2.6 mil-

lion, compared with \$17.7 million in the previous quarter, a figure which included a \$13.8 million charge associated with the discontinuation of the optoelectronics business.

AXT is expecting revenue from continuing operations to remain flat in its next quarter, coming in somewhere between \$8.3 and \$8.7 million, with a net loss of between \$2.8 and \$3 million.

In AXT's conference call, Young commented on the patent litigation suit filed by Cree and Boston University against the company. The next hearing in the case is scheduled for late February 2004, but in the meantime AXT expects to spend around \$200,000 in the final quarter of 2003 on litigation expenses.

Russo-German spin-out focuses on reducing wafer defects

By Michael Hatcher

A wafer-manufacturing company with expertise in quantum-dot lasers and metamorphic structures for microelectronic devices has been spun out of the Ioffe Institute in St Petersburg, Russia, and the Technical University of Berlin in Germany.

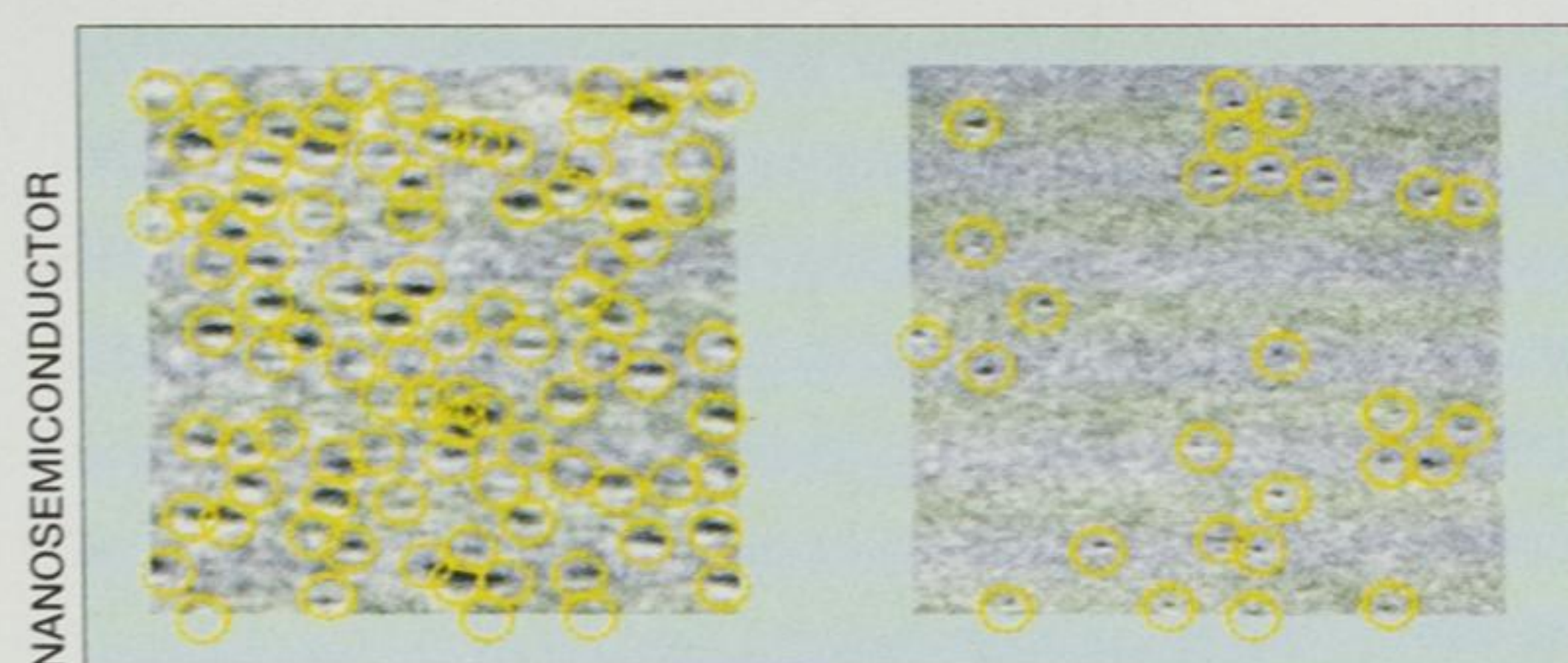
Called Nanosemiconductor (NSC), the Dortmund-based start-up recently attracted €7 million in venture capital funding led by Germany-based PolyTechnos Venture Partners.

NSC's technology is based on quantum-dot laser research that its chief scientific officer Nikolai Ledentsov and his team have been developing for more than a decade.

The company currently has a cleanroom facility featuring one MBE reactor, and can grow onto 2–6 inch GaAs and silicon wafers. It is focusing primarily on InGaAs-based long-wavelength quantum-dot VCSELs. Bernd Meyer, the company's general manager, told *Compound Semiconductor* that NSC will begin shipping wafers to "several" optoelectronics customers in January 2004.

"Our scientists are the pioneers of quantum-dot lasers," Meyer said. The NSC team says that its 1.3 μm quantum-dot VCSEL is fully developed and tested. Ledentsov and his colleagues have also recently fabricated a 1.5 μm VCSEL based on GaAs. The pulsed laser had an output power of 7 W and operated at up to 85 °C (*Elec. Lett.* **39** (15) 1126).

NSC claims that its "nanoepitaxy" growth technology greatly reduces the number of



Comparison of etch-pit density in GaN layers grown without (left) and with NSC's defect reduction technique.

defects in compound semiconductor wafers, thus improving device reliability.

The defect reduction technology (DRT) involves a manufacturing step where dislocations in the wafer structure are selectively removed (US patent application 2003 0203531). "We create strain fields around the dislocations by strained-layer growth. Then we deposit a temperature-stable capping layer that undergoes repulsive interaction with the dislocated regions," explained Ledentsov. "When the layer is annealed, this selectively creates holes at a certain depth, in regions where the dislocations were present. We can then overgrow a defect-free top layer." DRT is said to be particularly good at reducing the number of threading dislocations in strain-relaxed metamorphic layers, and local defects (e.g. defect dipoles and dislocation loops) in quantum-dot structures.

Ledentsov says that the 20 min DRT step, which takes place *in situ* and does not require removal of the wafer from the MBE or MOCVD chamber, typically reduces the dis-

location density by an order of magnitude. He added that the DRT step can be repeated to further reduce dislocation densities.

The team has applied the growth process to GaN on sapphire, reducing the dislocation density to $3 \times 10^7/\text{cm}^2$ from $10^9/\text{cm}^2$ with one DRT step. GaN devices are typically very sensitive to dislocation density; the fabrication of most GaN-based lasers requires the wafer to be removed from an MOCVD chamber for lithography and etching before a time-consuming epitaxial lateral overgrowth step is performed. Ledentsov says that NSC's manufacturing process will lead to cheaper, more reliable GaN-based lasers, and LEDs that can be driven at higher currents to achieve high brightness and long operating lifetime.

NSC is also targeting microelectronics applications, particularly m-HBTs and m-HEMTs, and Meyer says that devices based on NSC's metamorphic InGaAs on GaAs structures exhibit the same performance as InP-based devices with all the inherent advantages of the more mature technology.

"The challenge in microelectronics is to produce low-noise, high-mobility devices," said Ledentsov. "Using metamorphic InGaAs-on-GaAs structures gives us the high electron mobility at a much lower cost than devices based on InP."

Ledentsov says that DRT can also be applied to SiGe and strained-silicon structures for low-noise UHF amplifiers such as high-speed 77 GHz devices mooted for automotive radar systems.

**Times Square is
no longer a red
light district**

Thanks to GaNzilla™

GaNzilla™

Did you know?

More than 400 million
high brightness LEDs
light up New York's
Times Square

Now
featuring
RealTemp® 200
in-situ monitoring
technology

Featuring exclusive TurboDisc® technology, EMCORE's GaNzilla™ MOCVD system offers the highest throughput in the industry for the growth of advanced GaN materials, including green, blue, and UV LEDs, GaN FETs, and blue spectrum lasers.

- Fully configured high volume production platform
- Low power consumption and efficient use of reactants
- Exceptional wavelength uniformity
- Low maintenance requirements lead to maximum production time

Grow With GaNzilla™



For more information, please
contact TurboDisc sales at
EMCORE (732) 271-9090
or visit www.emcore.com

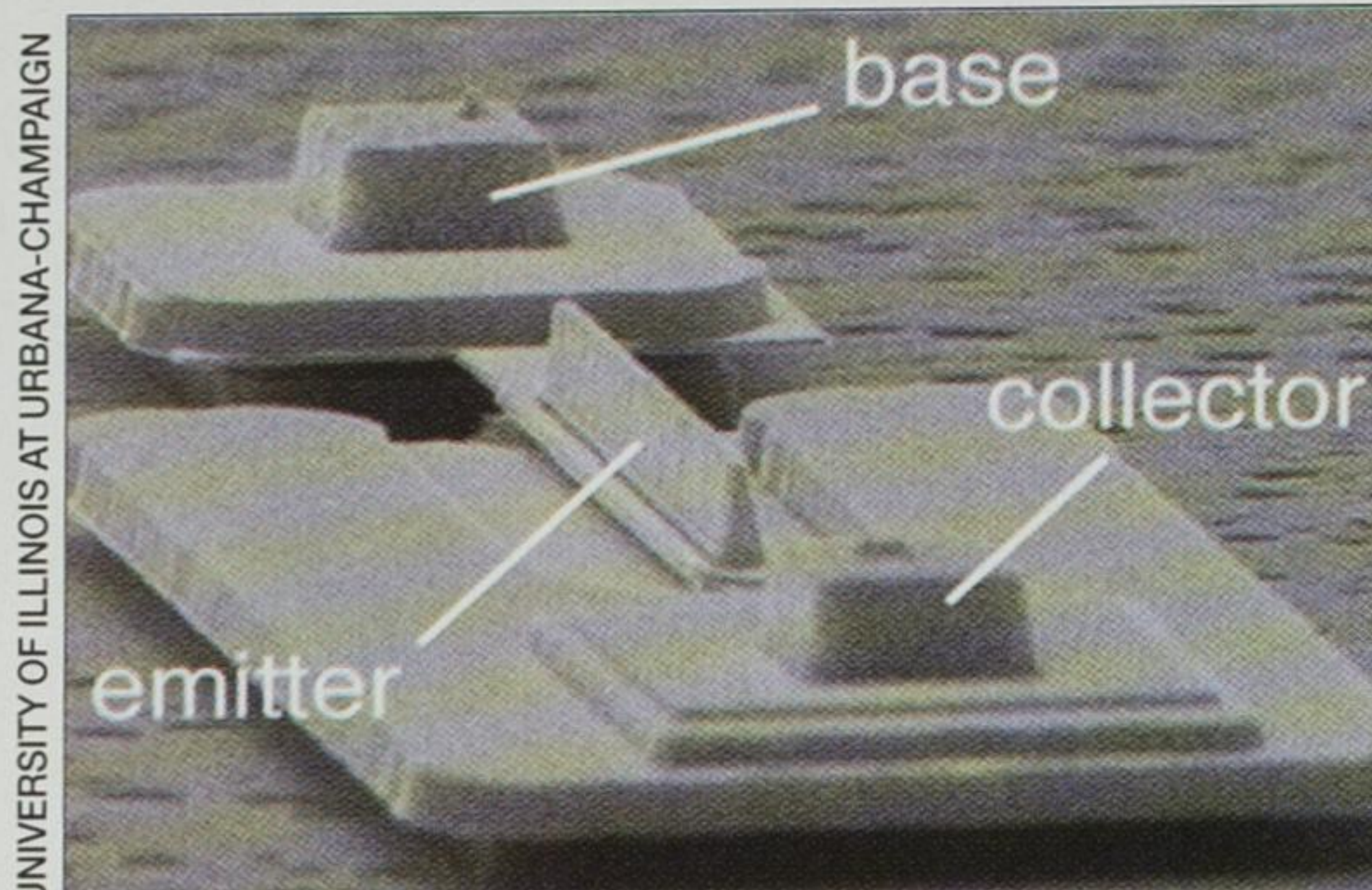
InP/InGaAs HBTs break record with f_t of 500 GHz

Another record in microelectronics has been broken by an InP-based SHBT that achieved an f_t of over 500 GHz. Milton Feng's group at the University of Illinois at Urbana-Champaign has published details of the fastest bipolar transistor to date with an f_t of 509 GHz, which the group says demonstrates the progress being made towards a THz transistor (*Elec. Lett.* 2003 39(20) 1475).

The steady rise in the speed of bipolar transistors has largely relied on vertical scaling to reduce carrier transit time. However, this comes at the cost of increasing the base-collector capacitance and reducing f_{max} and breakdown voltage. To compensate, lateral scaling of HBTs is now being addressed.

The devices were fabricated using a triple mesa design from epiwafers with a 25 nm graded base layer and 75 nm collector layer. The simultaneous achievement of a high f_t (509 GHz) and f_{max} (219 GHz) was attributed to the use of a microbridge which eliminates the base-collector capacitance inherent with designs that use large base contact posts.

A $0.35 \times 12 \mu\text{m}$ device showed a current gain of 50 at a collector current (I_c) of 50 mA, rising to 68 at $I_c = 25 \text{ mA}$. Base and collector junction ideality factors were 1.34 and 1.14 respectively. Thermal effects and gain compression limited the bandwidth of the device, with I_c reaching 47.2 mA at the peak f_t .



SEM photograph of the $0.35 \times 8.0 \mu\text{m}$ InP SHBT, which achieved f_t and f_{max} values of 504 GHz and 261 GHz respectively.

The variation of f_t and f_{max} with emitter dimensions was also measured, with the best performance coming from the $0.35 \times 12 \mu\text{m}$ device. A $0.35 \times 8 \mu\text{m}$ device showed f_t and f_{max} values of 504 and 261 GHz respectively, while a $0.35 \times 4 \mu\text{m}$ device gave 415 and 318 GHz. The reduction in f_t with emitter size was thought to be the result of an increase in emitter metal resistance.

The work on lateral device scaling was performed as part of DARPA's TFAST program, which is aiming to improve the performance of InP HBTs through lateral scaling with the goal of reducing emitter widths to $0.15 \mu\text{m}$ and increasing the integrated transistor count of InP chips.

Handset shipment figures rise again

Although fears persist of an inventory overhang of wireless handsets in the Chinese market, the overall picture looks remarkably healthy. RF Micro Devices, Anadigics and TriQuint all reported strong results based on wireless sales, while Strategy Analytics has raised its forecast for full-year shipments of handsets in 2003 to 492 million units. If the market research firm is correct, this will represent a 15% increase over sales of just under 430 million in 2002.

The industry has experienced its third consecutive year-on-year rise in shipments, says Strategy Analytics, estimating that shipments for the third quarter of 2003 were around 132 million units. Looking further ahead, growth of 9% to 536 million units is predicted for 2004. By way of comparison, Nokia has raised its forecast for 2003 to 460 million units, which it says represents growth of 14% compared with last year. Depending on which set of figures is trusted, global sales rose only 7% in 2002, but fell 6% in 2001 after several years of double-digit growth.

Growth is being driven largely by new subscriber growth in emerging markets and by sales in mature markets of handsets with color displays and cameras. A recent report from research firm iSuppli indicated that color LCD screens will be installed in 38% of all handsets sold during 2003, up from 16% last year. Most of the growth in phones with color screens is in entry-level handsets.

Orders for PAs and switches

● **Anadigics** is shipping production volumes of PAs and RF switches to **LG Electronics** for three of its CDMA phones. The VX4400 phone will utilize Anadigics' AWT6111 InGaP HBT PA, a dual-mode CDMA/AMPS module, while the VX3100 phone will use Anadigics' AWS5533 PHEMT RF switch, offered in a $3 \times 3 \text{ mm}$ plastic package. Both parts will also be used in LG's VX6000 CDMA handset, the first camera phone offered by Verizon Wireless.

● **Synad** of Reading, UK, is to incorporate two InGaP HBT PAs from **Microsemi** into reference designs provided with its dual-band SY8000 wireless LAN chipsets, which support multiple standards via a single

integrated dual-band (2.4 and 5 GHz) radio. The reference designs include Microsemi's LX5512E amplifier for 802.11b/g and the LX5506 for 802.11a applications.

● **RF Micro Devices** has announced production shipments of its RF3140 PowerStar PA module to **BenQ**, a leading handset original design manufacturer based in Taiwan. The handset is being manufactured for a leading handset OEM and is available globally. RFMD has also begun production shipments of its RF3110 PowerStar PA module to **Quanta Computer** for use in multiple E-GSM (EGSM900/GSM1800/GSM1900) handsets for enhanced-quality voice and data services.

Motorola to spin off semiconductor unit

Motorola is planning to sell off its Semiconductor Products Sector (SPS), leaving the parent company to focus on communications and integrated electronic systems.

Details of the transaction have not been finalized, but are likely to involve an initial public offering of a portion of SPS, followed by a distribution of remaining shares to Motorola shareholders in a tax-free manner.

Mike Zafirovsky, Motorola's COO, said that the company expects to continue to purchase chips for its handsets – which include ICs manufactured using GaAs and SiGe – from SPS once the unit is spun off.

Motorola's worldwide semiconductor sales were \$4.8 billion in 2002.

Anadigics buys Celeritek's Tavanza unit

RFIC manufacturer Anadigics has acquired Celeritek's wireless handset PA design subsidiary Tavanza for \$1 million. Anadigics says that the purchase will allow it to broaden its CDMA product line and accelerate its penetration into strategic handset OEM customers.

The agreement includes $3 \times 3 \times 1$ mm CDMA PAs, technology and intellectual property, as well as the recruitment of key RF engineering personnel.

Celeritek announced last month that it was to exit the handset PA business to focus on GaAs-based subsystems and semiconductors for defense markets (*Compound Semiconductor* October 2003 p6). It bought Tavanza around a year ago for an undisclosed sum.

"Tavanza is a highly recognized brand for innovative CDMA PA solutions," said Bami Bastani, president and CEO of Anadigics. "This acquisition complements our already strong CDMA PA module portfolio, which includes a robust new product pipeline of next-generation 3×3 mm modules, and expands

our portfolio beyond our competitors."

Anadigics will open a new development center in Santa Clara, CA, to house the Tavanza handset PA development group.

Celeritek sales grow slightly

Celeritek's revenues of \$7.1 million for the third quarter of 2003 were up \$0.5 million over the previous quarter, but less than half the figure for the equivalent period last year. Net loss for the quarter was \$5.7 million, compared with \$1.2 million for the year-ago period. The net loss included a charge of \$2 million related to Celeritek's decision to exit the wireless handset PA market.

Semiconductor revenues were \$2.2 million in the third quarter of 2003, compared with \$1.6 million in the previous quarter. The change was due to increased shipments to defense customers; Celeritek did not have handset-related revenues in either of these two quarters. The company's semiconductor revenues were \$11.4 million in the September

2002 quarter, which included \$10.1 million of handset-related revenue.

Anadigics' wireless sales up 31%

Total unit shipments in Anadigics' wireless business were up by 31% in the September quarter, while the company's net sales dropped slightly to \$17.8 million.

The company also reported a net loss of \$12.6 million, or \$0.41 per share. Although the loss was less than in the year-ago period, the company's revenue for the quarter failed to meet analysts' expectations and the company's shares fell sharply.

Wireless revenues in the quarter were \$9.5 million, reflecting an increase of 5.6% over the prior quarter. CDMA PA revenues accounted for 82% of Anadigics' wireless revenues. Total unit shipments in wireless were up by 31%, with CDMA PA unit shipments up 13% over the prior quarter. Broadband revenue declined 8.4%, although the WLAN segment increased 47% sequentially.

EPI NOVA III-V EPITAXIAL SOLUTIONS

- MBE epi wafers for production and development
- Wafers from 2" to 6"
- Competent and experienced
- Excellent analytical support
- ISO 9001 : 2000 certified

Epitaxial Solutions for

- Customized structures
- Laser diodes
- SESAM
- pHEMT and mHEMT

www.epinova.de

EpiNova GmbH

Tullastrasse 72
79108 Freiburg i. Br., Germany
info@epinova.de
Phone: +49 (0) 7 61 - 55 69 71 60

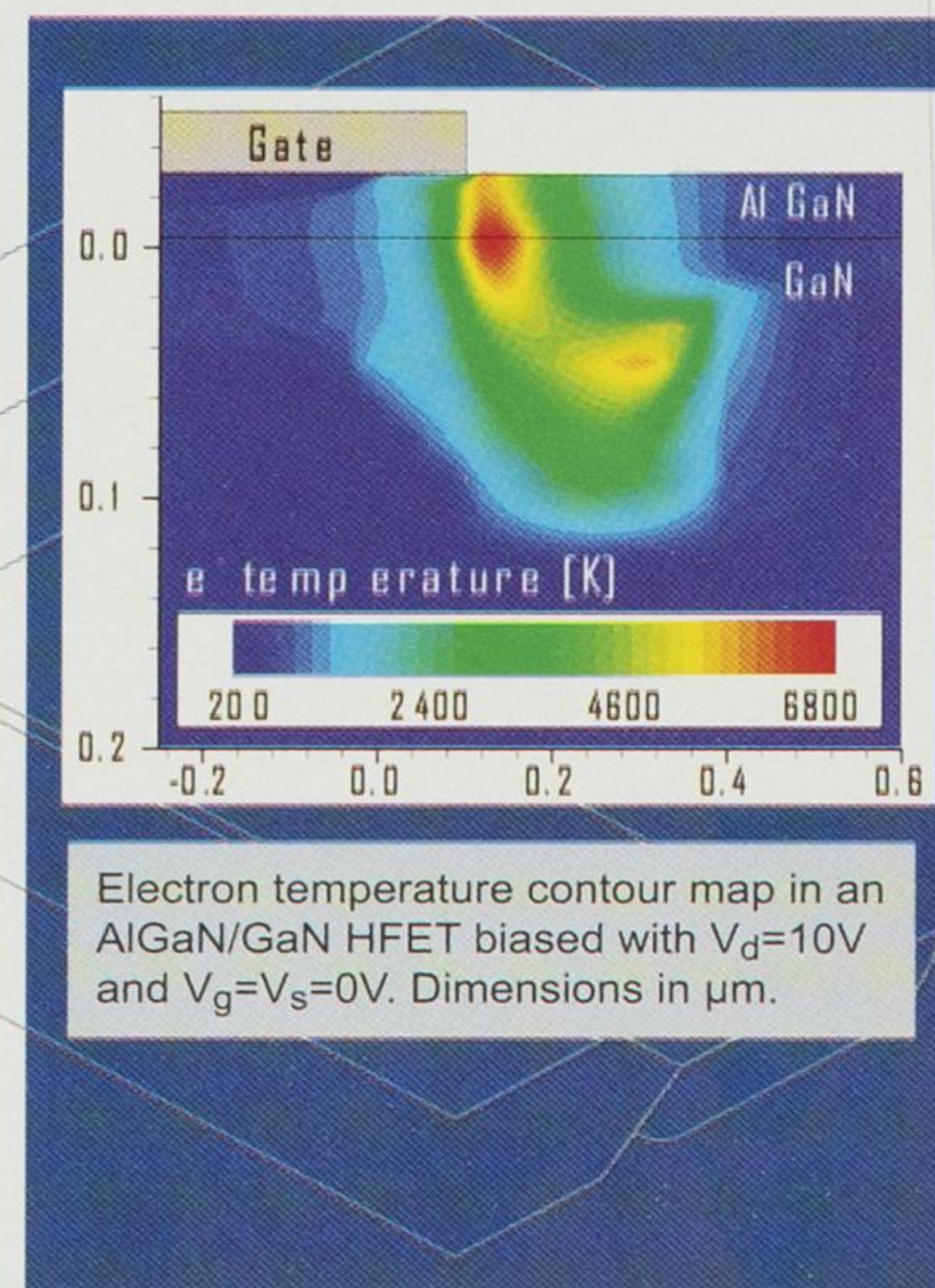


Integrated Systems Engineering

Development, Modeling, and Optimization of Microelectronic Processes, Devices, Circuits, and Systems

ISE Presents Advanced TCAD for Gallium Nitride Device Simulations

- True 3D capability
- Arbitrary semiconductors including III-Nitrides
- State-of-the-art physics
 - Hot electrons and holes
 - Quantum transport
 - Lattice self-heating
 - Trapping kinetics
 - Polarization charges
 - Strain
 - Composition-dependent parameters
- Wide spectrum of applications
 - HEMT, HFET
 - HBT
 - APD
 - LED
 - Laser



Meet ISE at 2003 IEEE International Electron Devices Meeting (IEDM) on Dec 7- 10, at the Churchill Hotel, Washington, DC.

USA

Integrated Systems Engineering, Inc.
Phone: +1 408 918 6300
Email: sales.us@ise.com
www.ise.com

Europe

ISE Integrated Systems Engineering AG
Phone: +41 1 389 9700
Email: sales.eu@ise.ch
www.ise.ch

III V PRAXAIR

Believe it or not, these numbers do add up. That's because you can go beyond what you thought possible with Praxair's III-V process gases and systems. Our unparalleled Bulk Specialty Gas Delivery System gives you a steady flow of gases at rates that are *three times higher than the industry standard*. And our 6.5-grade Ammonia offers 99.99995% purity for higher-yield blue and white LED production. Factor in our ultra-high-quality Arsine and Phosphine and you have a complete III-V package. **It's not fuzzy math at all when you can solve your III-V challenges at praxair.com**



More CyberLite custom for Kopin

In its recent quarterly conference call, Kopin reported that a second customer has qualified its CyberLite LED products.

John Fan, Kopin's president and CEO, said that the company is now shipping "significant quantities" of both blue and green devices. The blue devices are mainly used for keypad backlighting, while green LEDs are targeting RGB applications in handsets.

However, Kopin refused to reveal the value of its CyberLite revenue and how this had changed relative to the previous quarter.

Fan said that the SARS outbreak had had a negative impact on demand for LEDs, and that Taiwanese suppliers had responded by lowering their prices, especially for low-end blue

products. (Taiwanese manufacturers are much less successful at making green LEDs). The resulting disruption in the marketplace may have sparked Nichia's patent litigation against Epistar as the Japanese company attempted to secure its own position. Fan added when questioned that Kopin feels "comfortable" with its own intellectual property situation.

● Kopin's III-V revenue, mainly from HBT epiwafer sales, was \$6 million for the third quarter of 2003 versus \$8.7 million in the immediately preceding quarter. The drop was caused by Skyworks burning through its second-source HBT inventory, before transferring 100% of its business back to Kopin as part of a multi-year agreement.

Lumileds drives LEDs at 1 A to give 80 lm

Lumileds Lighting has unveiled a new high-power LED that generates a typical light output of 65 lm from a single emitter at 700 mA, or 80 lm when driven at 1 A.

The new Luxeon III product delivers more than twice the luminous flux of Lumileds' 25 lm white Luxeon in the same footprint while lowering the cost per lumen by 30–50%. Lumileds says that high-flux LEDs from other suppliers produce only 2–5 lm per package in white. The Luxeon III is also available in blue, royal blue, green and cyan.

Lumileds says that the single chip in the Luxeon III package incorporates improvements in current-carrying capability, increasing the robustness of the device and allowing it to be driven at higher drive currents.

Lumileds also manufactures a four-chip 120 lm product, the Luxeon V. The Luxeon III

has been designed to combine high optical output with high lumen maintenance, something that the Luxeon V lacks. The Luxeon III and the original 25 lm Luxeon have the same lumen maintenance spec, retaining 70% of brightness after 50,000 h of operation at 700 mA and 50% at 20,000 h when driven at 1 A.

"[Customers] asked for a new LED with light output between the Luxeon and Luxeon V products to provide new design options," said Jason Posselt, director of product marketing for Lumileds. "The optical and thermal characteristics of Luxeon III and the new 700 and 1000 mA drive current limits, without sacrificing lumen maintenance, uniquely qualify Luxeon III for a wide range of applications."

The Luxeon III Emitter and Luxeon III Star are immediately available in the Lambertian radiation pattern.

Green LEDs set to light up US airfields

Three commercial US airfields will soon be illuminated by high-brightness green LEDs instead of the usual incandescent lamps. The first installation by Lighting Innovations at a test runway in Atlantic City, NJ, is believed to be the only green LED runway threshold lamp currently in use in the world. A second system is being installed in Grand Forks, ND, with others planned in Arizona and Alaska. Despite the advantages offered by LEDs, a problem has arisen because the LEDs need to operate at three different brightness levels. Having initially been driven at 120 V for a

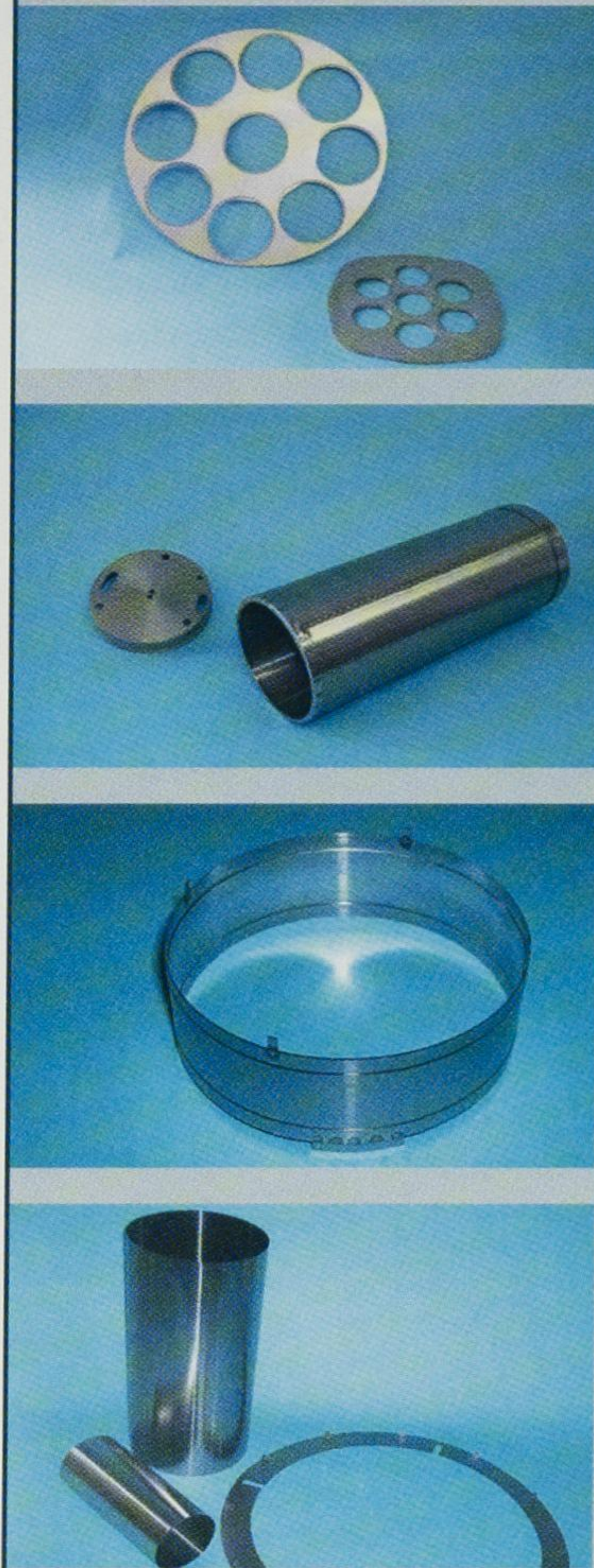


LIGHTING INNOVATIONS

month in Atlantic City, five LEDs failed when switched to lower voltages. The company is working with its LED supplier to overcome this problem.

**The world's largest
supplier of**

MBE & MOCVD Replacement Parts



- Purchase the highest quality replacement MBE and MOCVD parts without an OEM mark-up
- Schwarzkopf Technologies Corporation (STC) is the US affiliate of Plansee, the world largest refractory metals company
- STC, together with Plansee, is the leading supplier of Ta, W and Mo refractory metal replacement parts and materials for use in MBE and MOCVD

SCHWARZKOPF TECHNOLOGIES Corporation

115 Constitution Blvd • Franklin, MA 02038

Phone: 508-553-3800 ext 222 • Fax: 508-553-3823

Toll Free: 800-STC-MOLY (800-782-6659) ext 222

www.stcmetals.com

E-mail: stc.sales@stc-ma.com

SCHWARZKOPF
A PLANSEE Affiliated Company

Cree's LED sales top \$50 m for quarter

Driven by stronger demand from customers for LEDs used in mobile applications, Cree once again recorded an impressive set of results for the third quarter of calendar 2003. Its revenue was \$66.2 million, compared with \$64 million in the previous quarter and \$48.8 million in the year-ago period.

Revenue from LED sales was \$50.6 million, or 76% of the total. Cree's average LED sales price declined 20% compared with the September 2002 quarter, while its LED chip volume increased by 76%. The company also said that the average cost of manufacturing its LEDs decreased by 23% due to higher throughput in the factory and improved yields.

Cree said that its revenue from sales to its Japanese distributor, Sumitomo, increased by \$17.8 million over the same period last year due to strong demand among Japanese manufacturers for LEDs used in mobile appliances, consumer products, indicator lights and automotive and gaming applications.

However, sales to Osram Opto Semicon-

ductors in Germany and Agilent in Singapore decreased by a combined total of \$3.3 million due to factors including a seasonal decline in automotive production and a lower average sales price.

Sales of SiC wafers amounted to \$5.4 million, or 8% of the total, in the third quarter of 2003, and wafer unit shipments increased by 65%. Also, the company stated that it had invested \$3.6 million in patents and patent rights through the acquisition of a SiC patent portfolio from ABB Research.

Cree expands into packaged LEDs

In a departure from its previous business model, Cree announced that it is to begin offering packaged LEDs. Its new packaged device, the XLamp, will become Cree's first-ever packaged LED product. Pre-production sampling of 1 W surface-mount XLamp devices is targeted for early 2004, with initial production due to begin in mid-year. The XLamp will be available in multiple colors

for all applications.

This new product combines Cree's XBright power chip with packaging technology designed for high-power lighting applications in which LEDs can replace incandescent bulbs and other conventional light sources.

So far, Cree's LED business has centered on the sale of GaN-on-SiC LED die which are then packaged by its customers. The XLamp will compete with high-power products from the company's competitors such as Nichia, Lumileds and Osram.

"The introduction of the XLamp product family is the next step in our plan to drive the market for LED-based lighting," said Chuck Swoboda, Cree's president and CEO. "We believe that our ability to offer a high-power packaged LED product in addition to our power chip will be critical in accelerating the adoption of this important technology into the lighting market."

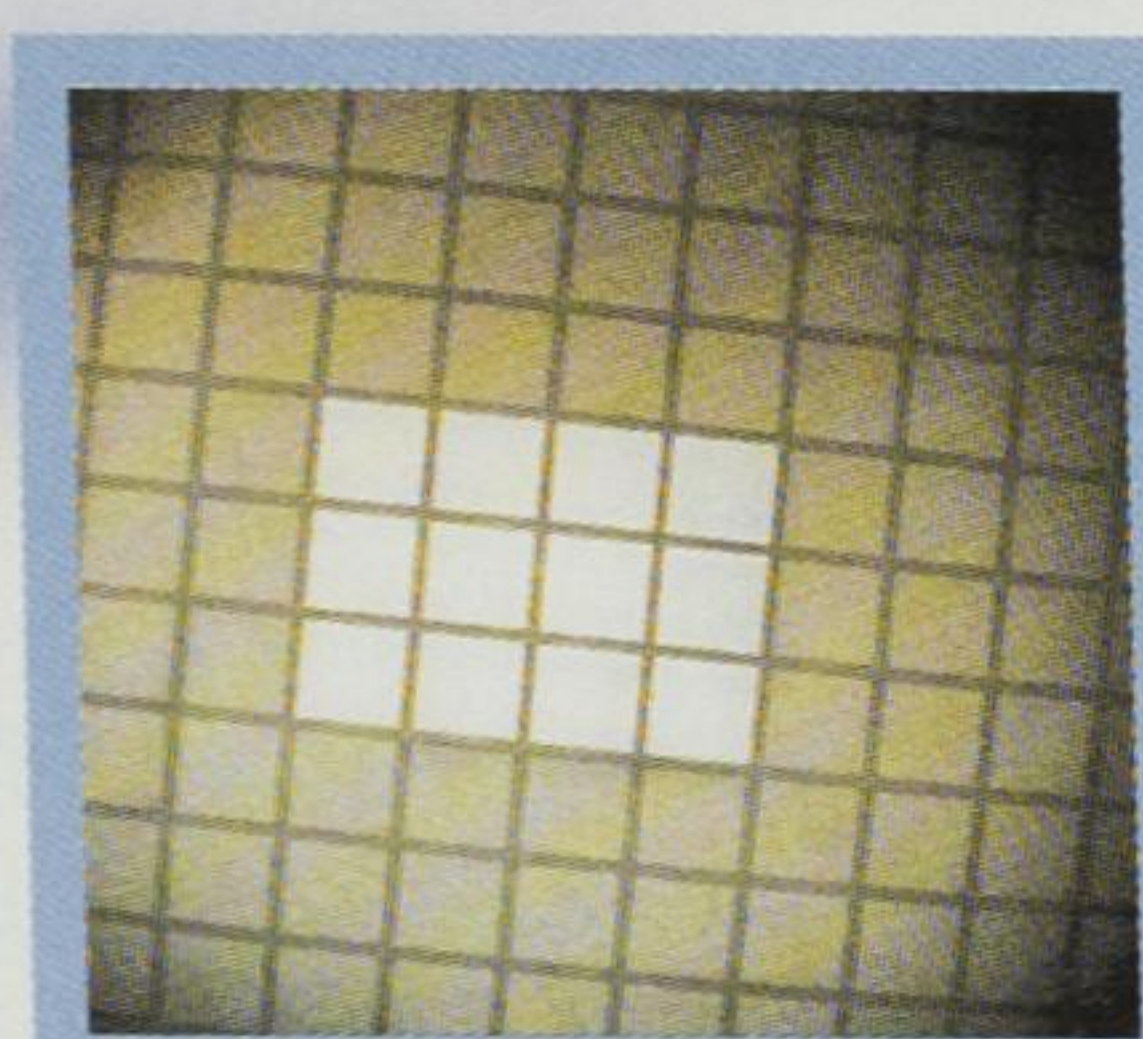
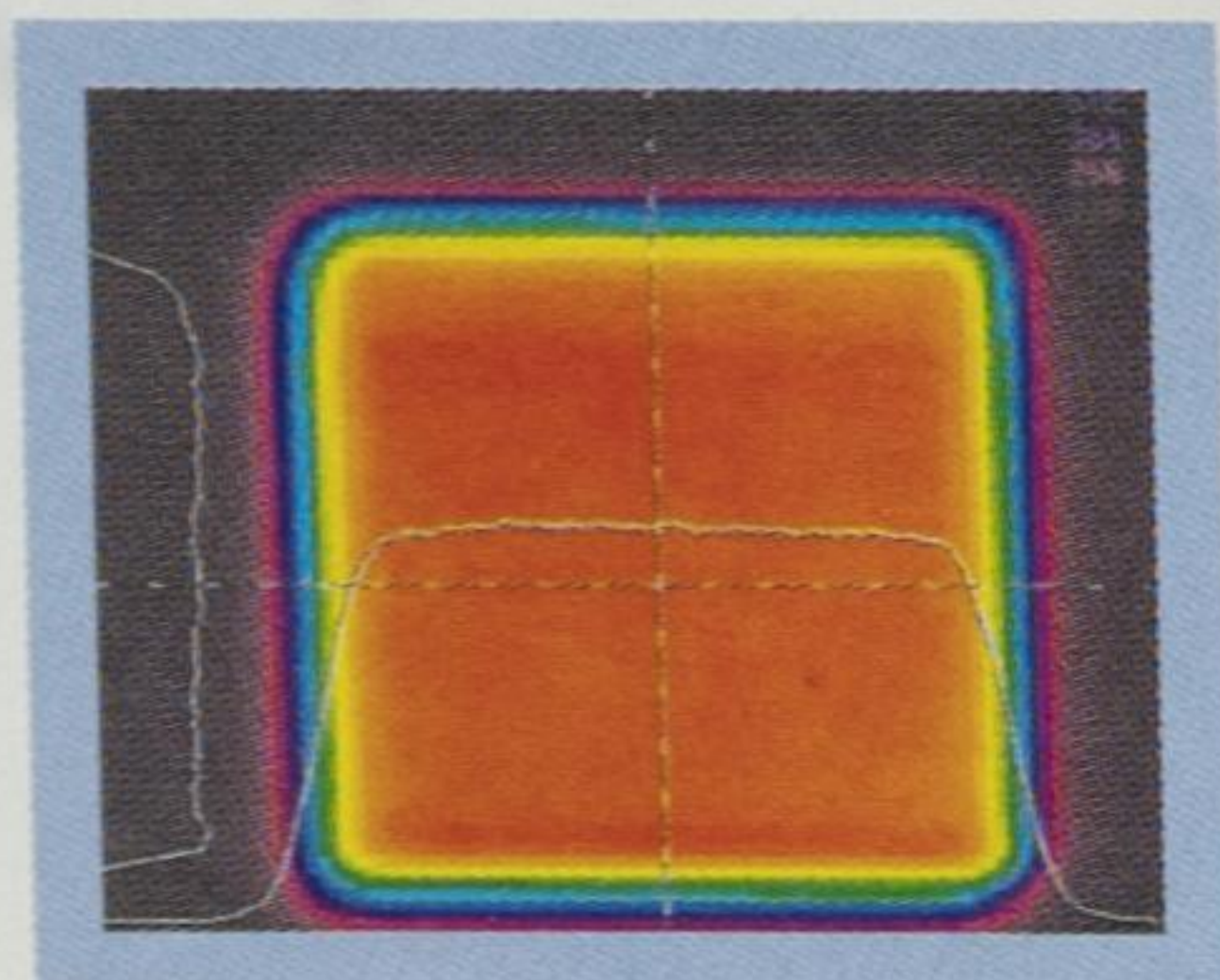
Fraud charges against Cree dropped

Eric Hunter, a co-founder of Cree, has dropped his accusations of securities fraud against Cree and his brother, the company's current chairman, thus removing a major source of uncertainty from Cree's business. Accusations of unfair trade practices were also dropped, although Hunter still claims that he and his wife were subjected to harassment and intimidation. Cree's expenses in the September quarter relating to the Hunter case and various class action lawsuits reached \$1.8 million.

White LED prices to be lowered in Japan

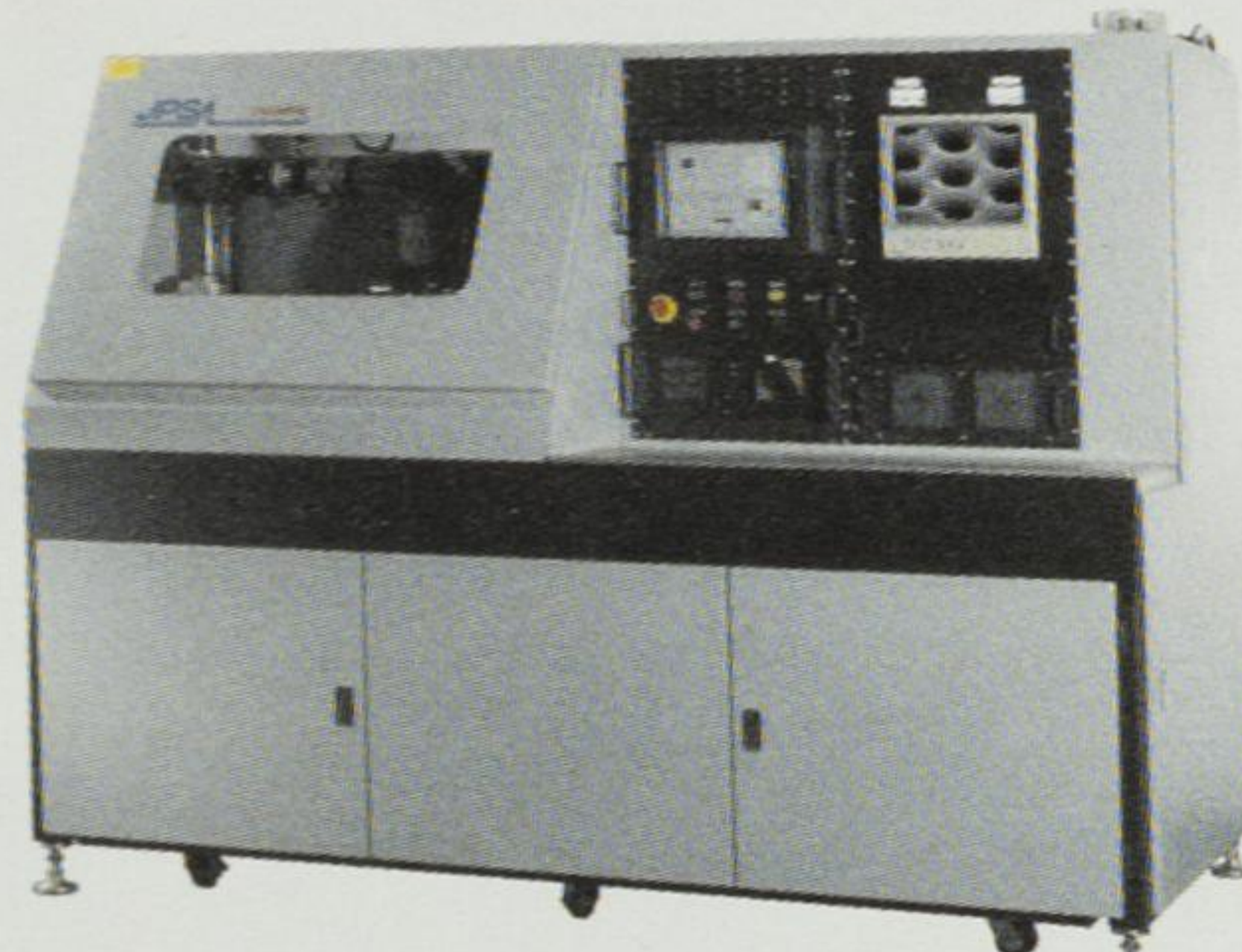
Japanese manufacturers of white LEDs have agreed to lower their prices by about 10%, according to a report in the *Nikkei Keizai Shimbun* newspaper. Several companies including Nichia and Toyoda Gosei have agreed with their customers that average selling prices will be reduced to around ¥59 (\$0.54) per piece. These prices apply to large-lot shipments during the October–December period made to mobile phone handset makers. Prices were about ¥6 higher in the July–September quarter. Although Nichia has traditionally dominated this market, Toyoda Gosei and a number of other entrants have recently increased competition, prompting customers to push for a price drop.

Advanced Excimer Laser Liftoff System



The JPSA ChromaLift™ GaN Laser Liftoff System

- Strain-free die lift off over large area
- Operates at low ambient temperatures
- Step & repeat or "fire on the fly" mode
- Micron accuracy patterning and stitching
- Ultra-uniform homogenized beam & adjustable FOV
- PC-controlled power meters and beam profilometer
- Doubles as lithographic system and dry-etching GaN
- Industrial grade reliability
- User friendly Windows 2000™ software
- New advances in LED liftoff – higher light output; lower leakage current; new extended packaging options



JPSA UV LASER SYSTEMS

WWW.JPSALASER.COM

Korea
JPark@jpsalaser.com
+ 82 (31) 427-0710

Taiwan
JPSA@lsttech.com.tw
+886 (3) 656-3716

USA Headquarters
J.P. Sercel Associates, Inc.
Hollis, New Hampshire
+1 (603) 595-7048
sales@jpsalaser.com

Norlux emerges from Uniroyal's shadow

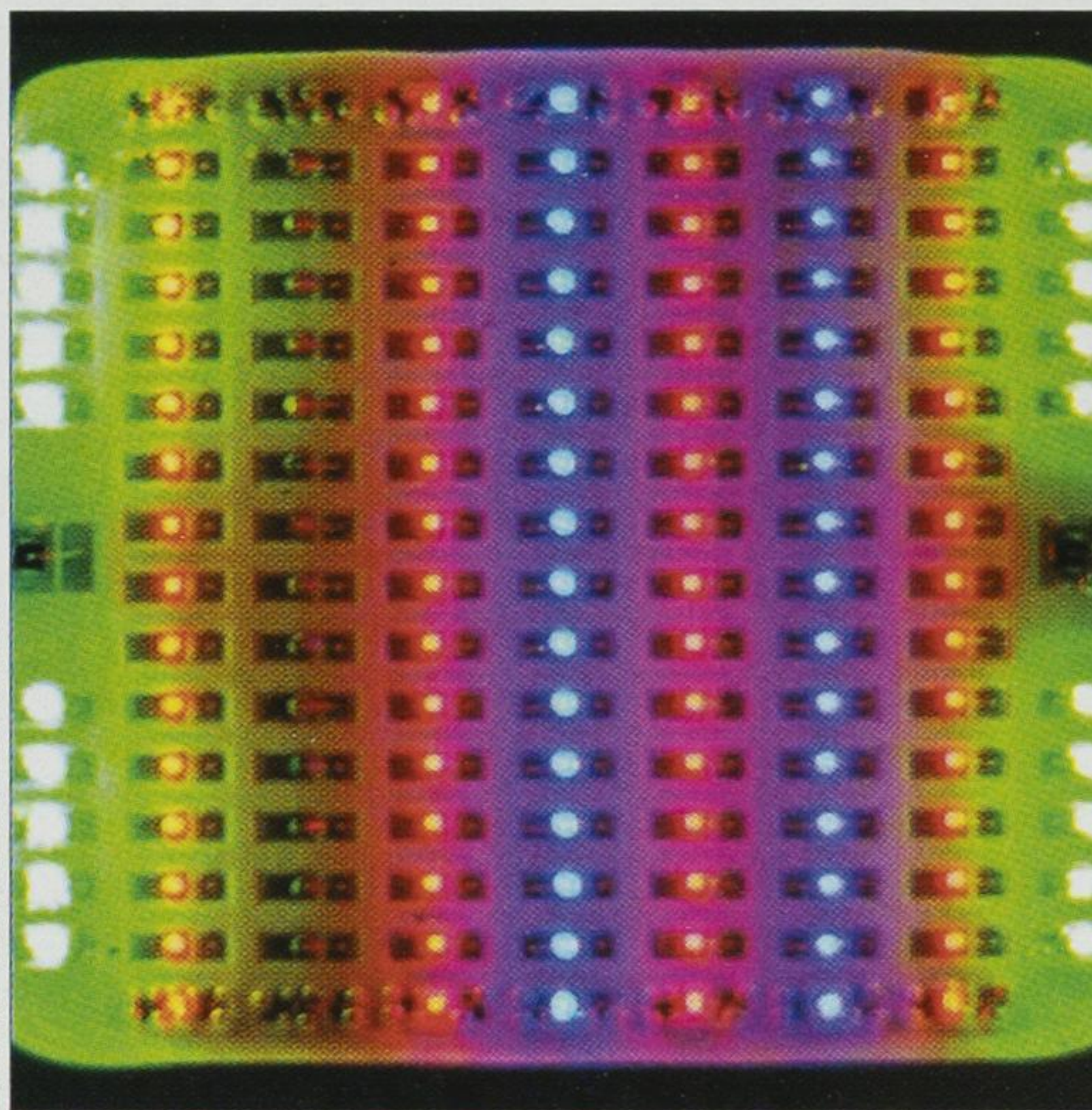
Norlux, the former Uniroyal Technology subsidiary manufacturing LED-based lighting products including high-power LED arrays, is now established as a private company after freeing itself from Uniroyal's chapter 11 bankruptcy situation.

The company was acquired by the two Norlux founders, John DiNardi and Doug Hamilton, with external backing. "We were able to get private funding from two strategic partners in the electronics industry," said DiNardi, Norlux's director of operations.

The deal was approved by the US bankruptcy court on August 14, 2003. Proceeds from the sale went to the debtor-in-possession lender CIT Group/Business Credit.

The deal was a full asset purchase acquisition, valued at \$425,000. "We assumed some of the liabilities and contracts of Norlux, and all of the assets," said Hamilton, the company's director of technology.

Norlux specializes in chip-on-board technology, with the capability to mount LED die



ORBITAL TECHNOLOGIES/NORLUX

A multiple-wavelength (UVA-far red) high-brightness LED irradiance source, which will be used for future plant growth research by NASA aboard the International Space Station. Specified by Orbital Technologies and designed and manufactured by Norlux, the tile contains 132 LEDs in 1 square inch.

on a wide variety of different substrates. The company developed a Hex platform, which allows high-density mounting of LEDs on a thermally conductive substrate (*Compound Semiconductor* January/February 2002 front cover), and also manufactures a number of multi-wavelength arrays (see photo, left).

"Our target markets are transportation, industrial, government and military," said DiNardi. "As well as manufacturing LED arrays, we can integrate electronic controls, optics and unique thermal management systems based on different substrate technologies."

Norlux has a 12,000 sq. ft facility, including a class 10,000 cleanroom, in Carol Stream, IL, for prototyping and production. "Due to high demand, we continue to add capacity to our production line," said DiNardi. "Our current capacity provides about 0.5 million die placements per month."

"We retained 100% of the employees in the new Norlux," said Hamilton. "We are very excited about Norlux moving forward."

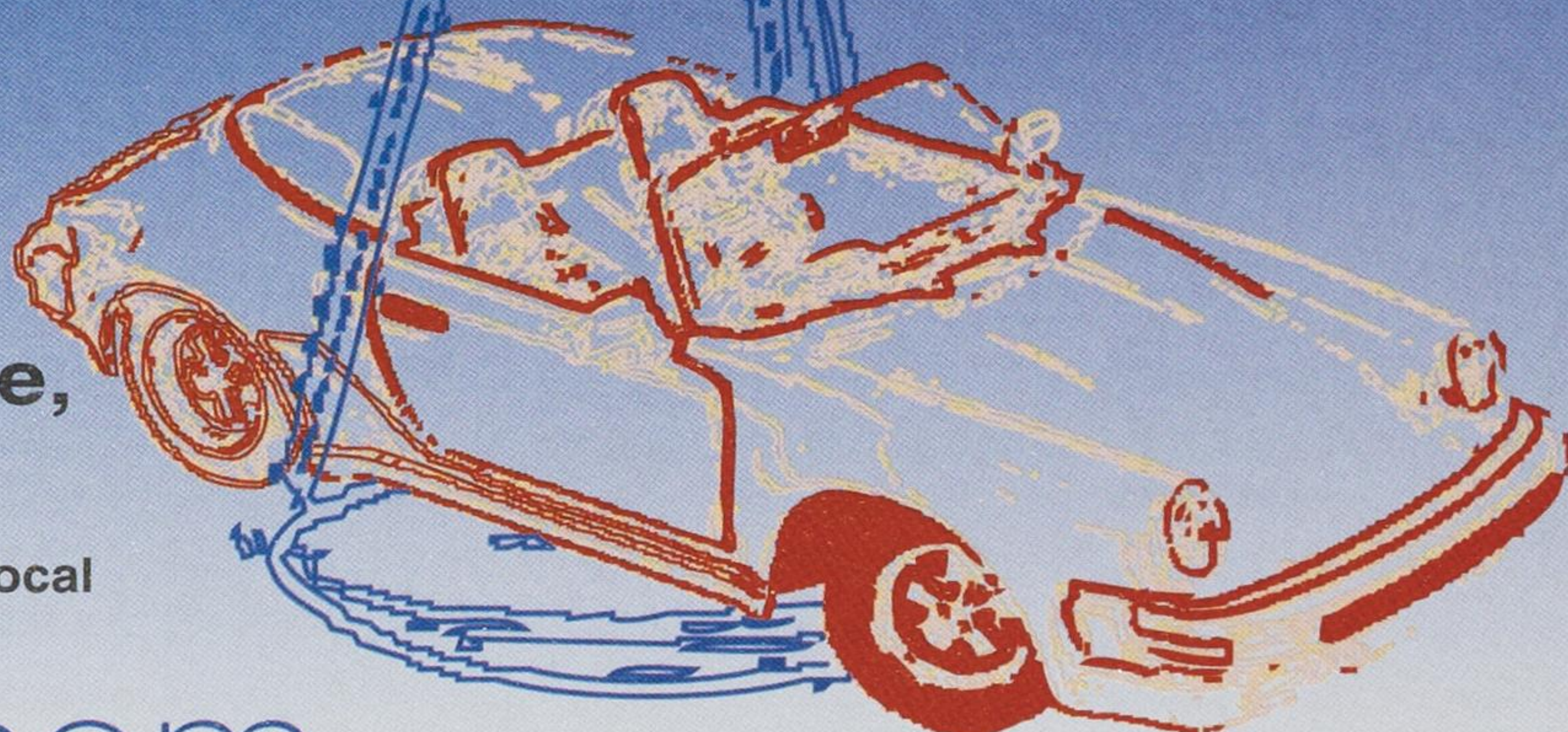
You wouldn't want to weigh your car to check the fuel level...

.... so why do it with your bubblers

Epichem introduce the EpiSensor™ System for accurate, continuous fill level indication.

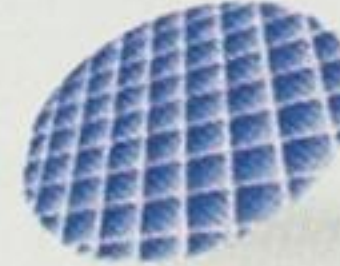
For more information on the EpiSensor™, contact your local Epichem representative or visit our website:

www.epichem.com



UK Tel: +44 151 334 2774
USA Tel: +1 610 706 0606
Germany Tel: +49 89 300 2241
Rest of Europe Tel: +46 85 716 2640
Japan Tel: +81 3 3432 7032

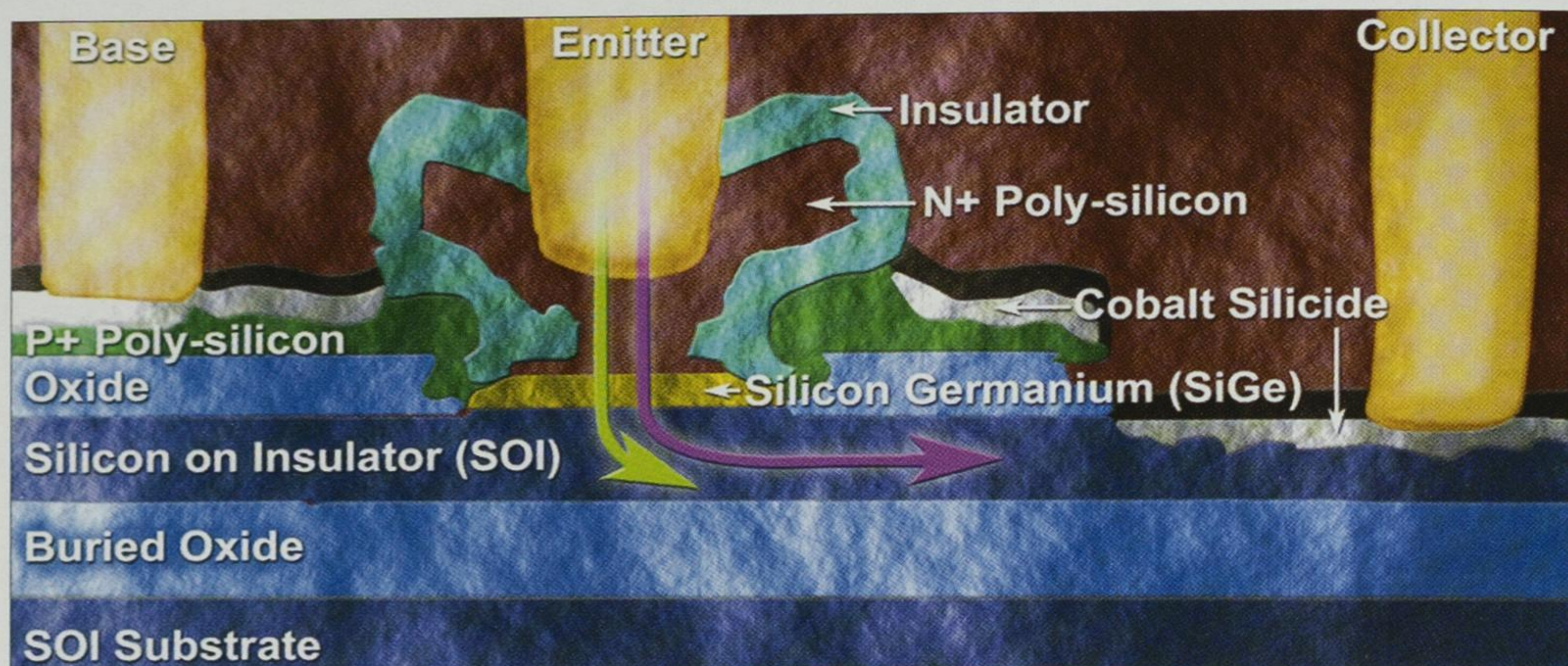
China Tel: +86 21 6472 0668
Singapore Tel: +65 483 3386
Taiwan Tel: +88 62 2 509 1399
Korea Tel: +82 31 764 4988

 **epichem group**

IBM demos SiGe transistor on SOI

IBM continues to find ways to push Si microelectronics to new performance levels, this time releasing details of a process that could lead to SiGe BiCMOS devices on thin SOI. The company says that its chip design can improve performance four-fold or reduce power consumption five-fold in wireless devices compared with the state-of-the-art thin-silicon bipolar technology.

This builds on IBM's recent announcements of other new design and manufacturing methods, such as strained Si directly on insulator, that improve the performance and lower the power consumption of computing chips (*Compound Semiconductor* October 2003 p14). As the wireless industry grows, device manufacturers will need better mixed-signal chips that support both computing applications and high-frequency communications. CMOS ICs for digital applications show higher performance when processed on SOI wafers that reduce parasitic losses through the Si substrate. Until now, no-one has found a technique to combine CMOS and SiGe bipolar onto one wafer in a way that would simultaneously maximize the performance of computing and communications functions.



IBM's SiGe bipolar transistor on a CMOS-compatible silicon-on-insulator wafer.

IBM is the first to build SiGe bipolar devices using a thin SOI wafer, thereby paving the way to integrate SiGe bipolar and CMOS on the same thin SOI wafer, which achieves optimization of the two functions. At zero or low voltage the current path in the SOI is long (pink arrow in the diagram), which results in a lower electric field in the SOI and makes the device suitable for high-voltage applications.

With a high positive voltage applied to the device, the collector is effectively extended

along the SOI layer under the emitter. The current path is therefore shorter (green arrow), making the device suitable for high-speed applications.

"IBM continues to find new methods to improve chips to ensure that the industry can meet consumer demands," said T Chen, VP of science and technology at IBM Research. "The new chip design could be implemented within five years, enabling applications such as video streaming on cell phones."

Communicant fab construction goes ahead despite problems with funding

According to a report on the Silicon Strategies website (siliconstrategies.com), construction work is continuing at Communicant Semiconductor Technologies' new fab in Germany from where it will supply its SiGe foundry services. However, concerns have surfaced over the status of the company's funding.

Last year Communicant received approval from the European Union for \$365 million of German government subsidies and loans, with a further \$650 million from commercial banks relying on the government's contribution. It now appears that the government is changing

its stance on guaranteeing the loans, although its exact position still remains unclear. One reason for a possible change of position by the German government is concern from the Gulf State of Dubai, which is a key backer of the Communicant project. Dubai is itself intending to construct a large amount of semiconductor manufacturing infrastructure at the so-called Dubai Silicon Oasis, a purpose-built semiconductor industrial park. The deep recession in the semiconductor industry also raises questions over the wisdom of bringing another fab online at a time of overcapacity.

Jazz signs up Chinese foundry

Jazz Semiconductor has signed up Shanghai-based foundry Hua Hong NEC as a second source for its 0.25 and 0.18 μm CMOS and SiGe BiCMOS processes.

The foundry is a joint venture between NEC and Shanghai Hua Hong Group, and Jazz plans to buy an 11% stake in the Chinese company. Last year, Jazz signed Shanghai-based ASMC as a licensee and second source for its 0.35 μm SiGe process.

Atmel offers SiGe HBT power process

Atmel Corporation has released its new 0.5 μm SiGe HBT technology, SiGe2-Power. The new process is a scaled version of Atmel's SiGe1-Power 0.8 μm process, which has been in production since 1999.

Two transistor types are available with switching speeds of 35 or 45 GHz f_t , 90 GHz

f_{max} , and breakdown voltages of 6 or 4 V. The new three-layer metal system introduced with SiGe2-Power has been optimized for high current densities. The transistor performance gives high gains, especially for RF applications above 2 GHz, reducing amplifier stages for simpler, cost-effective designs.

TI improves CMOS using strained Si

Texas Instruments has raised the performance of its conventional CMOS transistors by 50% through the use of strained silicon, according to a report in *Electronics News*.

The company has implemented strained silicon in its first 90 nm process, which will see its first use in Sun Microsystems' UltraSparc 64-bit processor, due to start shipping in 2004.



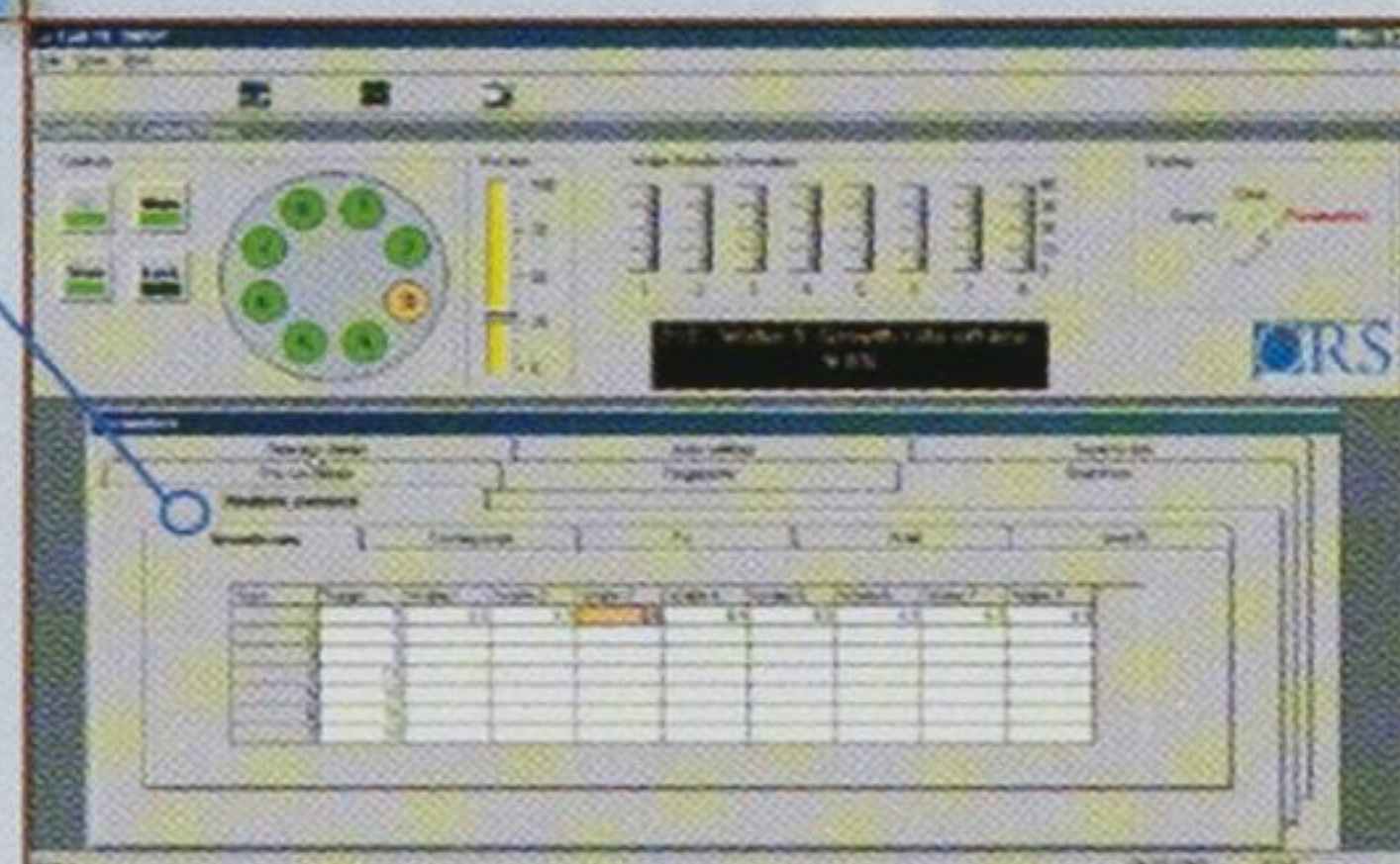
EpiEYE©

The most advanced epi-monitoring system in the world.

Immediate and automatic analysis of reflectance data from all materials on any reactor.

ORS-Ltd products are capable of a wide range of tasks, ranging from:

- Simply recording an interferogram from a wafer in a single-wafer reactor.
- Automatically performing real-time analysis of interferograms recorded from each wafer in a multi-wafer production tool.
- Compatible with multi-wafer production tools reliant on gas-foil rotation



The number 1 choice for process control

BandiT Goes Where Pyrometers Can't!



Band-Edge Temperature Monitor

- Optically-based, real-time wafer temperature sensor utilizing band-edge absorption for GaAs, Si, InP, ZnSe, ZnTe, SiC.
- Ideal for MBE, sputtering, evaporation, or any process where accurate substrate temperature measurement is critical.
- Provides measurements from room temperature through growth temperature with 0.1 degree resolution.
- Features a single USB connection, and utilizes powerful software that can be run from a laptop.

kSA BandiT™

k-Space Associates, Inc.



tel 734.668.4644 fax 734.668.4663 info@k-space.com • www.k-space.com

Freiberger

Gallium Arsenide substrates for micro- and optoelectronics



Semi-insulating VGF and
LEC wafers up to 6"

Semi-conducting VGF and
LEC wafers up to 4"

Comprehensive crystal and
wafer characterization

Bulk material with extremely low
residual impurity concentration

Excellent surface quality
for epitaxial growth

Laser-marking options

**Freiberger
Compound Materials**

Freiberg, Germany:

Phone: +49 3731 2800

Fax: +49 3731 280 106

Dayton, OH, USA:

Phone: (937) 291 2899

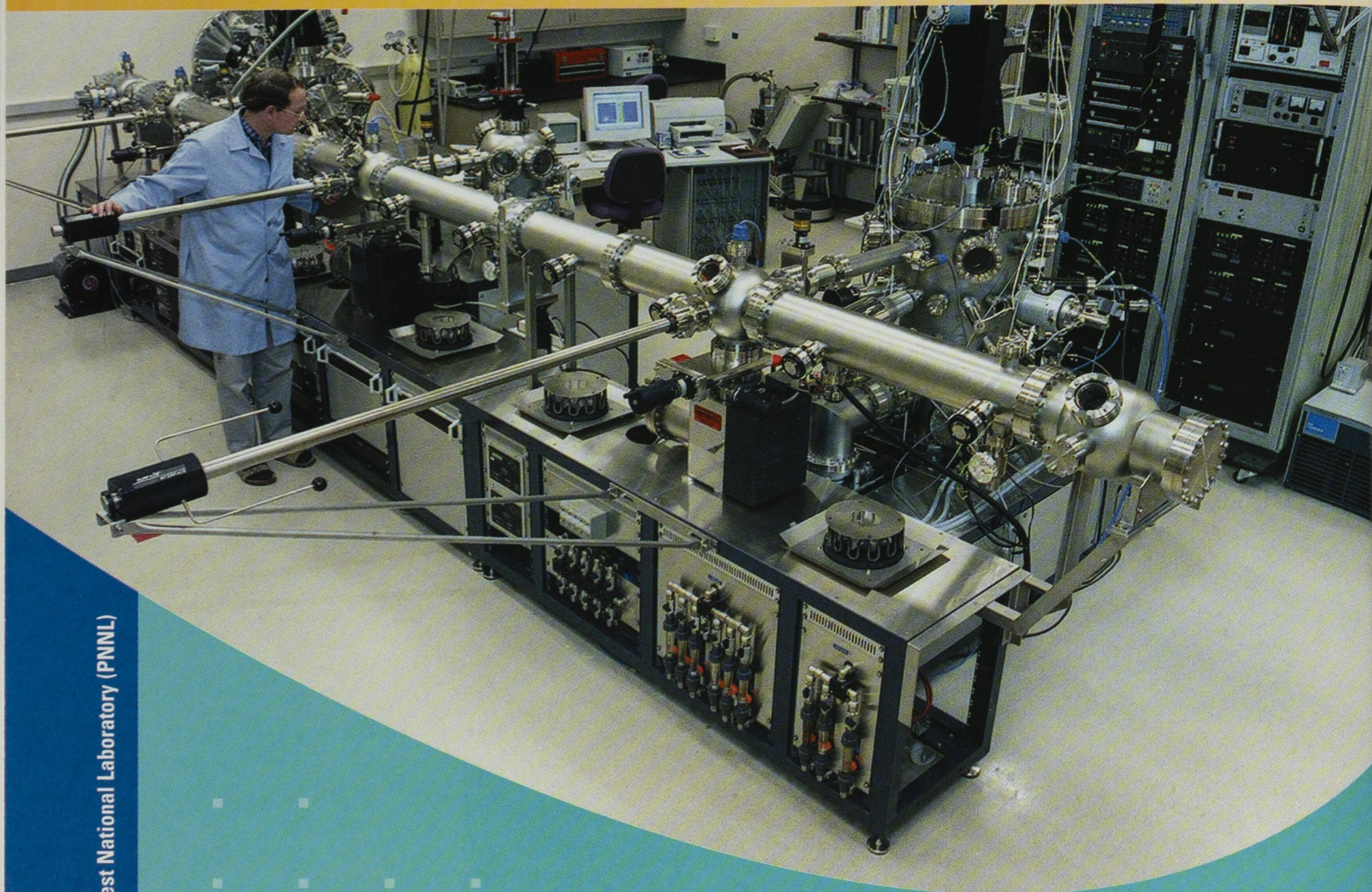
Fax: (937) 291 2898

www.fcm-germany.com

In alliance with the future

Spintronics Research

Proven Technology for Demanding Materials



Courtesy: Dr. Scott Chambers, Pacific Northwest National Laboratory (PNNL)

From spintronics research to GMR device production DCA thin film deposition systems are leading the way forward. Through our expertise in Molecular Beam Epitaxy, UHV sputtering, Ion Beam and Pulsed Laser Deposition we can provide technology for the most demanding thin film processes. Whether it is for custom design R&D system or a turn-key production system DCA has the right solution.

For your nearest representative
please visit our web site at: www.dca.fi
or email us at: info@dca.fi

DCA
INSTRUMENTS

If you need
answers
not surprises



With EpiTT the future
of GaN epitaxy has
never been brighter

EpiTT is the newest development in LayTec's line of unique in-situ epitaxy monitoring tools. It has been especially developed for maximizing yields in mass production GaN environments. Features include measurement of real-time growth rate and true wafer temperature.



LayTec GmbH
Helmholtzstr. 13-14
D-10587 Berlin · Germany
Tel.: +49 (30) 31 80 82 36
Fax: +49 (30) 31 80 82 37
Email: info@laytec.de
www.laytec.de

LayTec
optical sensors for epitaxy

No Surprises!

II-VI Inc and SemiSouth develop SiC epiwafers

SemiSouth Laboratories and II-VI Inc are combining their strengths in SiC substrates and epitaxy to offer a SiC epiwafer service. The collaboration combines 4H-SiC substrate production capabilities at II-VI with a SiC epitaxial material growth technology developed using SiC epitaxy reactors at SemiSouth. The team plans to begin sampling 2 inch diameter SiC epiwafers containing layer structures up to 20 μm thick, with a wide range of n- and p-type doping (5×10^{15} – $1 \times 10^{19} \text{ cm}^{-3}$).

"We believe that close collaboration with

SemiSouth has enabled both companies to make rapid progress in technology development and will ultimately lead to a lower cost of manufacturing," said Thomas Anderson, general manager of the wide-bandgap materials group at II-VI. Anderson said that II-VI obtains valuable feedback from the epitaxial material growth and device work provided by SemiSouth. "This helps us rapidly improve the material quality of our SiC substrates and tailor the substrate to meet specific requirements of SemiSouth's epitaxial process."

In brief...

Rohm to begin SiC Schottky diode production

According to Japanese newspaper *Nihon Keizai Shimbun*, Japanese device manufacturer Rohm plans to begin shipping SiC Schottky diodes in early 2004. At present, the only other commercial producers of SiC Schottky diodes are Infineon and Cree. Rohm, which already manufactures silicon Schottky diodes, uses its own SiC substrates to fabricate the devices, the first generation of which will have a blocking voltage of 600 V.

Kyma completes equipment line of credit

GaN substrate manufacturer Kyma Technologies has completed a \$1.4 million line of credit with GE Technology Finance. Kyma will use the credit facility for equipment purchases and the expansion of its manufacturing capacity. "This equipment line will allow Kyma to move rapidly from R&D to production of our GaN substrates," said CEO Ed Pupa. The company completed a \$4 million series B round of funding earlier this year.

Compound semiconductor pioneers honored with award

Compound semiconductor pioneers featured prominently in the list of names honored with the 2002 National Medal of Technology, the US's highest honor awarded for technological innovation.

Calvin Carter of Cree received his medal for "exceptional contributions to the development of silicon carbide wafers, leading to new industries in wide-bandgap semiconductors and enabling still other new industries in efficient blue, green and white light, full-color displays, high-power solid-state microwave amplifiers, more efficient/compact power supplies, higher-efficiency power distribution/transmission systems, and gemstones".

A team consisting of George Craford of

Lumileds Lighting, Nick Holonyak of the University of Illinois at Urbana-Champaign and Russell Dupuis of the Georgia Institute of Technology were also honored for "contributions to the development and commercialization of LED technology, the world's most efficient light source being mass-produced today, with applications to digital displays, consumer electronics, automotive lighting, traffic signals and general illumination".

Coming in December
**A special issue on LEDs
and solid-state lighting**

Alfalight project targets 80% efficiency lasers

DARPA has awarded diode laser manufacturer Alfalight of Madison, WI, a contract worth \$3.9 million under its super-high-efficiency diode source (SHEDS) project.

Alfalight makes aluminum-free diode lasers based on phosphide structures that emit in the near-infrared. Its devices are used in telecom applications, while its high-power arrays are used to pump industrial lasers.

The SHEDS project is aiming to improve the overall efficiency of high-power diode-pumped solid-state lasers used in industrial and military applications. Further extensions to the contract could result in a total award to Alfalight of \$5.3 million.

Alfalight will use the money to improve the wall-plug efficiency of its diode lasers, which it already claims are the highest-efficiency diode laser bars available in the industry at 51%. "The goal is to achieve 65% by the end of the first 18 months, and to target 80% efficiency by the end of 36 months for a high-power laser array," said a spokesperson.

According to the company, the high effi-

ciency of Alfalight lasers arises from two key characteristics: low electrical resistance and low free-carrier absorption, which minimize electrical and optical losses respectively. The broad-waveguide structure employed also minimizes interaction between light and the doped layers in the device, which further reduces optical loss.

Alfalight believes that it can attain the 65% efficiency goal by evolutionary device improvements. At present, the lasing efficiency is primarily restricted by optical effects (spontaneous emission, scattering and absorption), and to a slightly lesser degree by carrier leakage, Joule heating and band alignment. Money from the award will be used to optimize the semiconductor hetero-interfaces and the waveguide design of the laser. Alfalight also says that it will develop some innovative designs of the quantum-well gain medium to improve efficiency.

However, the company admits that some revolutionary changes to the laser structure will be needed to exceed 70% efficiency.

Indigo InGaAs detector sees visible light

Imaging specialist Indigo Systems of Golenta, CA, has developed a method for processing standard InGaAs that allows the detector material to function in the visible range.

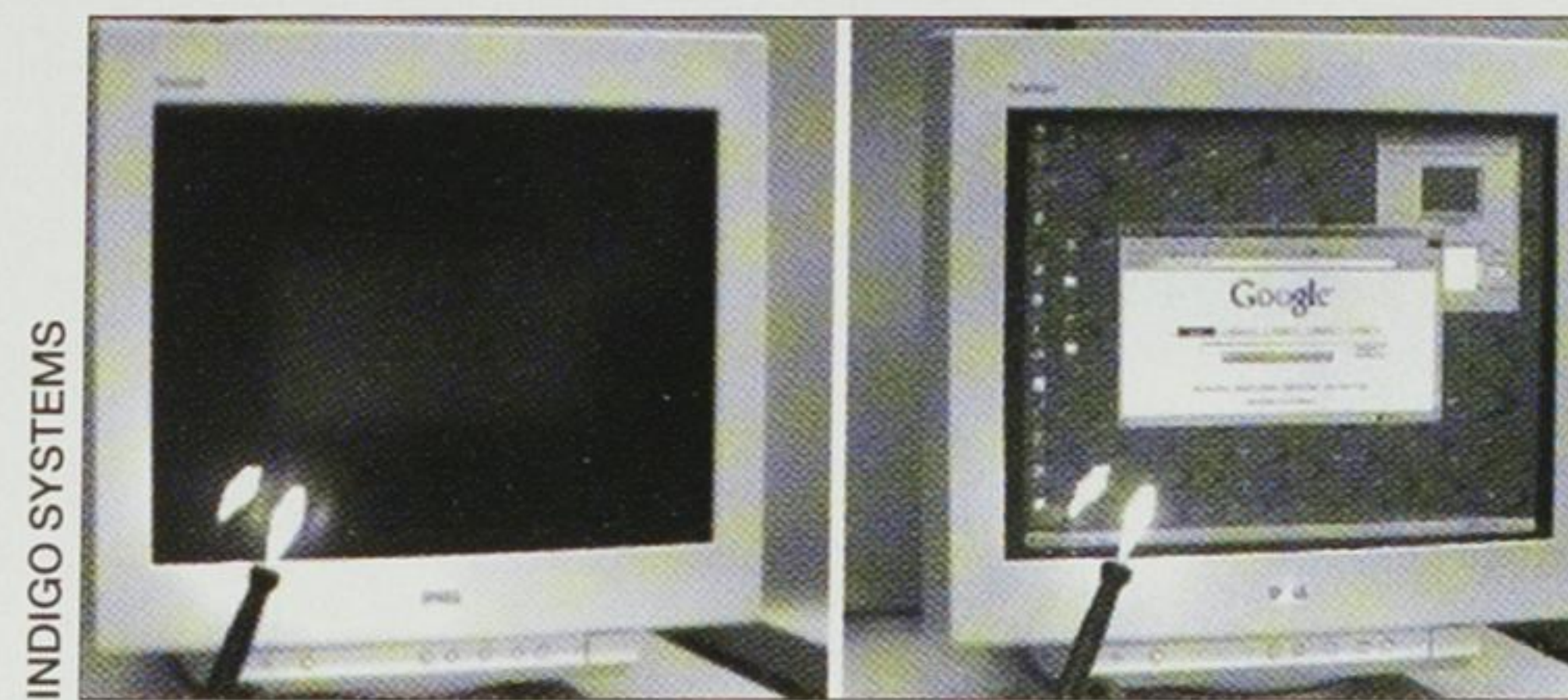
Calling the material "VisGaAs", Indigo says that its tests have shown that the spectral response extends from 1700 nm down to 400 nm, covering the entire visible spectrum. Standard InGaAs detectors operate in the 900–1700 nm range.

Although he wouldn't reveal any details of the new processing method, Indigo's Ted Hoelter told *Compound Semiconductor* that it "did not deviate from our standard InGaAs processing in terms of altering the chemical composition or the material properties".

Hoelter says that the spectral response of VisGaAs slowly decreases from 900 to 400 nm. "At 400 nm, the spectral response is roughly 10% of the peak response," he added.

Indigo says it currently has one customer that will use the new detector to image in both the visible and near-infrared. Other applications could include spectroscopy.

● Infrared camera manufacturer FLIR



Both images show the same computer monitor, a hot soldering iron and a red laser pointer. On the left, a standard InGaAs camera shows almost no response to the visible light from the monitor or the laser spot on the Dell logo. On the right, a VisGaAs camera clearly shows the output of the monitor and the laser spot while maintaining all the near-infrared response evidenced by the hot soldering iron.

Systems of Portland, OR, has announced plans to acquire Indigo Systems. FLIR has offered approximately \$165 million in cash, plus stock options taking the overall value of the deal to \$190 million. The acquisition is expected to close in early 2004, subject to Indigo shareholder approval.

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

CONVERGENCE WITH SILICON

Time for the compounds industry

The integration of silicon and non-silicon technologies is a crucial issue facing the entire semiconductor business. In order to create a successful hybrid industry, the compounds sector needs to adopt business models from its silicon counterpart while developing new technologies, as **Michael Hatcher** reports.

Convergence of the silicon and compound semiconductor industries promises the best of both worlds for device manufacturers – the high performance, flexibility and enhanced functionality of compounds coupled with the low-cost manufacturability and sheer scale of silicon.

GaAs may have once been regarded by many as the material of the future, but gone is the idea that it will directly replace silicon in the years to come. “Gallium arsenide will not replace silicon; the compounds industry has to learn the concepts of the silicon industry,” said Alain Kaloyeros. Kaloyeros is the executive director of Albany Nanotech, a research center at the University of Albany, New York, that is investigating ways to integrate optoelectronic and microelectronic systems at the nanoscale. Kaloyeros is approaching the convergence issue from the perspective of the silicon IC manufacturer.

“Convergence is about the marriage of technological opportunities. It’s about the silicon industry adopting materials and device concepts from the compounds industry and integrating them,” Kaloyeros told *Compound Semiconductor*. “We know that compounds can bring specific benefits [to silicon], and the silicon industry is on the verge of accepting them. The biggest challenge for compounds is to get used to the silicon world.”

To some extent, this is already starting to happen, with the silicon industry embracing epitaxial processes to make strained silicon and SiGe devices, but for Kaloyeros, convergence means more than this. “It means equipment vendors learning that they aren’t just

Veeco's Process Integration Center: imitating the silicon business model

Veeco's Process Integration Center (PIC) is a 15,000 sq. ft cleanroom facility that has been designed to help the company's customers to develop new products and processes. It houses two GEN200 MBE systems and is essentially a place to which companies can outsource product development.

The center, which is housed next-door to Veeco's manufacturing base in St Paul, MN, is an idea that the company has adopted from the silicon industry. Applied Materials, one of the biggest names in silicon-based semiconductor equipment manufacturing, opened its Equipment Process and Integration Center (EPIC) in 1998, and this has provided the inspiration for Veeco's own version to help its customers develop compound semiconductor devices.

According to Hwa Cheng, who heads up the PIC for Veeco, the idea is to help position the compound semiconductor industry for its next upturn, in much the same way that the silicon industry gears up for each successive technology node.

Veeco says that the key benefit for PIC customers is the ability to streamline the product development process and significantly reduce time-to-market. “We work to bridge the gap



VEECO

Veeco's PIC currently houses phosphide, arsenide and nitride growth. It can produce 100,000 devices a year, while there are plans for II-VI materials in the pipeline. MOCVD

between product development and product shipping,” said Cheng. It generally takes around a year to go from ordering a new tool to shipping wafers, and Cheng says that using the PIC can reduce this by 6–8 months for all types of device.

The idea is that while its new MBE tool is being built (a process that takes upwards of 6 months), a Veeco customer can begin the procedure of wafer qualification and device processing on an existing tool at the PIC. Once this qualification is complete, the customer can start to ship devices direct from the PIC tool.

This is what Cheng calls “the silicon capacity”. Meanwhile, the customer's own tool goes through the qualification process and when this is complete, device production can begin. From the PIC to the new device production can begin.

While Veeco ideally wants its customers to order a new tool, they don't have to. The qualification will only be provided if it is requested by the customer, but there are other options. Start-up with a novel device structure without the cash to buy a new system can use the PIC to license their validated process.

selling a machine, but an entire technological process, a total solution.” That may sound like marketing puff, but Kaloyeros says it is critical for tool and equipment suppliers to work hand-in-hand with customers from an early stage in the development process.

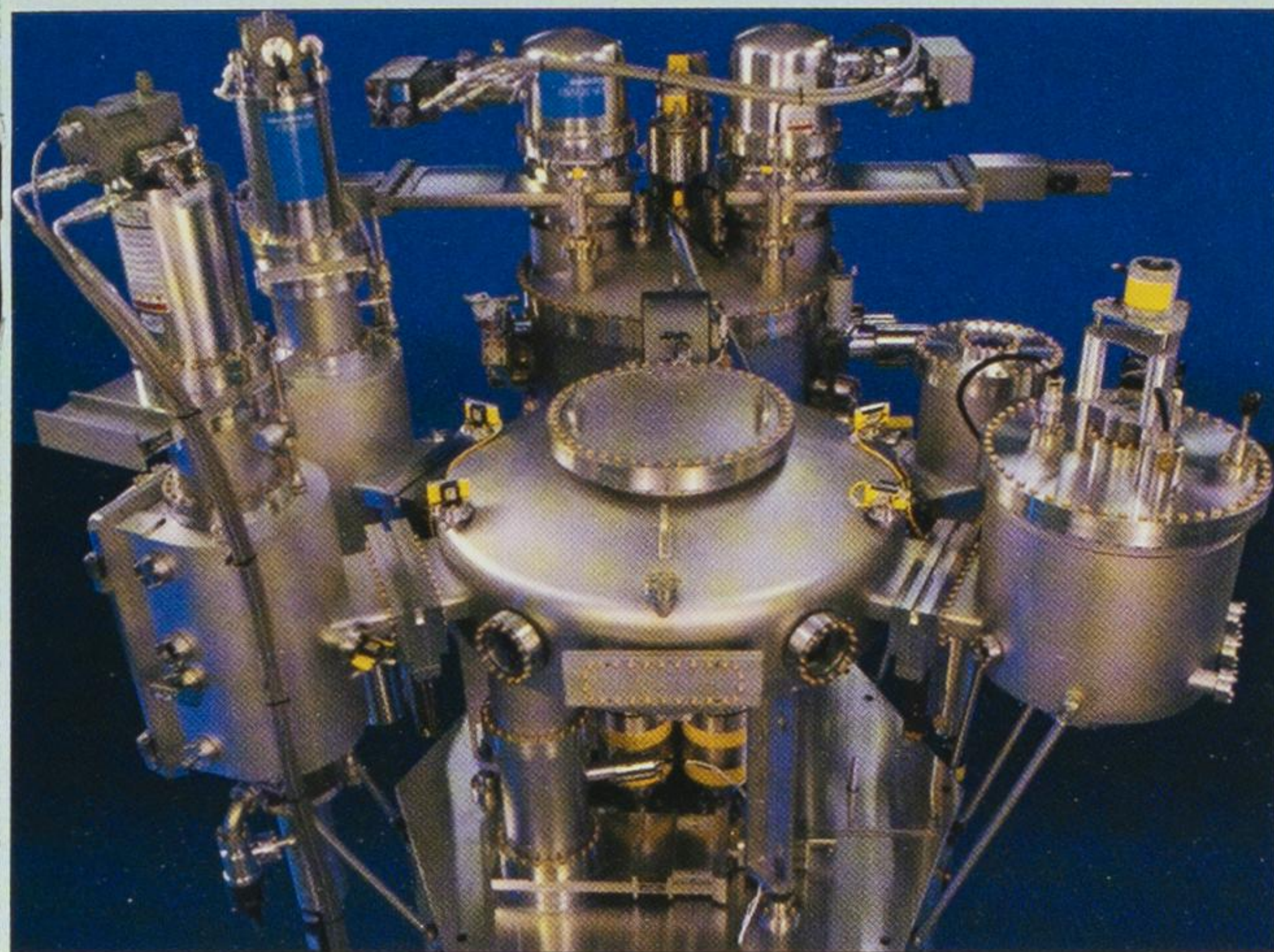
Pioneering PIC

Perhaps the first sign that this silicon-type business model is being initiated in the compounds industry is the recent opening of Veeco's Process Integration Center (PIC). Kaloyeros told *Compound Semiconductor* that the PIC is a “pioneering step” that is lead-

ing the compounds industry in the right direction. “In terms of manufacturing throughput and yield, the compound semiconductor industry is 10–20 years behind silicon,” he said. Kaloyeros believes that the compounds sector has to adopt these kinds of business models to create a hybrid industry. (See box for more information on the PIC.)

Another key requirement for convergence, according to Kaloyeros, is to develop the equivalent of the Semiconductor Equipment and Materials International standards that have been adopted in the silicon industry. “There are no universal standards [for equip-

Industry to adopt silicon concepts



side growth facilities. Antimonide growth will be added next. MOCVD systems are now set to follow.

ng calls the "bridge" while, the customer's through the qualification of this is completed, n can be transferred renew tool. eally wants PIC eran MBE tool, they e "bridge capacity" ded if a tool is ordered bit there are a variety Start-up companies ce structure but to buy an MBE he PIC and then ated process to other

manufacturers. Non-traditional MBE users from the mainstream electronics industry can use the PIC to scale up or validate a proven R&D process in a production environment. Finally, existing compound semiconductor manufacturing companies can transfer their process onto a PIC GEN200 system to help improve process yields without interrupting their own production line, or use the PIC characterization laboratory.

"The PIC is particularly good for companies with limited MBE experience, or those with a limited budget," said Cheng.

ment] in the compound semiconductor industry. The industry needs to adopt a cluster-tool approach that leads to a lower cost of ownership for the customer."

A crucial part of the process will be the drawing-up of a technology roadmap emulating the International Technology Roadmap for Semiconductors (ITRS) that is the cornerstone of the silicon industry. "In the silicon industry, the ITRS is like the Bible," said Kaloyeros. "Everybody's presentation begins with a couple of slides on the ITRS. You just don't get that in the compounds industry."

The problem for the compounds industry

when it comes to roadmaps is that it is a lot more complex than silicon. Whereas silicon is primarily concerned with two key areas – logic processing and memory – compound semiconductor devices fill a much wider range of applications in optoelectronics and microelectronics.

So, rather than joining the ITRS, Kaloyeros suggests that the compounds industry develops its own roadmap, which overlaps that of the silicon industry in the appropriate places.

Serge Otkyabrsky, a colleague of Kaloyeros at the University of Albany, is looking to develop silicon-compatible compound semi-

conductor devices. He cites three key technology areas that are driving the two industries towards convergence. The first driver, he says, is the interconnect "bottleneck" that looms over the silicon industry.

Already installed at Veeco's PIC are GEN200 MBE systems for phosphide and arsenide growth, and at the time of writing a nitride facility was being installed and should now be up and running. Veeco is hoping that its customers will use the tools to develop processes for devices including GaN-based HFETs, InGaP/GaAs HBTs, InP-based HBTs, and 1.3 μm and 1.55 μm VCSELs. So far, one Veeco customer has bought an MBE tool and started to use the PIC. Currently, the tool is producing infrared optoelectronic devices.

Next to come online will be an oxide system, which Veeco says will be used to investigate new material systems for data storage and lighting. Installation is planned for the first half of 2004, while facilities for growing antimonides (with a view to making InSb-based Hall sensors) and II-VI materials (for white-light LEDs) are also in the pipeline.

According to Cheng, some "top-tier" device manufacturers and companies completely outside the normal sphere of the compound semiconductor industry, including data storage, are already negotiating to use the PIC.

● Veeco said that it plans to integrate MOCVD systems with the PIC, following its recent purchase of Emcore's MOCVD business (see p35).

conductor devices. He cites three key technology areas that are driving the two industries towards convergence. The first driver, he says, is the interconnect "bottleneck" that looms over the silicon industry.

The problem is not with increasing the speed of individual chips, to do which there are realizable technologies capable of extending Moore's Law well into the next decade. The stumbling block is to keep the individual chips communicating with each other sufficiently quickly as their processing speed becomes ever faster. The communication speed possible in metal wire connections is approaching its theoretical limit as the complexity of chips increases and their size decreases. The narrower the interconnects are, the bigger the problem of electron scattering becomes. For copper interconnects, resistivity becomes a problem when the wires reach a line width of 39 nm.

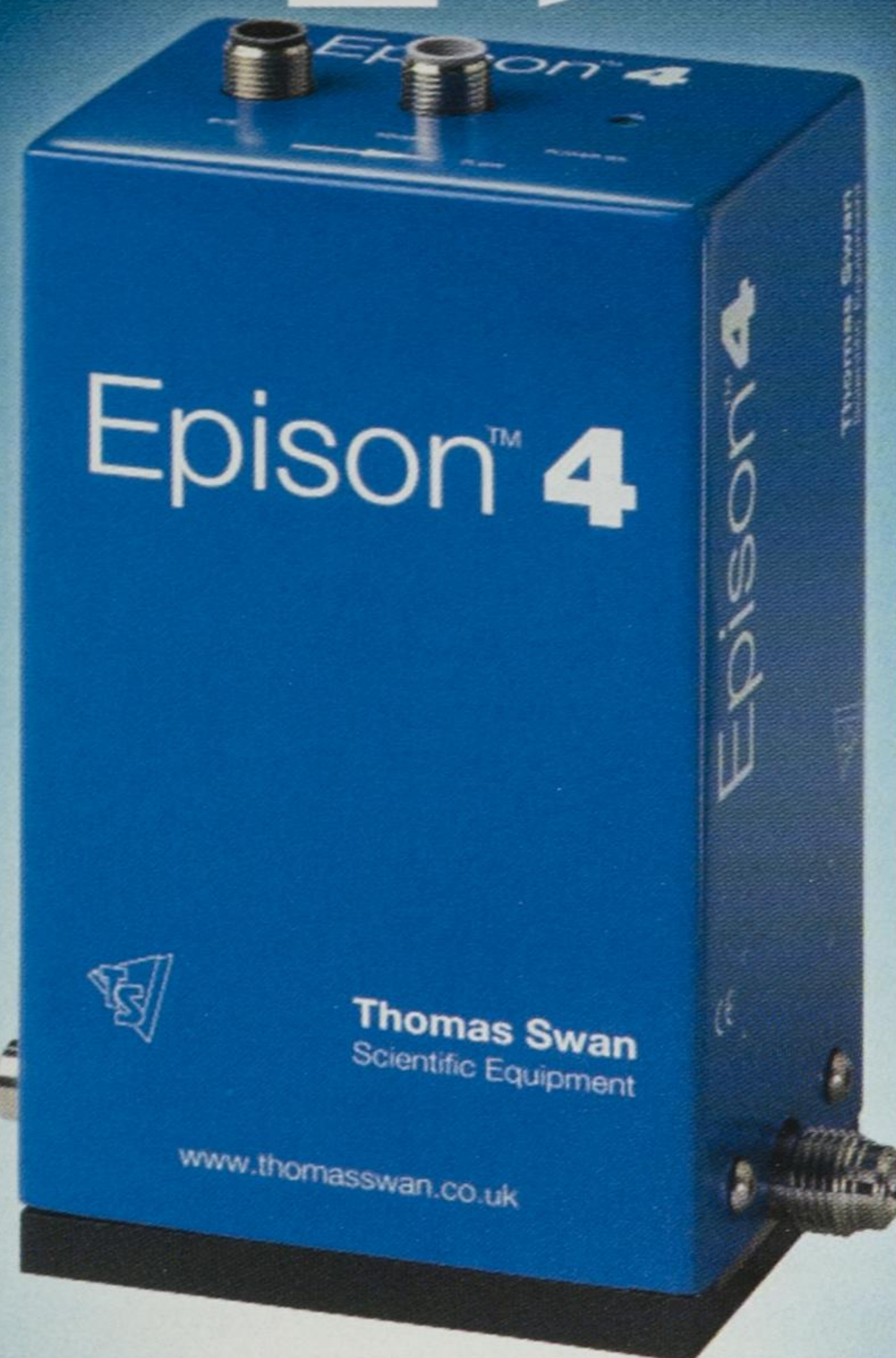
Optical solution

The precise timing of this bottleneck is a matter of some debate, but copper interconnects are expected to continue to scale for the next three to five years before novel technology is needed. One solution would be to integrate optical interconnects at first the system level, then at the board, and ultimately at the chip level. "We need photons to solve this problem, as they don't interact with each other like electrons do," Otkyabrsky said. Being an indirect-bandgap semiconductor, silicon doesn't emit light very well, so compound devices are essential if optical interconnects are to be realized.

A key recent development in this area is the collaboration between IBM and Agilent Technologies (*Compound Semiconductor* October 2003 p16) in a \$30 million funded project for the Defense Advanced Research Projects Agency. With two of the biggest companies from the silicon and optoelectronics industries working together, some exciting developments are expected.

The second driving factor, says Otkyabrsky, is the convergence of telecommunications and silicon ICs, which will demand integration of optical and wireless technology with silicon. The speed of communication is now driven largely by the speed of optical links, and to keep up, optical speeds will need to extend all

new 4yo



- The Next Generation of an Industry Standard: Epison 4 OM Gas Concentration Analyser
- Improved accuracy, extended to lower concentration, better signal to noise ratio
- Optimised design – integrated ultrasonic cell and control unit
- DeviceNet and Profibus fieldbus communications for system integration

Thomas Swan
Scientific Equipment Ltd
Buckingway Business Park
Swavesey
Cambridge CB4 5FQ UK

t +44 (0)1223 519444
f +44 (0)1223 519888
e sales@thomasswan.co.uk
www.thomasswan.co.uk



Thomas Swan
Scientific Equipment

A member of the AIXTRON group of companies

COVER STORY CONVERGENCE WITH SILICON

compoundsemiconductor.net

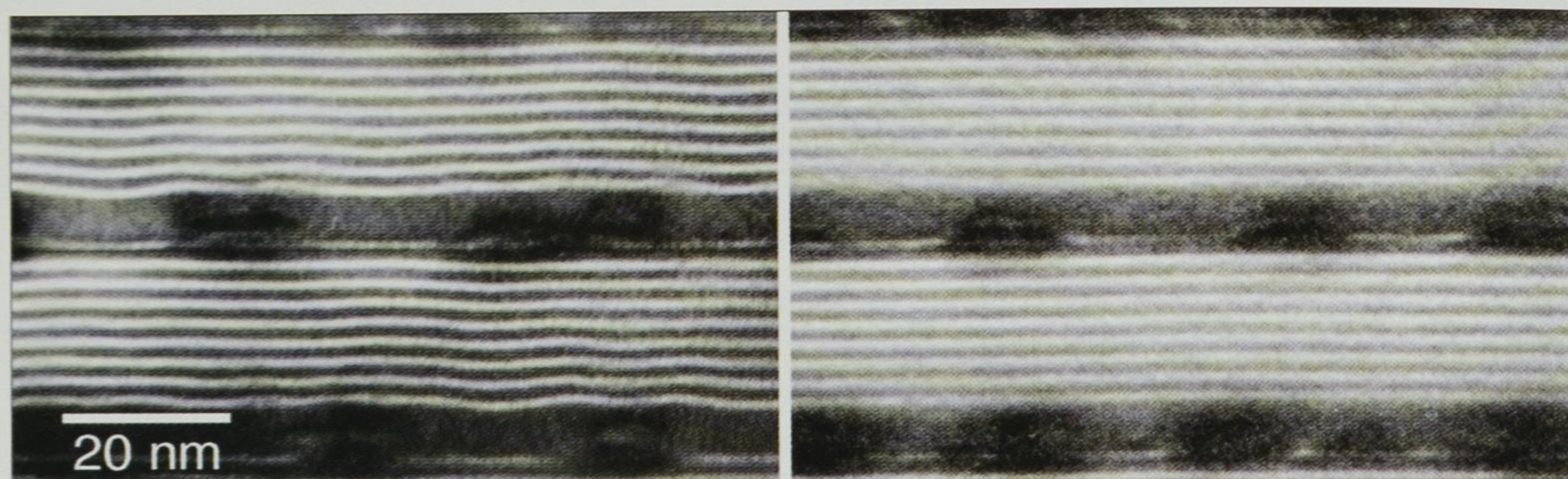


Fig. 1. These TEM images show that under normal growth conditions, the device layers are slightly wavy (left), but the “truncated” quantum-dot structures engineered by the Albany team improve the layer uniformity (right), enhancing electron-hole recombination and producing better high-temperature performance.

the way to the chip.

According to Otkyabrsky, the third driver of convergence is the potential use of optical clocks in silicon ICs. He says that a good global clock will be crucial to maintaining good communications within current silicon IC architecture, and that an optical clock is one way to do this.

With the marriage of optoelectronics and silicon central to the convergence issue, Otkyabrsky has been concentrating on developing semiconductor light sources that are compatible with silicon.

“The problem is that current optical sources do not meet silicon requirements. For example, III-V optoelectronic devices are usually thermally stabilized, but a silicon chip gets very hot when it is in use,” he explained.

Silicon chips don’t heat up in a regular fashion either; instead, “hot-spots” tend to form, sometimes reaching 100 °C. This is exacerbated by the fact that the position of the hot spots aren’t precisely known. These problems will require a semiconductor laser that can withstand sudden, and potentially very large, changes in temperature.

Quantum-dot advantages

Otkyabrsky believes that quantum-dot VCSELs may be the answer to this particular integration problem. The predicted performance of quantum-dot lasers suggests that these ought to offer a number of advantages over quantum-well devices. However, the actual performance of quantum-dot VCSELs has not quite lived up to expectations, he says.

“They do show the expected low threshold current, but this isn’t such an important characteristic for us. The real benefit of quantum-dot lasers should be their thermal stability.” For chip-level interconnects, the operating temperature needs to be in the 80–120 °C range, but the current state-of-the-art quan-

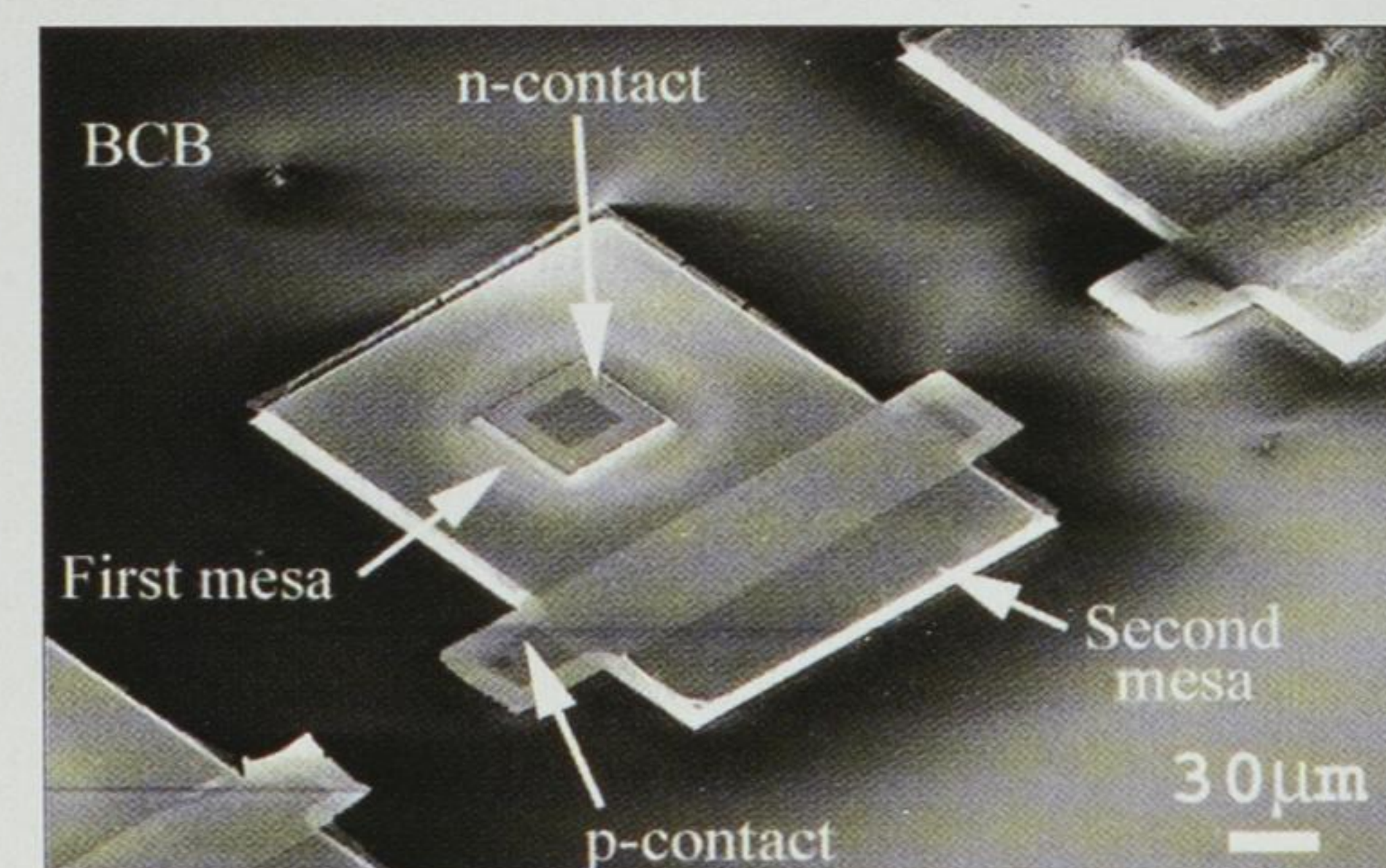


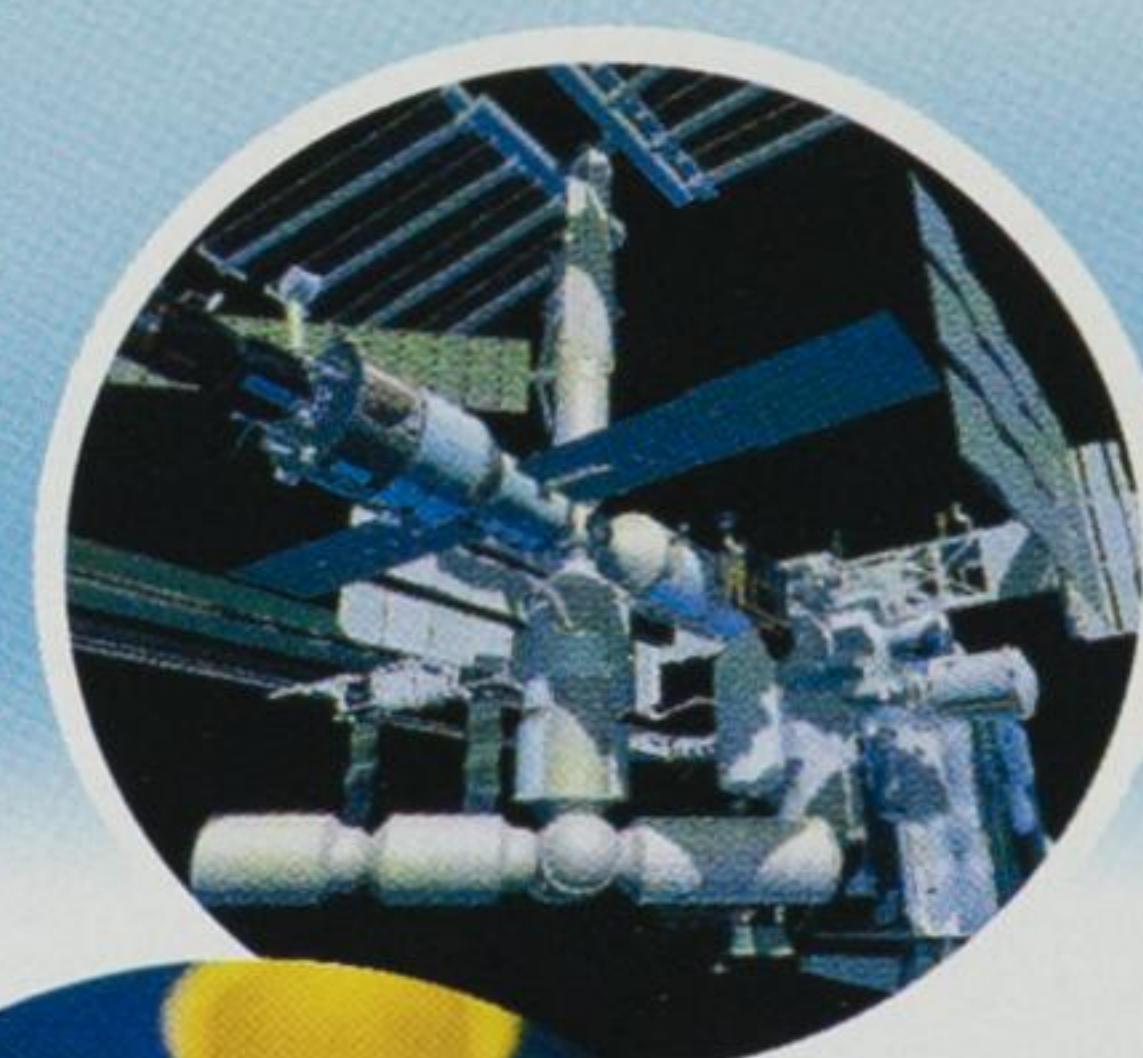
Fig. 2. Serge Otkyabrsky and colleagues at the University of Albany bonded this InAs quantum-dot VCSEL to a silicon substrate using a BCB intermediate layer. The Albany team has greatly improved the performance of the VCSEL at high temperatures by engineering the shape of the quantum dots.

tum-well VCSELs are only stable up to 40 °C.

Along with colleagues at the University of Albany, Otkyabrsky has improved the thermal stability of InAs quantum-dot VCSELs by what he calls “shape engineering”. Growing the quantum dots by MBE, the Albany team adjusted the thickness of the GaAs overlayer and used an additional heating step. This truncates the shape of the dots and improves defect tolerance in the laser by two orders of magnitude (figure 1). The upshot is that shape-engineered quantum-dot lasers operate at up to 219 °C, compared with a previous best of 167 °C.

The quantum-dot lasers have been bonded to a silicon substrate using BCB (figure 2) to illustrate how an integrated silicon-optoelectronic chip might look.

In developing silicon-compatible optoelectronics, scalability will become a critical issue. The silicon industry is used to working with technologies that can be applied for three or four generations of product, and optoelectronics will have to prove its scalability before it is accepted.



Wafer sizes to:
GaAs 150mm
InP 150mm
Ge 100mm

Low EPD
Epi-Ready
High Mechanical Strength
Excellent Electrical Uniformity

VGF - The Right Choice For Compound Semiconductors

USA Corp office

American Xtal Technology
 4487 Technology Drive
 Fremont, CA 94538
 U.S.A
 Tel: 510-226-4300
 Fax: 510-683-5901
 E-mail: sales@axt.com

Taiwan

Conary Enterprise Co., Ltd.
 9F No.28, Sec.3
 Nan-King East Road
 Taipei, Taiwan, R.O.C
 Tel: +886-2-2509-1399
 Fax: +886-2-2501-6279
 E-mail: sale@conary.com.tw

Korea

Iantek Corporation
 CheongMyung Towntel 607
 1021-4 YeongTong-Dong PalDal-Gu
 SuWon-Si, KyungGi-Do,
 442-813, Korea
 Tel: +82-31-204-4221
 Fax: +82-31-204-4220
 E-mail: iankim@kebi.com

Japan

AXT-Japan
 302 Urban Plaza Lzumi
 2-26-4 Myojin-cho
 Hachioji, Tokyo
 192-0046 Japan
 Tel: +81-426-56-2032
 Fax: +81-426-56-6885
 E-mail: yohashi@axt.co.jp

China

Beijing Tongmei Xtal Technology
 4 Eastern Second Street
 Zhangjiawan Ind. Development Zone
 Tongzhou District
 Beijing, China 101113
 Tel: +86-10-6156-2241
 Fax: +86-10-6156-2245
 E-mail: sales@axt.com

United Kingdom & Scandinavia

West Associates Ltd.
 73 Lodge Close
 Cobham, Surrey
 United Kingdom, KT11 2SQ
 Tel: +44-1932-868-006
 Fax: +44-1932-860-932
 E-mail: westonweb@compuserve.com

France & Germany

Geo Semiconductor Ltd.
 4 Quai Gustave Ador
 POB 6464
 CH-1212 Geneve 6
 Switzerland
 Tel: +33-145-3162-84
 Fax: +33-145-3339-43
 E-mail: ralph_hananel@compuserve.com

Let's grow together

Germanium Wafers For GaAs-based applications

Up to 8 inch wafers / Zero EPD and Epi-ready / Minimum thickness 120 μm
N-type resistivity 0.020 - 50 $\Omega\cdot\text{cm}$ / P-type resistivity 0.003 - 50 $\Omega\cdot\text{cm}$

Umicore Electro-Optic Materials is a leading supplier of germanium substrates. Since the early nineties we have provided the telecom industry with epi-ready germanium wafers for the production of gallium arsenide-on-germanium solar cells for satellites. Thanks to the matching thermal and crystallographic properties of germanium with GaAs, large size epi-ready germanium substrates provide a

cost effective alternative for your epitaxial growth of III-V compounds. This opens opportunities for the most demanding applications both on and off the planet.

Umicore Electro-Optic Materials is currently starting production of InP substrates and is also developing SiC substrates.

Umicore Electro-Optic Materials

Watertorenstraat 33, B - 2250 Olen, Belgium, Tel: + 32 14 24 57 02, Fax: + 32 14 24 58 00, substrates@umicore.com, www.advancedmaterials.umicore.com

Solar cell manufacturers come back down to Earth

For III-V solar cell manufacturers, it is Earth rather than space that represents the final frontier. However, recent advances in the performance of cells and high-concentration optical modules suggest that multi-junction photovoltaics can infiltrate the silicon-dominated terrestrial energy market. **Michael Hatcher** reports on the latest developments.

While multi-junction III-V cells now dominate the solar energy market for space applications, their cheaper silicon rivals have maintained a stranglehold on the terrestrial photovoltaics industry.

Large-scale terrestrial solar power plants that are currently being built in Arizona and Australia rely on silicon cells, despite recent advances that have seen multi-junction cell efficiencies reach almost double that of their silicon counterparts.

Late last year the US company Amonix installed the first 35 kW unit of the 1 MW solar energy plant that it is building in Arizona. By June this year, the plant's installed capacity had reached almost 600 kW. Meanwhile, the Japanese solar systems builder Kyocera is stepping up its manufacturing output to 120 MW per year to meet increased demand for residential solar energy.

Given this dominance of silicon technology in Earth-bound photovoltaics, the opportunities for III-V technology might seem limited. However, the latest III-V technology from Emcore, Spectrolab and Sharp looks likely to change this scenario in the medium term.

This year, all three companies have pushed the efficiency of their multi-junction cells towards the 40% mark. In May, Japan-based electronics giant Sharp announced the development of its 36.5% efficiency InGaP/InGaAs/Ge cell at the 3rd World Conference on Photovoltaic Energy Conversion in Osaka. At the 11th Biannual Workshop on OMVPE in July, Boeing subsidiary Spectrolab of Sylmar, CA, announced that it had developed a 36.9% terrestrial concentrator cell (figure 1). Emcore Photovoltaics has produced its own terrestrial triple-junction cells with an efficiency of 30% at 200 suns concentration, and recently won a contract to supply the solar panels for the two STEREO satellites being built by Johns Hopkins University.

In terrestrial applications, direct sunlight

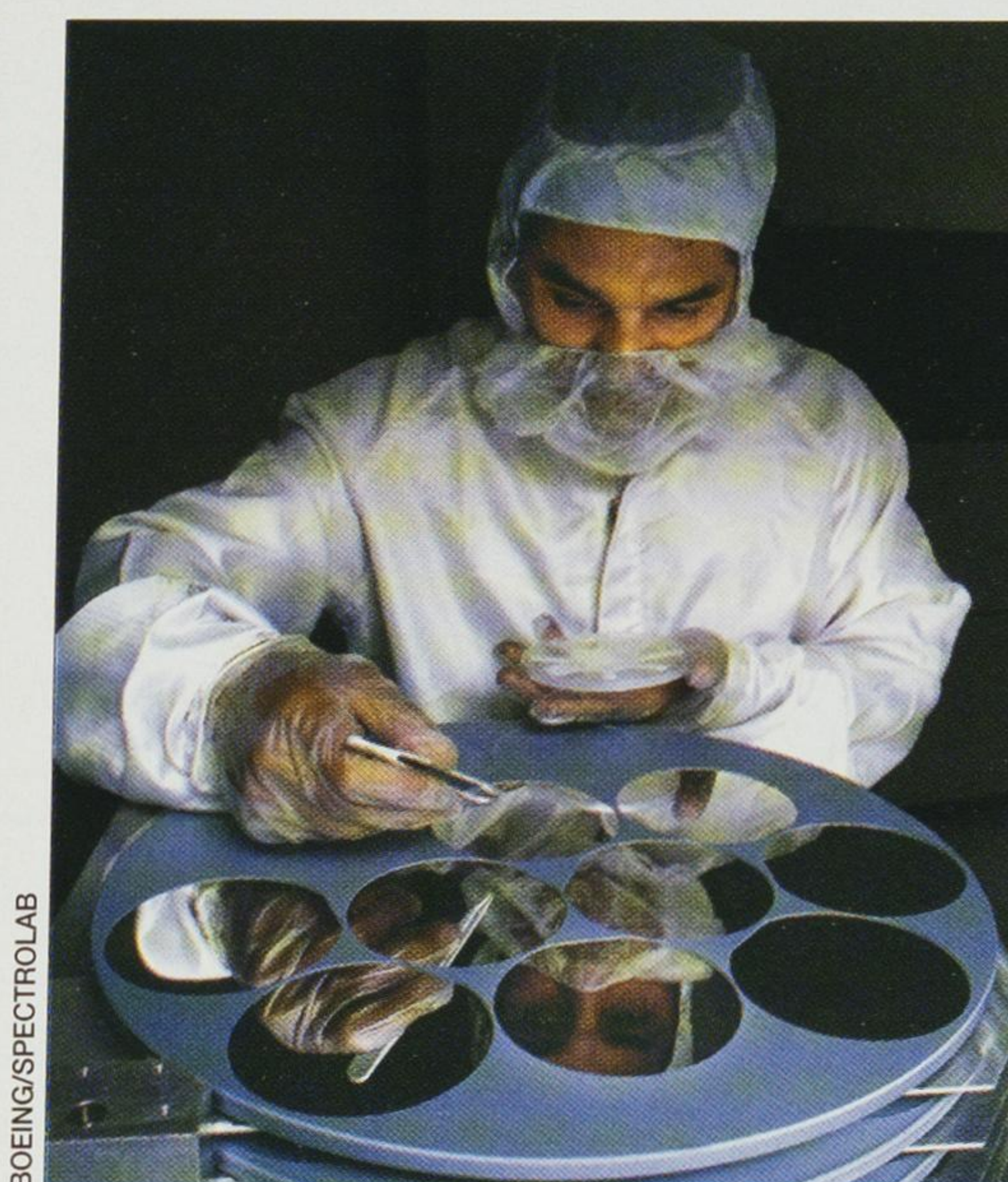


Fig. 1. Spectrolab wafers being prepared for epitaxial growth. The company's solar cells recorded a world record conversion efficiency of 36.9% earlier this year.

must be concentrated onto the multi-junction cells using focusing optics. A significant advantage of these concentrator systems is that fewer solar cells are required to achieve a specific power output, thus replacing large areas of semiconductor materials with relatively inexpensive optics that provide optical concentration. The higher cost of multi-junction cells is offset by the use of fewer cells. Their higher efficiency means that only a small fraction of the total cell area is required to generate the equivalent power output, compared with crystalline silicon or thin-film flat-plate modules.

Nasser Karam, Spectrolab's vice-president for Advanced Technology, told *Compound Semiconductor* that recent improvements in space cells should result in better efficiency for terrestrial cells. "During the last few years, multi-junction solar cells have doubled the

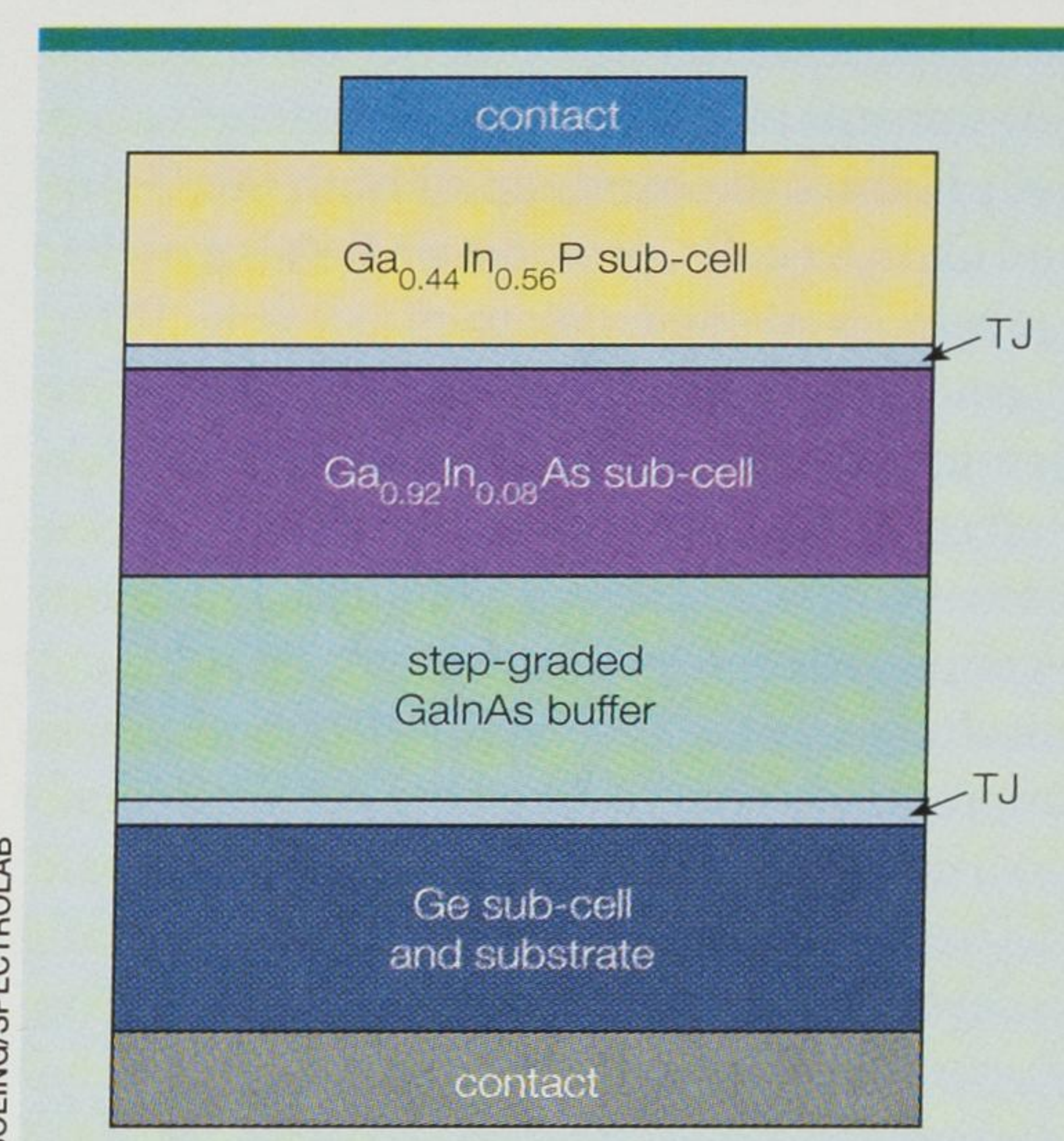


Fig. 2. Spectrolab's "metamorphic" triple-junction cell. The alternative lattice-matched structure lacks the step-graded buffer and has a lower In concentration and a wider bandgap in the GaInP and GaInAs layers in the top two sub-cells.

power output of large commercial satellites, and substantially improved their revenue-generating capability. We believe that further optimization of terrestrial concentrator cells will yield the potential to surpass 40% conversion efficiency," he said.

One of the major stumbling blocks in adapting multi-junction cells for terrestrial use has been the tunnel junction used to combine the currents produced from each of the three sub-cells. Compared with space applications, terrestrial solar modules with a high sunlight concentration ratio generate a much higher current density than the tunnel junctions had originally been designed to handle. Further complications arise from the need to extract current and heat efficiently from the cells without causing hot spots that can degrade cells.

Spectrolab has been tackling the tunnel junction issue on two fronts, by developing

both lattice-matched and metamorphic solar cells. In the first approach, the idea is to match the lattice spacing in all three junctions to address the terrestrial spectrum. However, in both dual- and triple-junction cells, the bandgap combination of 1.8–1.9 eV for the GaInP top cell and 1.424 eV for the GaAs junction is not ideal for either the space or terrestrial spectrum. According to Spectrolab, the conversion efficiency can be improved by grading the composition of a GaInAs buffer on a germanium substrate. In this lattice-mismatched or “metamorphic” approach (figure 2), the top two sub-cells can then be grown with a higher indium content and larger lattice constant than the lattice-matched cells. This lowers the bandgap of both the GaInP and GaInAs cells, providing a better match to the terrestrial solar spectrum.

Karam said that the metamorphic and lattice-matched structures were “neck and neck” in terms of the progress made so far. The lattice-matched structure has shown a 32.5% conversion efficiency, with the metamorphic cell reaching 31.3%. “We believe that both can be improved further to reach the 40% efficiency goal under concentration in the future,” he said.

Crucially, Spectrolab’s new cell and receiver designs are said to be capable of supporting concentrator modules that increase the sun’s irradiation by up to a factor of 1000. In Spectrolab’s tests on cells optimized to operate at 300 suns concentration, the cells successfully withstood prolonged illumination under 997 suns concentration, although conversion efficiency dropped to 27.9% from 34.2% at 161 suns.

Mark O’Neill is president of Entech Solar, a company based in Keller, TX, that builds concentrator solar energy systems. Entech made the 720 Fresnel lenses that were used to concentrate sunlight onto 3600 dual-junction cells used to power NASA’s Deep Space 1 probe launched in 1998, which included the first solar array to use dual-junction cells as a spacecraft’s major power source.

One of Entech’s latest developments for the space market is a prototype wing (figure 3) that houses four complete 50 cm long photovoltaic receivers consisting of 14 triple-junction cells each. Spectrolab and Emcore each supplied two of the receiver modules. Entech has come up with a new prismatic cell cover that eliminates the normal gridline shadowing loss on the solar cells, and O’Neill says that the best of the receivers achieved 31% average cell efficiency and 27.5% net lens/receiver efficiency.

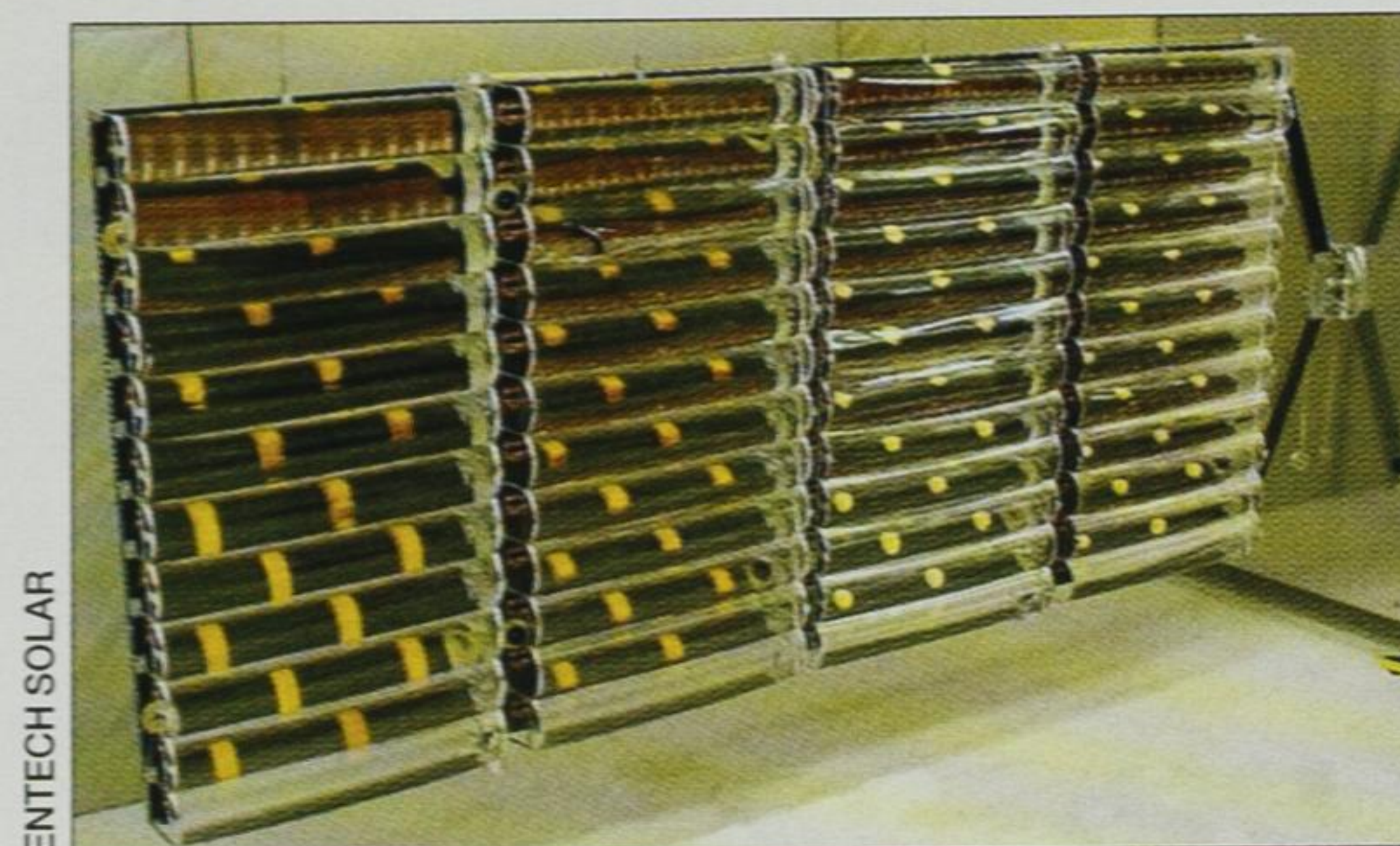


Fig. 3. Entech Solar’s stretched lens array optics concentrate sunlight onto this prototype triple-junction cell solar wing for space applications. Cells from both Spectrolab and Emcore Photovoltaics are used.

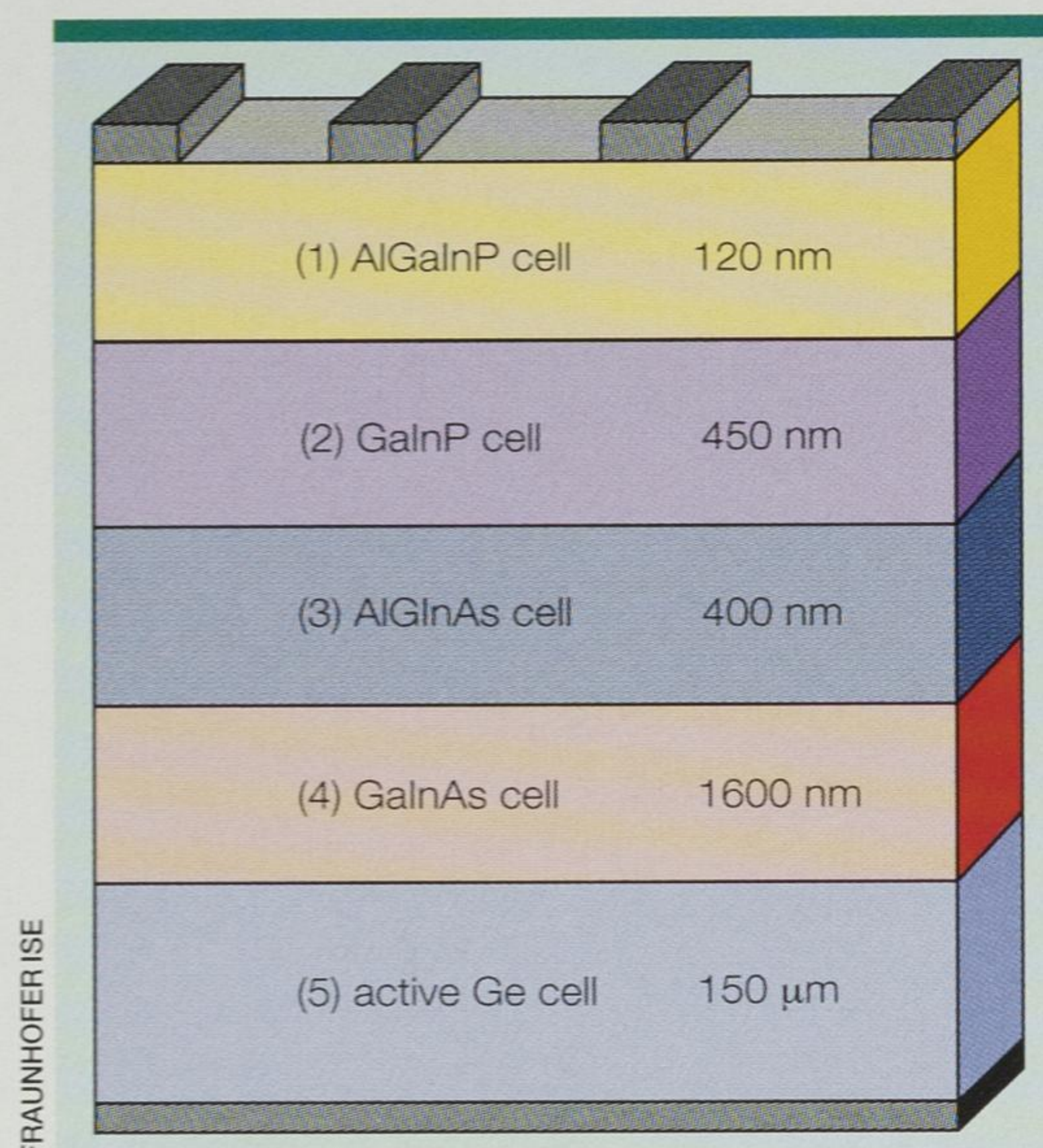


Fig. 4. Fraunhofer ISE researchers have built a five-junction solar cell based on this structure, which features better radiation hardness for space applications.

O’Neill and his company have been fielding silicon-based terrestrial systems for the past 15 years, and developing terrestrial concentrators based on multi-junction cells for the past four years. The aim is to double the operational solar-electric conversion efficiency of silicon-based systems.

In order to challenge silicon-based cells on the terrestrial front, O’Neill has calculated that III-V concentrator cells must operate at a few hundred suns concentration. “Our approach to using such cells in the next generation of our terrestrial equipment is relatively simple – operate at a high enough concentration ratio (about 400 suns) so that the cells are so small that they become cost-effective,” he explained. The calculation is based on the assumption that multi-junction cells are around two orders of magnitude more expen-

sive per cm^2 than silicon cells. By focusing sunlight in two planes in a 21:1 ratio, the concentration increases to 440 suns.

O’Neill is bullish on the prospects for multi-junction cells in terrestrial applications: “The multi-junction cells developed for spacecraft in the 1990s provide such a huge performance advantage over silicon that the terrestrial concentrator market is certain to explode when such cells are incorporated into cost-effective systems,” he said. “At the end of the day, I believe that high performance will win on the ground just like it has already won in space.”

Karam claims that Spectrolab is the only company to have deployed multi-junction cells in both terrestrial and space-based photovoltaic systems. “We have had our multi-junction cells operating inside several high-concentration modules. The longest test data we have is on a terrestrial system that has been in the field for six months now. I am confident that the technology is viable,” he said. While all of the terrestrial systems built so far are relatively small, and capable of generating kilowatt output, Karam predicts that megawatt-scale concentrator systems will be deployed in the next decade. He told *Compound Semiconductor* that for III-V-based concentrator modules to infiltrate terrestrial photovoltaics the key requirement now is financial support: “We are looking for governments and utilities to embrace the technology. If individual companies are expected to put up all the investment, entering the terrestrial market will take a very long time.”

Emcore Photovoltaics’ director of sales and marketing Patrick Park says that his customers are looking to introduce commercial terrestrial systems in 2005. “Governments and utilities are warming up to it,” he said.

The concentrator systems need direct sunlight to work. As a result, the likely deployment of III-V concentrator photovoltaics will be restricted to regions of reliable sunshine. Spectrolab has drawn up a map of the places where concentrator photovoltaic systems are most likely to succeed.

According to Karam, there is plenty more scope for further improving the cell efficiencies by adding more junctions. Four-, five- and six-junction cells are all being pursued. In the Spectrolab technology roadmap (see table on p27), triple-junction cell efficiency based on the existing structure is predicted to reach 40% in 2005, with five-junction devices expected to reach 45% in 2007.

It is not just Spectrolab that is looking at increasing the number of junctions per cell.

Researchers at the Fraunhofer Institute for Solar Energy Research in Freiburg, Germany, have fabricated five-junction cells that are based on layers of AlGaInP, GaInP, AlGaInAs, GaInAs and Ge grown by MOVPE (figure 4). These particular cells have been designed with extra radiation hardness in mind for space applications, but could also be adapted for terrestrial use.

Although further improvements in cell efficiency would undoubtedly be welcome, the critical issue now appears to be one of financial support for the developers of the III-V solar cells and modules to enable the technology to get a foothold in terrestrial energy. Sarah Kurtz, a senior scientist at the National Renewable Energy Laboratory in Golden, CO, is urging the US funding bodies to pool some resources to fund research into III-V photovoltaics and solid-state lighting based on HB-LEDs. Currently, the two areas are dealt with by different funding bureaus.

Kurtz believes that there are technological issues common to both LEDs and concentrator photovoltaics that could be addressed in joint studies. For instance, concentrator cells

Spectrolab's technology roadmap

Year	Solar cell type	Efficiency (%)
1995	single-junct GaAs/Ge	24
1997	dual-junct GaInP/GaAs/Ge	27
1999	triple-junct GaInP/GaAs/Ge	32
2001	triple-junct AlGaInP/GaAs/Ge	34
2003	triple-junct AlGaInP/GaAs/Ge	36.9
2005	triple-junct AlGaInP/GaInAs/Ge	40
2007	five-junction	45
2009	six-junction	>45

BOEING/SPECTROLAB

in the field will go through cycles of getting very hot during the day and cold at night. After thousands of such heating cycles, delamination of bonded parts within the cells could become a problem. Kurtz says that the experience gained by LED manufacturers could come in useful here. Protecting the cells from weathering effects such as ultraviolet exposure will also need to be dealt with and, again, the experience that LED manufacturers have in encapsulating devices could be invaluable.

A completely different breed of compound semiconductor materials is also making headway in photovoltaics. First Solar of

Perrysburg, OH, is taking the low-efficiency, low-cost approach with its CdTe and CdS solar modules. The modules are based on CdTe and CdS films deposited by vapor transport deposition. This process involves vaporizing CdTe or CdS powders, using a carrier gas to transport the vapor and allowing the material to settle on a glass superstrate.

First Solar began pilot-line production in 2002 and is planning to increase output from the current level of 2 MW per year to 25 MW per year by November 2004. The average module conversion efficiency is only 8%, but First Solar is aiming to increase this to 13% over the next five years by improving the deposition technique to reduce variations in grain size, crystallographic orientation and structural defect density.

Whether it is this relatively low-technology approach or the more expensive high technology that has evolved from solar panels used in space applications that is ultimately more successful remains to be seen, but compound semiconductors look like becoming a fundamental element of the terrestrial solar energy market.

NSC

NANOSEMICONDUCTOR

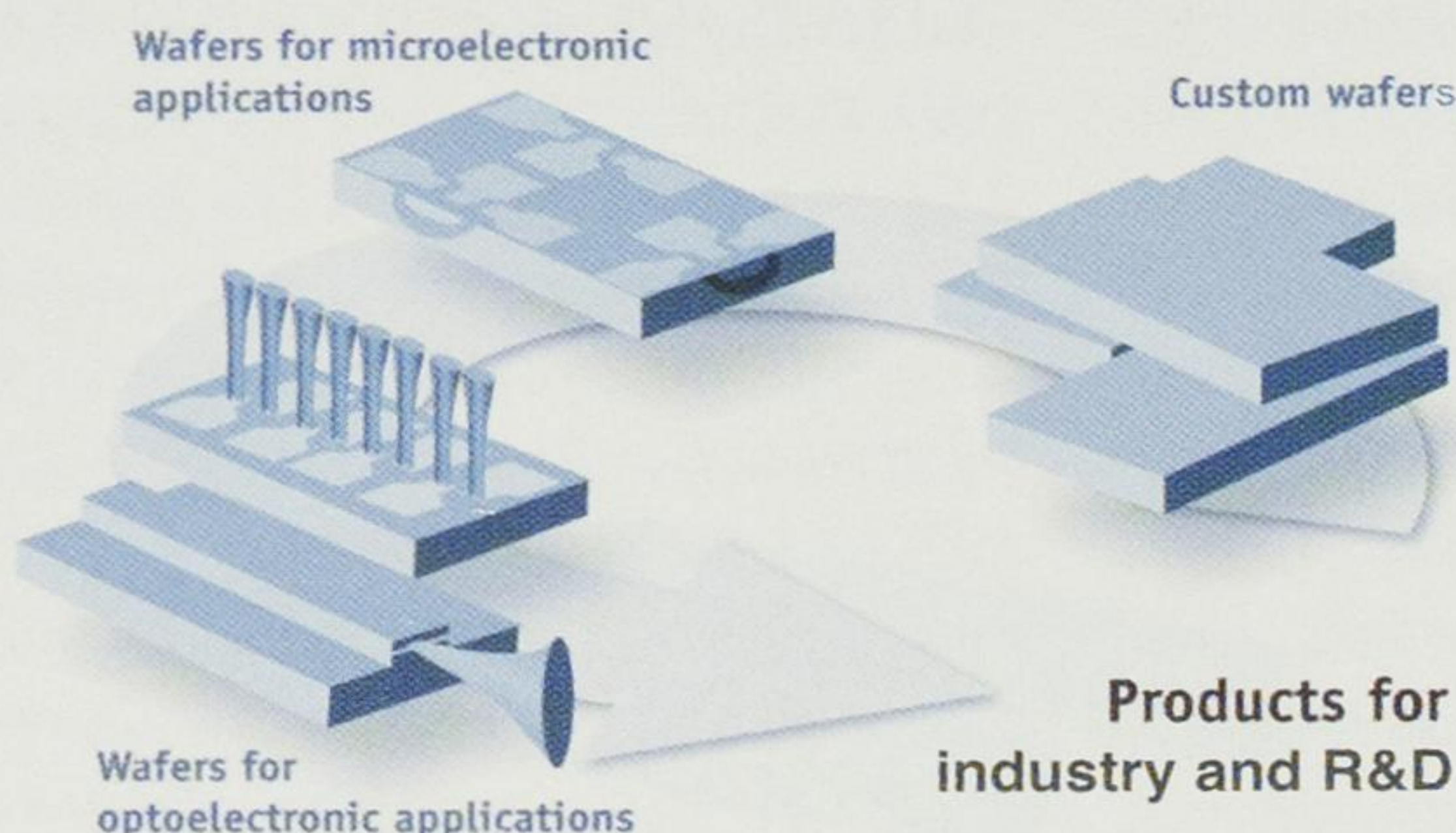
MBE foundry for advanced Quantum Dot and Quantum Well wafers

Our product range:

Pseudomorphic GaAs Wafers	Wavelength range
Quantum Dot Edge Emitting Laser (EEL) or VCSEL structure	within 0.78 μm - 1.3x μm
Quantum Dot structures for SOAs and gain chips	within 0.78 μm - 1.3x μm
Quantum Well EEL or VCSEL structure	within 0.78 μm - 1.1x μm
Metamorphic GaAs Wafers	Wavelength range
GaAs Quantum Dot Edge Emitting Laser (EEL), SOAs, gain chip or VCSEL structure	within 1.4 μm - 1.5x μm

Wafers for: pHEMTs, mHEMTs, HBTs, QW and QD photodetectors, LEDs, GaAs Quantum Dot structures for photo/electro luminescence (0.8 μm - 1.5x μm) and resonant tunneling studies and other epi-products.

Your partner in the development of custom-design products!



NSC-Nanosemiconductor GmbH Joseph-von-Fraunhofer-Str. 13
44227 Dortmund, Germany Tel: +49 231 9742 7003 Fax: +49 231 9742 7030
info@nanosemiconductor.com www.nanosemiconductor.com

BANDWIDTH SEMICONDUCTOR



With a cohesive and complete team of professionals, **Bandwidth Semiconductor** continues to grow in today's marketplace. We operate a complete compound semiconductor growth & device fabrication line housed in a 13,500 sq. ft. class 100/1000 cleanroom.

Epitaxial Services

MOCVD Experts – 20 Years Experience
Our extensive MOCVD experience and capacity enable us to grow a wide range of GaAs and InP epitaxial structures to our own or to customer's designs.

- GaAs and InP-based materials
- 2", 3", 4" Custom Epi-Wafer Capability
- Excellent Uniformity & Reproducibility
- Production & Development Quantities

Foundry Services

We design the process steps and conditions to meet the desired device characteristics and implement the process in our fab. Process equipment includes:

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

BANDWIDTH SEMICONDUCTOR, LLC

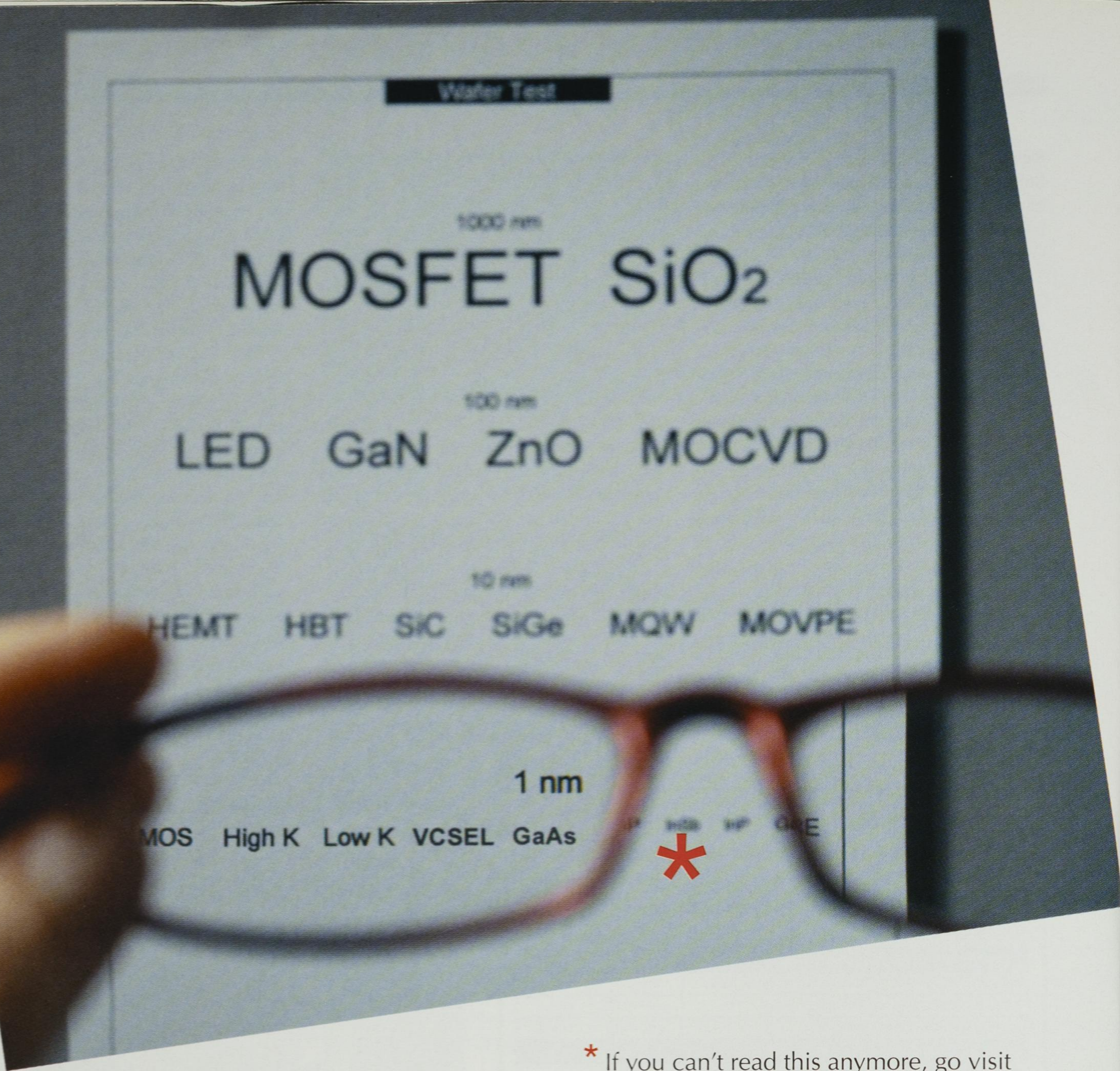
25 Sagamore Park Rd., Hudson, NH 03051

www.bandwidthsemi.com

(603) 595-8900

Epitaxial and Foundry Inquiries: sales@bandwidthsemi.com

EOE M/F/D/V



* If you can't read this anymore, go visit your local Bruker AXS specialist to get your personal Advanced X-ray Solutions – **D8 DISCOVER** for **SEMICONDUCTORS**

**find out
what's inside**

BRUKER ADVANCED X-RAY SOLUTIONS

www.bruker-axs.com • info@bruker-axs.com



CONVERGENCE WITH SILICON

Epitaxy and the high- κ dielectric contest

The race is on to find a replacement for SiO_2 as a gate dielectric in CMOS. **Jörg Osten** describes the challenges faced, and how knowledge from III-V materials science will help.

Device miniaturization has been the primary means by which the semiconductor industry has achieved the unprecedented gains in productivity and performance known as Moore's Law. These gains have historically been paced by the development of new optical lithography tools, masks and photoresist materials. Now, a new challenge has appeared on the horizon that will require considerable resources to overcome. If not addressed, this could result in a major showstopper for the silicon industry (Green *et al.* 2001). The challenge is the replacement of the traditional SiO_2 gate dielectric by new high dielectric constant (high- κ) materials. Meeting this challenge may require the CMOS industry to draw upon technologies such as epitaxial deposition and characterization techniques developed by the compound semiconductor industry. Such technologies are already being used for other new materials, such as strained Si/Ge alloys, which are now being developed.

The gate dielectric problem

SiO_2 has been used as the primary gate dielectric material in field-effect devices since the beginning, and the thickness of SiO_2 films has decreased with each device generation. Table 1 shows the timeline for the anticipated future size reduction and the required oxide thickness. In a production environment it is very difficult to obtain oxides thinner than 8–10 Å as will be required in the next 5 years.

One of the fundamental limits to the scaling of the gate dielectric is the exponential increase in tunnel current with decreasing film thickness. For SiO_2 , at a gate bias of ~1 V, the leakage current changes from ~ 10^{-6} A/cm² at ~3 nm to ~10 A/cm² at ~1.5 nm – seven orders of magnitude in current for a thickness change of only a factor of 2. A high gate leakage current can conceivably alter device performance, to say nothing of the difficulties associated with power consumption and dis-

Gate dielectric requirements according to latest ITRS roadmap

Production year	Technology node (nm)	Gate dielectric (SiO_2 equivalent thickness) (Å)	Gate bias, V_{dd} (V) (high-performance MPU)	Leakage current for SiO_2 @ V_{dd} (for maximum SiO_2 equivalent thickness) (A/cm ²)
2001	130	13–16	1.1	>0.1
2002	115	12–16	1.0	>0.1
2003	100	11–16	1.0	>0.1
2004	90	9–14	1.0	>1
2005	80	8–13	0.9	>2
2006	70	7–12	0.9	>5
2007	65	6–11	0.7	>10
2010	45	5–8	0.6	>100
2013	32	4–6	0.5	
2016	22	4–5	0.4	

Table 1. One of the fundamental limits to the scaling of gate dielectrics is the exponential increase in leakage current with decreasing film thickness.

sipation. Although higher power dissipation may be tolerable with some high-performance processors, it quickly leads to problems for portable machines. Assuming that the total gate-on-silicon surface area of an IC is of the order of 0.1 cm², this would lead to 10 W static power consumption for an oxide thickness of 1.2 nm at 1 V supply.

Alternative high- κ dielectrics

The solution requires a thicker film with a higher dielectric constant. A desirable alternative gate insulator material would have a dielectric constant of about 15–40, leading to an increase in film thickness by a factor of 4–10 without changing the capacitance. The term equivalent oxide thickness (EOT) refers to the thickness of any dielectric scaled by the ratio of its dielectric constant to that of SiO_2 (3.9). The use of such high- κ dielectrics would provide the EOTs required to maintain current drive, while keeping the tunneling current at an acceptably low level (table 2).

At first glance, this would seem to be a winning proposal, since a substantial reduction in the current should be possible by just increasing the layer thickness. However, there is

Gate leakage for different dielectrics with EOT = 1.4 nm

Material	Gate leakage current density J_g (A/cm ²) @ $V_g = 1$ V
Pr_2O_3	7×10^{-9}
HfO_2	1×10^{-4}
ZrO_2	5×10^{-4}
SiO_2	~1
SiO_2 (EOT = 3 nm)	~ 10^{-4}

Table 2. High- κ dielectrics would provide the EOTs required to maintain current drive, while keeping the leakage current acceptable.

another factor influencing the tunneling current – the barrier height between the electrode/silicon channel and the appropriate bands of the insulator. Therefore, not only is a material with a higher dielectric constant required, but this material must also have suitably large barrier heights, to keep the gate leakage currents within reasonable limits. Other basic limitations for high- κ substitutions include chemical and physical bonding constraints. Bonding at the Si– SiO_2 (and also Si– Si_3N_4) interface is isovalent, with bond charge exactly matching nuclear charge.

CONVERGENCE WITH SILICON

Most high- κ materials are generally more ionic, and also more highly coordinated on average than SiO_2 . One would expect these dielectrics to form heterovalent interfaces with Si, with a mismatch between bond and nuclear charge. This mismatch can give rise to interfacial traps and/or fixed charges reducing carrier mobility.

Material selection

A systematic consideration of the required properties of gate dielectrics indicates that the key guidelines for selecting an alternative gate dielectric are (a) permittivity, band gap, and band alignment to silicon; (b) thermodynamic stability; (c) film morphology; (d) interface quality; (e) compatibility with the current or expected materials to be used in device processing; (f) process compatibility; and (g) reliability.

Many dielectrics appear favorable in some of these areas, but very few materials are promising with respect to all of these guidelines. The most common of these are the simple binary metal oxides such as Ta_2O_5 , TiO_2 , ZrO_2 and HfO_2 . Ferroelectric materials such as barium strontium titanate have also been suggested as gate dielectrics. Unfortunately, a number of these materials, specifically Ta_2O_5 and TiO_2 , are not stable on silicon, and even assuming that there is a material with a reasonably high- κ that reduces the leakage current for a given EOT, there is still the problem of integrating this material into device fabrication processes.

The easiest integration would involve direct substitution of the SiO_2 in a given CMOS process with no further changes. Unfortunately, most of the materials studied are not sufficiently stable thermally. They can change phase (and therefore their material properties) at much lower temperatures than are needed for CMOS processing. The high- κ dielectric would be most likely deposited on a silicon channel; therefore it should not show any tendency to form silicides, silicates, silicon oxides, or mixtures of these during post-deposition annealing. In addition, chemical reactions of the metal oxide with capping poly-Si have been observed for most of the materials being studied. The aggressive scaling of FETs aggravates the problems of poly-Si gate depletion, high gate resistance, and dopant penetration from the highly-doped poly-Si gate into the channel region. As a result, there is immense interest in metal gate technology. At least one, if not two gate materials would have to be metals. Since most of the materi-

High- κ dielectrics for III-Vs

By Jon Newey

The formation of a native oxide on silicon is one of the foundations upon which the silicon industry has been built. The need to replace SiO_2 with a high- κ dielectric finally takes the native oxide out of the equation. At the same time, the silicon industry is embracing the epitaxial technologies and vertical engineering that the compound semiconductor industry has always relied upon. Add to these the move back towards metal gates and silicon devices begin to look rather like III-V devices with a gate oxide.

However, soon devices in the two material technologies could look even more alike. The III-V material systems do not benefit from the presence of native oxides, and ever since the first III-V devices were fabricated, researchers have been trying to find ways of depositing high-quality gate oxides onto III-Vs in order to add MOS devices to the FET and HBT families. There are plenty of references in the literature to the formation of CVD-deposited silicon oxide and nitride dielectrics on III-Vs, but to date the device results have been disappointing. The quest is now gathering pace to find a suitable oxide that can be deposited in a manufacturable way to give reproducible device performance. This area of technology is being taken seriously by some major electronics companies, and also by universities and smaller commercial organizations that are tapping into funding made available by the US Department of Defense.

Osemi, Inc of Rochester, MN, is one such small company. Although it has an established custom epiwafer business, the

company has been busy behind the scenes with a DARPA-funded effort to refine its oxide-on-GaAs materials and deposition technology. The company is pursuing gallium sulphide and oxide compounds as suitable dielectrics for deposition by MBE. David Braddock, Osemi's president, is enthusiastic about the prospects for III-V MOS devices and Osemi's progress with the quality of its oxide material and deposition process. "This is an exciting area for compound semiconductors as the dielectrics are now just maturing and there are a number of groups looking at these materials for a variety of circuits," he said. "High- κ gate dielectrics for GaAs, InP and GaN exist already and we are possibly some way ahead of where the silicon people are."

One of the most likely homes for III-V MOS devices would be in devices for wireless communications, which would benefit from the enhanced levels of integration that MOS devices could offer by placing analog and digital circuits on the same chip. SiGe BiCMOS technology has already stolen ground from GaAs in some analog and mixed-signal applications, leaving GaAs to the niche analog areas, such as the PA stage in cell phones that need its performance advantages. To a large extent, III-Vs have been pushed out of the digital space, first by the delay in the implementation of 40 Gbit/s optical networks and then by the subsequent catching up of CMOS to enable it to perform adequately in such applications. The performance benefits of GaAs in a silicon CMOS-like process flow could change the prospects for GaAs in digital electronics.

als would not be compatible with the high temperatures required for most CMOS processes, the whole gate stack processing might have to be moved to the end of the device fabrication process instead of remaining at the beginning.

Aside from the issues related to the thermal stability of these high- κ materials, other processes including the chemical and reactive ion etching of these materials and new gate electrodes will also have to be developed. Moreover, introduction of gate dielectrics other than SiO_2 requires that these be prepared by deposition, rather than conventional thermal growth processes. Therefore, the use of

high- κ materials would require not only the discovery and development of a new material, but possibly a complete re-engineering of the CMOS manufacturing process.

Epitaxial high- κ materials

The common approach has involved amorphous materials with higher dielectric constants, such as metal oxides and their silicates. A good interface requires either that the oxide is amorphous, or that it is epitaxial and lattice-matched to the underlying silicon. Amorphous oxides are one low-cost solution, as they are expected to be able to adjust the local bonding to minimize the number of silicon dan-

SHUTTLELINE

SHUTTLELINE

YOUR TOOL for R&D and Pilot Production



SHUTTLELINE – ICP version

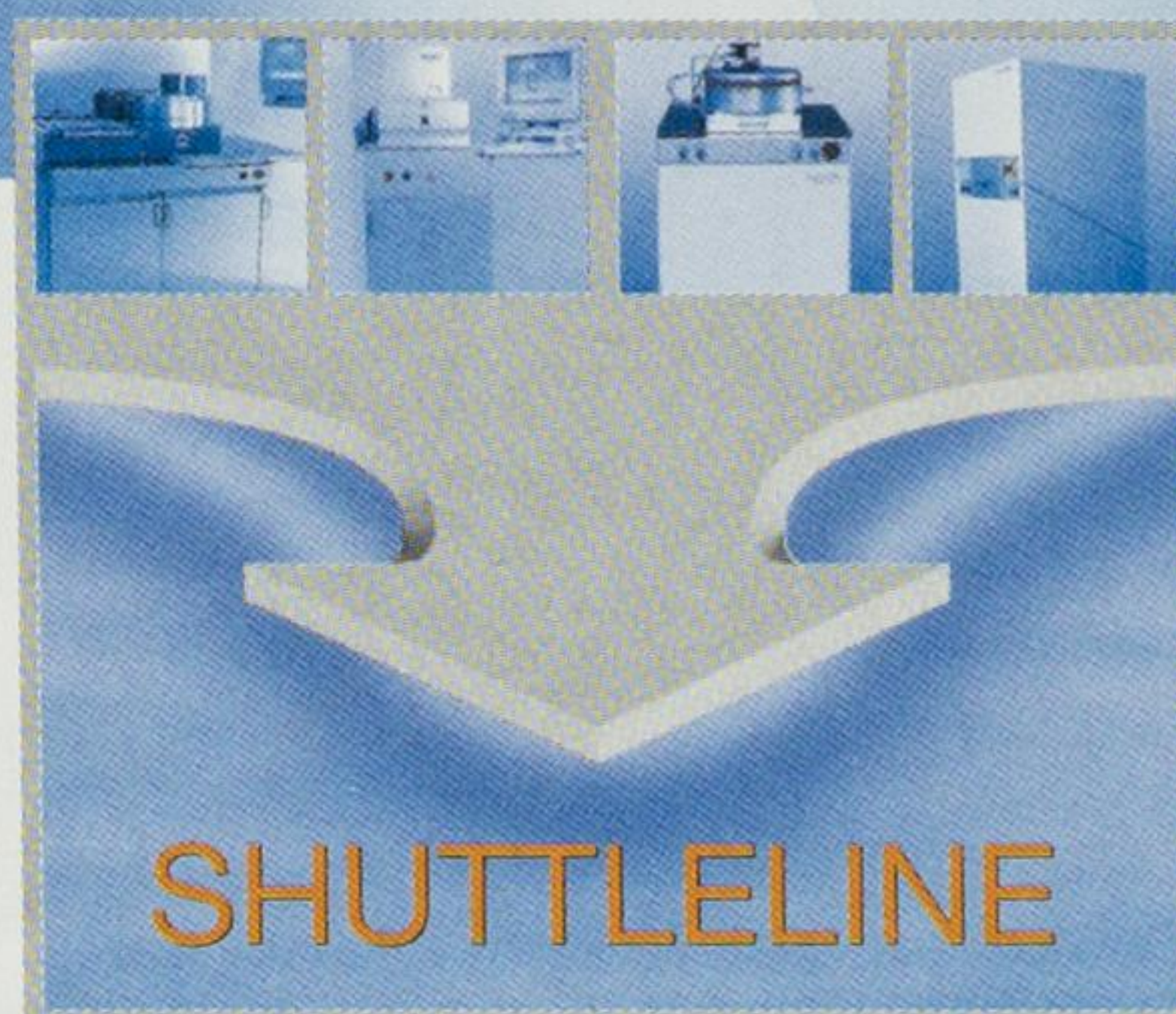
The **SHUTTLELINE™** merges the technology of four systems and extensive experience with an installed base of over 650 tools, making it an ideal platform for R&D and pilot production:

- Multi-process platform for etching and deposition including ICP, RIE and PECVD
- Superior process solutions for HBTs, HEMTs, SAW, Photonics and MEMS
- Loadlock equipped for consistent process results
- User friendly software standardized for all versions
- Unmatched process support from the Unaxis technology centers in the US and Switzerland

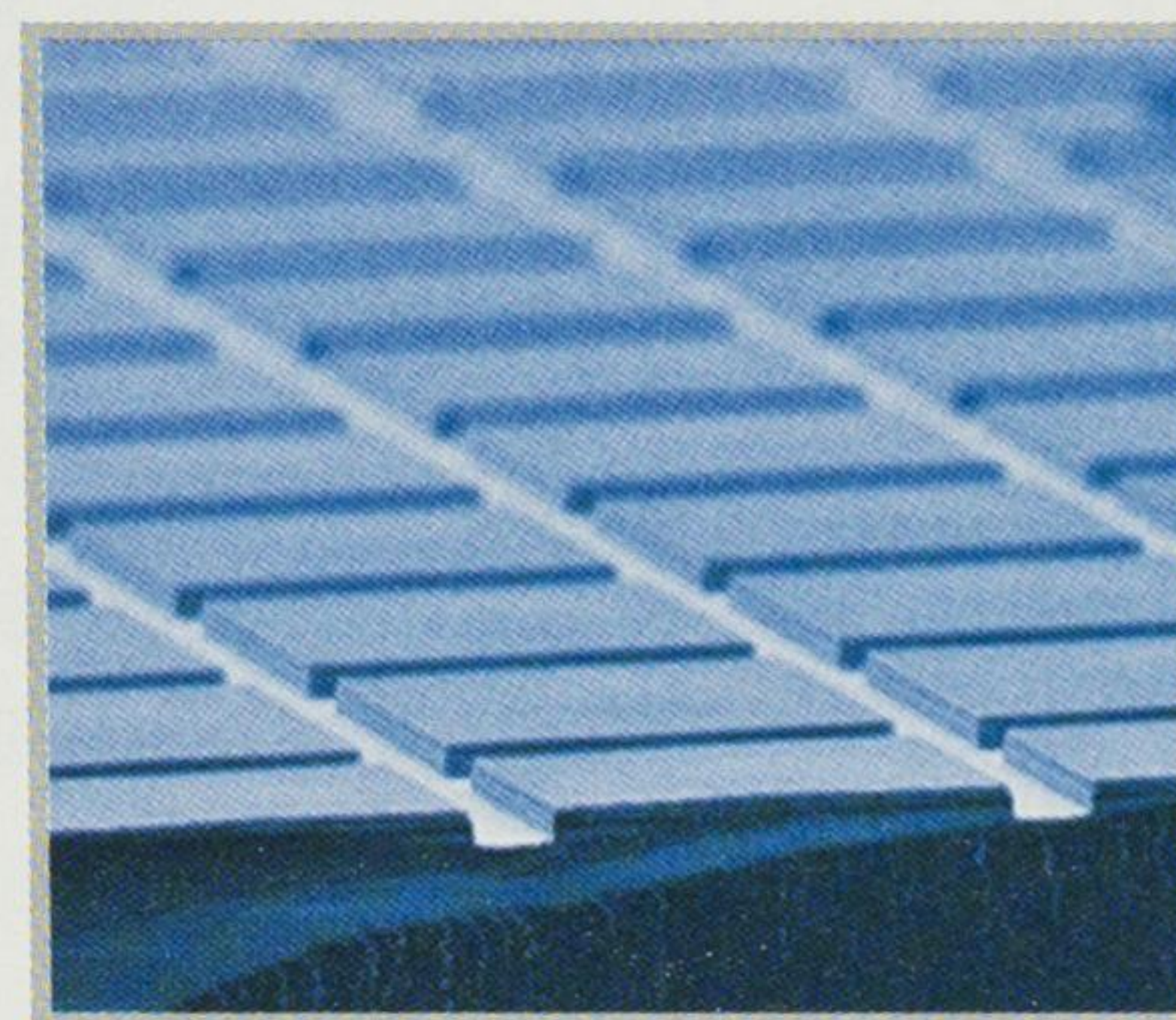
Secure your success in the Semiconductor business with the new SHUTTLELINE and the support of our experienced Unaxis professionals.

www.semiconductors.unaxis.com

USA	Tel. +1 727 577 4999	KOREA	Tel. +82 31 708 8666
EUROPE	Tel. +49 89 7550 5251	TAIWAN	Tel. +886 3597 7771
CHINA	Tel. +86 21 5057 4646	JAPAN	Tel. +81 3 3225 9020
SINGAPORE	Tel. +65 6890 6288	Other	Tel. +423 388 4986



Merging the essence of the SHUTTLELOCK, 790, NE 860 and NE D200



Etching of quantum well LEDs

unaxis

making IT possible

CONVERGENCE WITH SILICON

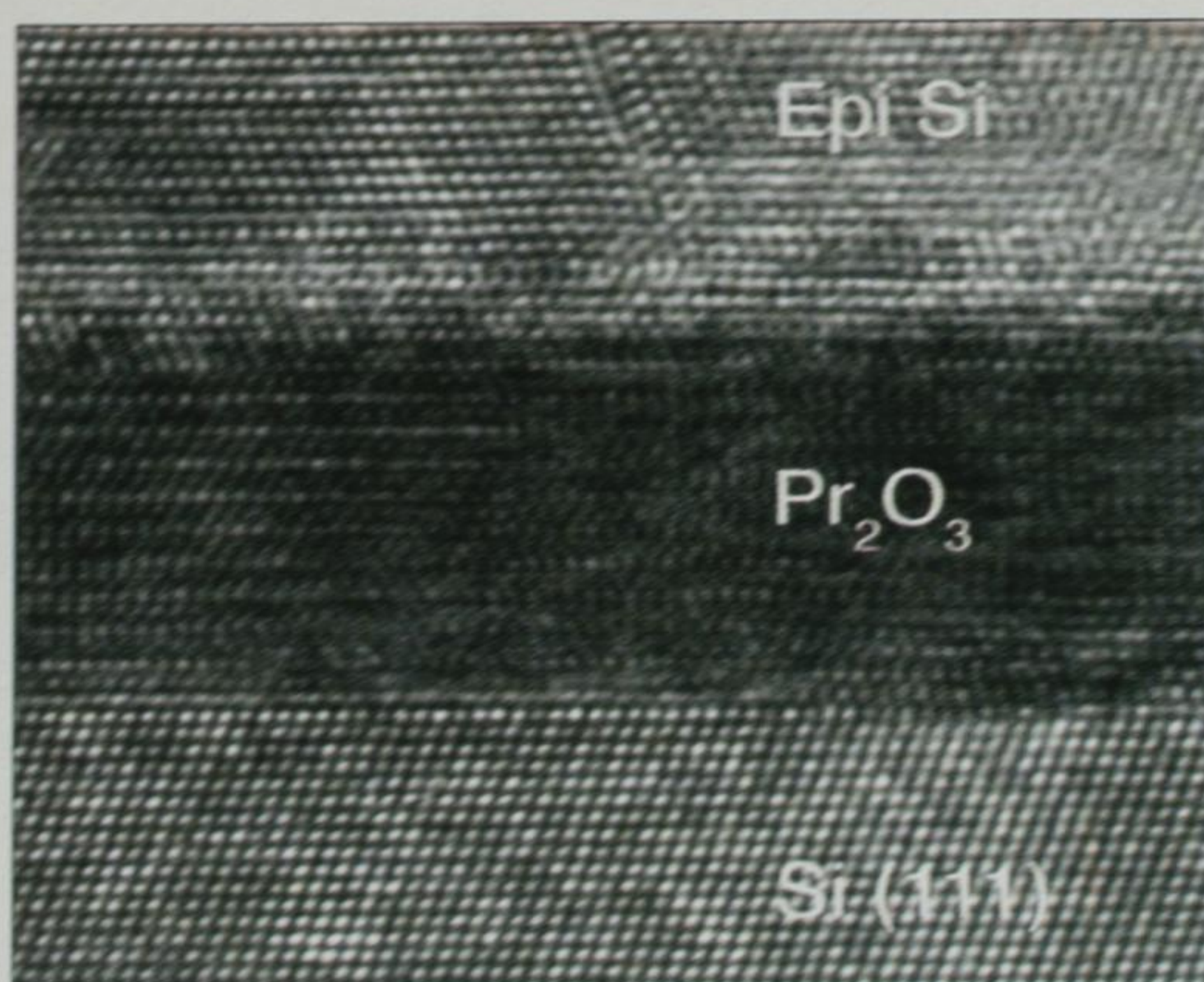


Fig. 1. High-resolution cross-sectional TEM lattice image of a 6 nm thick Pr_2O_3 film grown by MBE onto a Si(111) substrate and overgrown with silicon.

gling bonds at the interface. However, these ionic materials must be kept amorphous even after post-deposition high-temperature processing to avoid increased surface roughness and additional leakage due to the formation of grain boundaries. An epitaxial oxide involves more effort, but it has the advantages of enabling defined interface engineering and higher thermal stability. MBE is known for its superior capability in atomic level engineering and interface control, and is one of the techniques being investigated for the epitaxial growth of various high- κ materials.

Generally, there are two groups of possible candidates for epitaxial growth on silicon, perovskite-type structures and binary metal oxides. Various perovskite-type metal oxides (ABO_3 where A and B are different metals) have become a technologically important class of materials due to their unique dielectric, piezoelectric, ferroelectric, ferromagnetic, optical, electro-optic and catalytic properties (Yu *et al.* 2003). These perovskite oxides cover a wide range of materials from insulators to conductors and superconductors, and everything in between. The successfully demonstrated heteroepitaxy of these metal oxides on silicon has opened the door to a wide range of novel device technologies with enhanced functionality and flexibility.

In general, epitaxial growth on a clean surface requires matching in symmetry as well as in atomic spacing. In principle, binary metal oxides with the cubic calcium fluoride structure (having the MO_2 stoichiometry) or the cubic bixbyite structure (M_2O_3) are also suitable candidates as epitaxial high- κ dielectrics on silicon. The calcium fluoride and the bixbyite structures have lattice symmetry suitable for epitaxial growth on Si(100) and

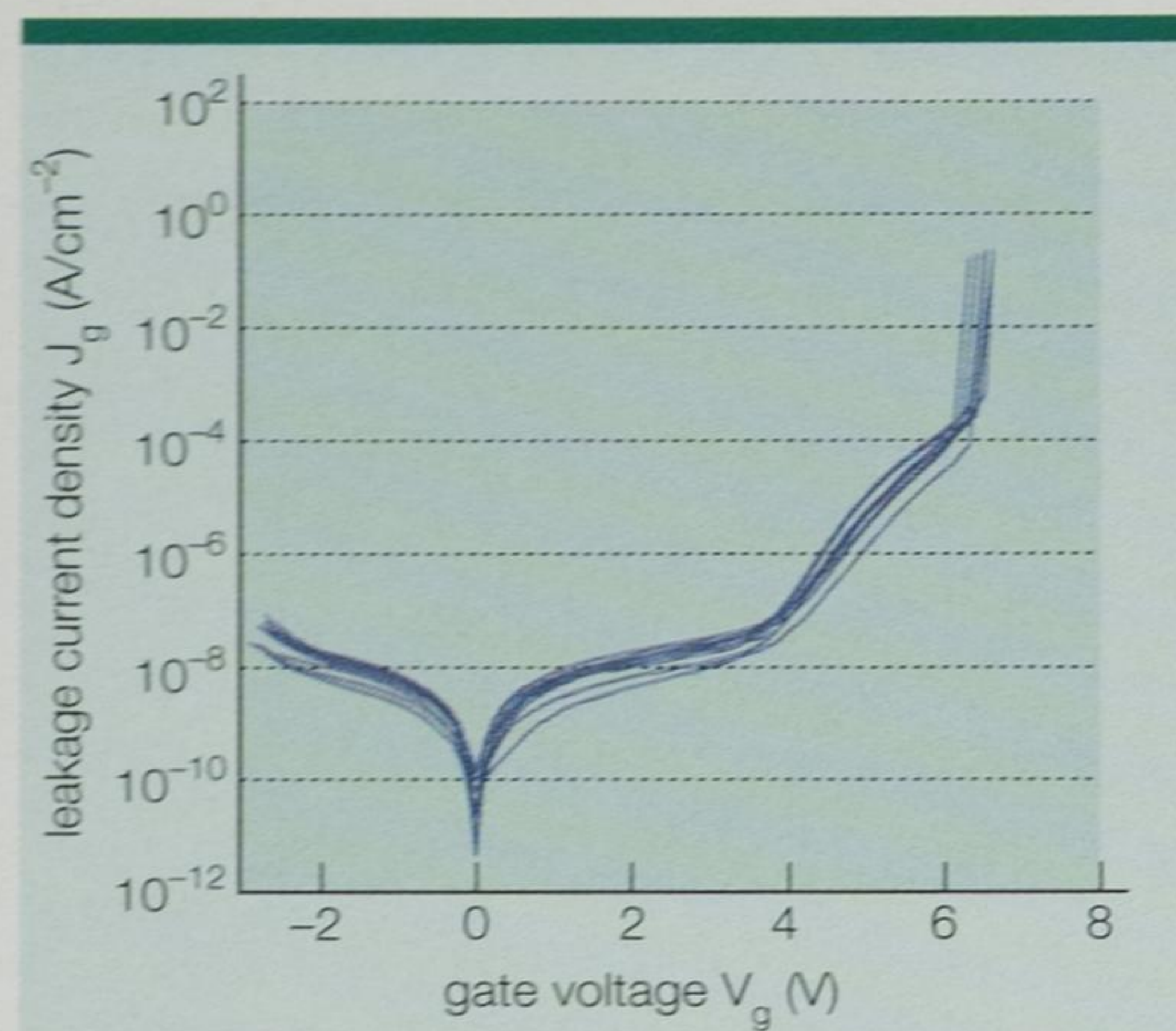


Fig. 2. Gate leakage plots for 16 Au/ Pr_2O_3 /n-Si capacitors. The EOT is 1.4 nm and the area of the devices is $1.9 \times 10^{-3} \text{ cm}^2$.

Si(111). Some binary metal oxides also crystallize at higher temperatures in the hexagonal lanthanum oxide structure, which is suitable for epitaxy only on Si(111).

Recently, we reported results using MBE growth of crystalline praseodymium oxide (as Pr_2O_3 in the bixbyite structure) on silicon substrates with different crystallographic orientations (Osten *et al.* 2002). On Si(100) oriented surfaces, crystalline Pr_2O_3 also grows as (110)-domains, with two orthogonal in-plane orientations. Detailed investigations indicate that the occurrence of these domains is due to the nucleation on neighboring terraces with silicon dimer rows (2×1 reconstruction) perpendicular to each other.

MBE is known for its superior capability in atomic level engineering, and is one of the techniques being investigated for the epitaxial growth of various high- κ materials.

Epitaxial overgrowth of silicon onto oxide layers grown on Si(001) has so far not been realized. However, we have obtained perfect epitaxial growth of hexagonal Pr_2O_3 on Si(111) (figure 1). These layers can be overgrown epitaxially with silicon leading to novel tunneling structures. Crystalline Pr_2O_3 on Si(001) is a promising candidate for highly scaled gate insulators, displaying sufficiently high- κ value of around 30, ultra-low leak-

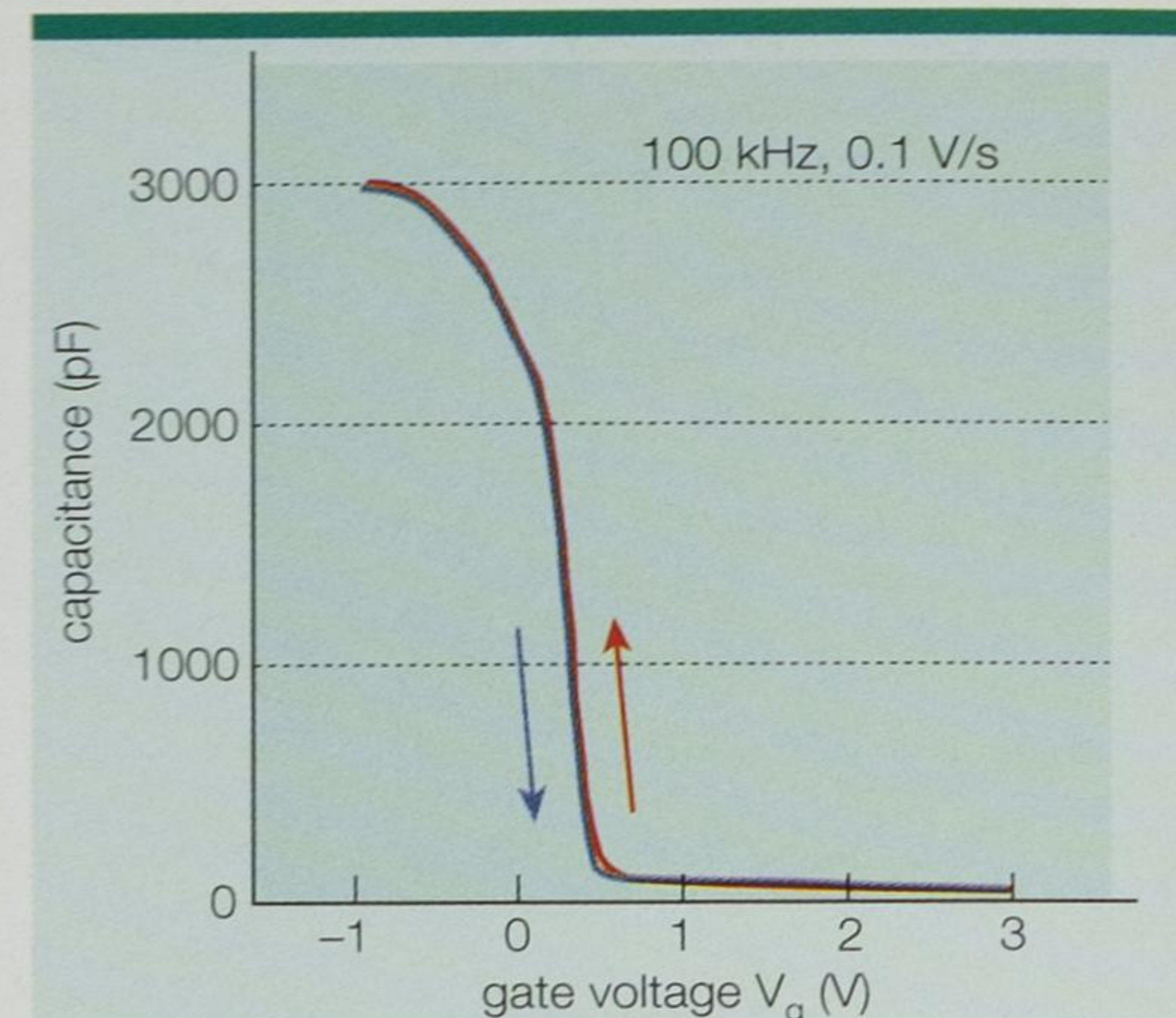


Fig. 3. Gate capacitance for a 13.4 nm Pr_2O_3 layer on p-Si. The EOT value is 1.7 nm, and the extracted dielectric constant is 30.

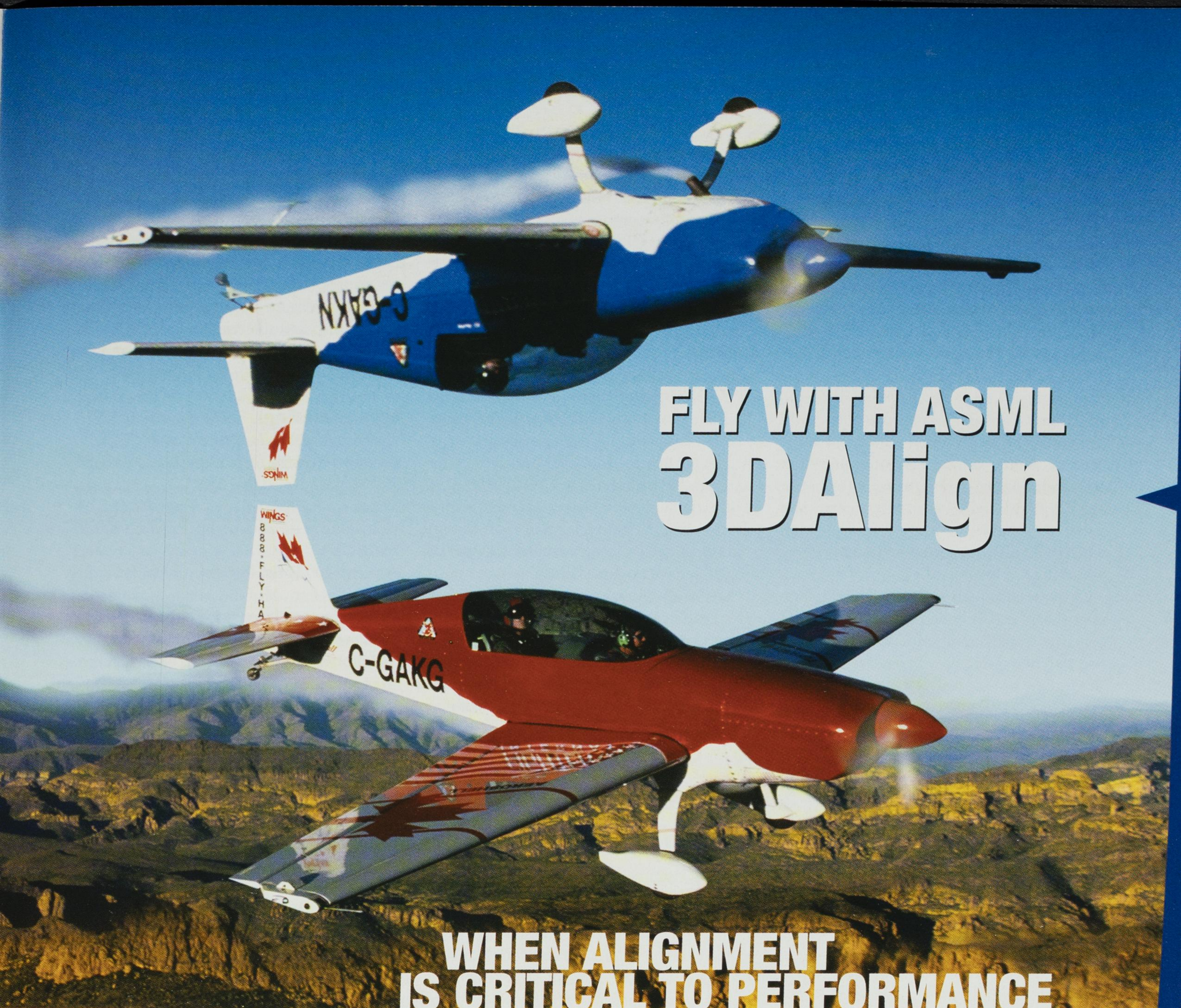
age current density, good reliability, and high electrical breakdown voltage (Osten *et al.* 2000). Some electrical characteristics are shown in figures 2 and 3.

The Pr_2O_3 /Si(001) interface exhibits the symmetric band alignment, desired for applying such material in both n- and p-type devices. The valence band as well as the conduction band offset to silicon is above 1 eV. The electron masses can be assumed to be very heavy in the oxide due to the existence of flat, localized electron states. This effect, together with the suitable band offsets, leads to the unusually low leakage currents that have been observed experimentally. Finally, the integration of crystalline Pr_2O_3 high- κ gate dielectrics into a conventional CMOS process has also been demonstrated (Schwalke *et al.* 2002).

High- κ gate dielectric deposition

The specific deposition process and the associated pre-surface cleans and surface conditioning procedures, in conjunction with post-deposition annealing, are critical in controlling high- κ film structure and interfacial properties and therefore device performance.

The extension of CVD to high- κ material deposition has been widely explored, including, for example, single-wafer methodologies such as MOCVD, rapid plasma-enhanced CVD and liquid source CVD techniques. The significantly reduced deposition temperature in MOCVD, compared with other deposition techniques, may require reassessment of the mass transport and surface limitation regimes as well as their dependency upon the selection of chemical precursors and equipment configuration. In particular, the compatibility of chemical precursors with environmental safety and health requirements has



FLY WITH ASML 3DAIalign

WHEN ALIGNMENT IS CRITICAL TO PERFORMANCE

3DAIalign™, an optical front-to-back alignment technology, allows ASML's production-proven lithography steppers to provide fully automated, high-throughput, double-sided processing of MEMS devices.

The 3DAIalign option also enables high accuracy, back-to-back and mixed front/back alignment for power, discrete and compound chip manufacturers. This capability solves process-induced challenges such as CMP lapped marks, epi shift for thick epi layers and noisy signals from grainy metal.

ASML's commitment to special applications solutions is making the world's best ideas fly. See 3DAIalign in action at www.asml.com/3DAIalign.



ASML
Commitment

CONVERGENCE WITH SILICON

assumed a significantly increased level of importance.

Progress on single-wafer deposition techniques such as atomic layer deposition (ALD) has been accelerating with apparently significant benefits, such as film uniformity. ALD is a surface-controlled layer-by-layer process for the deposition of thin films by sequential, self-limiting surface chemical reactions. Thus, the thickness of the films can be controlled in a straightforward manner by counting the number of reaction cycles, which enables controlled growth of ultra-thin films. Generally, the success of all chemical techniques depends on the availability of appropriate precursors. In particular the easy formation of SiO₂ interfacial layers inhibits deposition under oxygen supersaturation, a problem when most of the known precursors are oxygen-rich.

Other techniques such as physical vapor deposition, jet-vapor deposition, oxidation of metallic films, *in situ* reoxidation and MBE are also being intensively investigated. The advantage of those physical techniques (in particular MBE) is the oxygen-free, UHV

deposition conditions. MBE tools are now available as large multiwafer systems designed for the sort of high-volume manufacturing environments prevalent in the CMOS industry. Interface engineering on an atomic level will be even more crucial for epitaxial high- κ materials, making MBE a logical choice.

Outlook

Aggressive scaling of CMOS devices requires gate EOTs below 1 nm for future generations. This necessitates introduction of an alternative insulator with a dielectric constant $>\kappa_{\text{SiO}_2}$. Achieving the material requirements for alternative gate dielectrics is very challenging. There are demanding issues for process integration compatibility, such as morphology, interfacial structure and reaction, thermal stability, and gate compatibility.

So far, all of the investigated materials have been unable to completely satisfy the requirements for an alternative gate dielectric. High- κ materials grown epitaxially on silicon are crucial as they allow well defined interface engineering. However, it is not yet clear if any

"silicon technology friendly" high- κ dielectric can be found. Recently, many promising candidates and metal gate electrode materials have been identified and some preliminary prototype FETs have been produced. The grand challenge is not only to find the appropriate dielectric that fulfills all material requirements but also the integration of these disparate materials and processes into a cost-effective and reliable manufacturing process. ●

Further reading

Green *et al.* 2001 *J. Appl. Phys.* **90**(5) 2057.
Osten *et al.* 2000 *Tech. Digest IEDM* (IEEE, Piscataway, NJ, 2000) 653.
Osten *et al.* 2002 *J. Cryst. Growth* **235** 229.
Schwalke *et al.* 2002 *Proc. 32nd ESSDERC* 407.
Yu *et al.* 2003 *Mat. Res. Soc. Symp. Proc.* 747.

Professor Jörg Osten is the director of the Institute for Semiconductor Devices and Electronic Materials at the University of Hannover, Germany. E-mail: osten@ihw.uni-hannover.de.

STRATEGIES in Light 2004

February 2-4, 2004
San Mateo Marriott Hotel
San Mateo, CA, USA

Charting New Directions in High-Brightness LEDs

The 5th Annual STRATEGIES IN LIGHT 2004 conference will tune you in to the future of high-brightness LED applications. Lighting, displays, signs, signals and automotive applications are shaping the future of the market. Attend this executive-level conference and you'll not only glimpse the future - you'll shape it.

At the longest-running LED conference in the industry, you'll gain insights from companies pioneering new LED markets, and engage in comprehensive discussions about the technology evolution required to penetrate the large-scale lighting market.

PLUS: Market update and forecast presented by Strategies Unlimited ... the world's experts in LED market research.

Early Registration Discount!

\$1,295 for registrations received by December 19, 2003!
(That's \$200 off of the full price of \$1,495.)
For more info: www.strategies-u.com
or call +1 650.941.3438 ext. 23

Sponsorships Available!

Call Tim Carli at +1 650.941.3438
or email tcarli@strategies-u.com

**strategies
unlimited**
Intelligence for Advanced Technologies
Since 1979

201 San Antonio Circle, Suite 205, Mountain View, CA 94040
Phone: +1 650.941.3438 • Fax: +1 650.941.5120
www.strategies-u.com • info@strategies-u.com

A Research Unit of **PennWell**

Albis to focus on short-reach 10 Gbit/s datacoms

Following the demise of the Swiss LED and photodiode manufacturer Opto Speed, a new company has emerged to take over its photodiode chip and receiver sub-assembly product lines.

Albis Optoelectronics was founded in August 2003 by Markus Blaser, former product line manager for photodiodes at Opto Speed, and Jörg Wieland, president and CEO of Zurich-based optical chip-set maker Helix.

Albis took over all assets associated with the photodiode business, including intellec-

tual property, key employees, and the 2000 sq. ft cleanroom facilities and equipment located in Rueschlikon, near Zurich.

Financing has been committed to the company by a group of private individuals, including the founders and senior management.

Albis sells InGaAs/InP-based *pin* photodiodes for optical interconnects, long-haul, metropolitan and high-speed LAN/SAN applications, as well as analog optical microwave signal transmission.

The company will have a strong focus on

developing advanced photodiode products for 10 Gbit/s short-reach data communication, says Blaser. "An active area of 65–70 μm diameter at speeds of 10 Gbit/s and operating bias voltages below 2 V has been demonstrated," he added. "Development of such products is finalized and single-channel as well as array prototypes are now available."

Opto Speed's superluminescent LED product line has been taken over by Exalos, also based in Zurich (*Compound Semiconductor* October 2003 p36).

Emcore acquires 10 Gbit Ethernet business

Emcore has acquired Molex Inc's 10 Gbit Ethernet transceiver business. The transaction includes assets, products, technology and intellectual property related to Molex's Xenpak and X2 form-factor products, and is currently located in Downers Grove, IL. The financial terms have not yet been disclosed.

As part of the agreement, approximately 17 Molex employees will join Emcore. The business will become a part of Emcore's fiber-optics division and will initially continue to operate in a portion of Molex's Downers

Grove facility to be leased by Emcore.

In January 2003, Emcore acquired Agere's west-coast operations, giving it better access to the market for cable TV, telecom access and satellite communication products.

The market for 10 Gbit Ethernet products has been slow to take off, but is expected to expand significantly in the near term. According to market research firm Strategies Unlimited, the market for 10 Gbit transceivers operating at 1310 nm will grow 66% per year, to over \$380 million by 2007.

OCP considers sale in strategic review

Fiber-optic subsystem manufacturer Optical Communication Products (OCP) is considering a merger or even a sale of the company as part of a strategic review.

The Woodland Hills, CA, company, which acquired VCSEL specialist Cielo Communications in October 2002, has set up a committee of its independent directors to evaluate its options. These also include share repurchase and issuing a special dividend.

MATERIALS & EQUIPMENT NEWS

Veeco buys MOCVD unit from Emcore

Emcore, which began life nearly 20 years ago as an MOCVD equipment supplier, has sold its MOCVD systems business to Veeco Instruments. Emcore will now concentrate on its optical communications products business and maintain its part in the Gelcore joint venture with GE to develop HB-LEDs.

Emcore has been expanding its optical communications products business for some time, most notably through the purchase of Agere's west-coast optoelectronics operation in January this year. Since then, the MOCVD systems side of its business has accounted for less than half of the company's income. Emcore's system revenues for the 12 month period ending June 30, 2003 were approximately \$51 million, down from a peak of \$135 million two years ago.

The transaction is valued at up to \$80 million, with \$60 million in cash when the deal

closes. In the subsequent two years Emcore will receive from Veeco 50% of all TurboDisc revenues above \$40 million in each year to a maximum payout of \$20 million.

The transferred MOCVD business includes the business unit's manufacturing facility, equipment and applications lab in Somerset, NJ, and Emcore's significant MOCVD intellectual property. It is expected that approximately 120 Emcore employees involved in the TurboDisc business will become Veeco employees.

The acquisition significantly expands Veeco's interest in epitaxial technology, which began when it acquired Applied Epi, a manufacturer of MBE systems, in 2001. It also gives Veeco a unique slant to its business as it will be the only company to offer both MOCVD and MBE systems. One of the main drivers behind the acquisition appears to be Veeco's

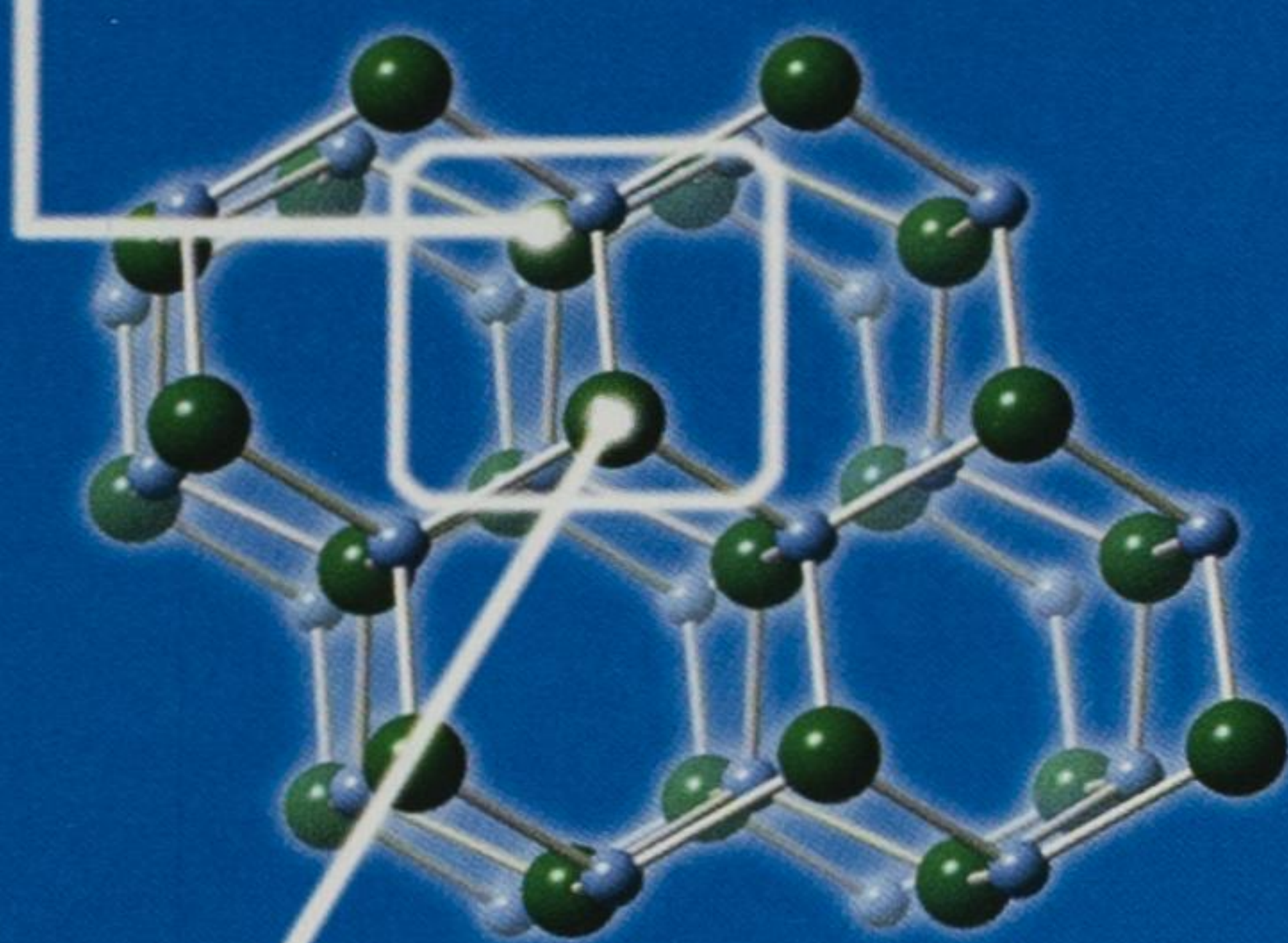
desire to get a foothold in the rapidly growing LED market, particularly GaN-based blue, green and white LEDs. The manufacturers of these have become the largest consumers of MOCVD reactors.

Veeco has already indicated that it plans to apply the supplier-user relationship model that it has adopted for its MBE business to its new MOCVD activity. This model resulted in the opening of Veeco's Process Integration Center for MBE earlier this year (see "Veeco's PIC: imitating the silicon business model", p20).

"This acquisition strengthens Veeco's position in the compound semiconductor market, as we are now uniquely able to provide 'one-stop' shopping for epitaxial deposition solutions—both MOCVD and MBE," said Edward Braun, chairman and CEO of Veeco. "The MOCVD market is twice the size of the MBE available market."

A REVOLUTION in the EVOLUTION

of materials...



ATMI GaN

Substrates • Epitaxy

Look to **ATMI GaN** to be your partner in developing and manufacturing advanced semiconductor devices.

ATMI GaN Substrates — improve epitaxy quality, ease the processing of devices and enhance device performance.

ATMI GaN Epitaxy — realize optimal device performance with our epitaxy on GaN, SiC or Sapphire substrates.

ATMI GaN...

Growing your future.

**See us at the Fall MRS
Conference, Booth 1007**

ATMI

7 Commerce Drive
Danbury, CT 06810
Tel: 203.794.1100

Fax: 203.830.2123
www.atmi.com
GaN@atmi.com

Miller receives MBE award

The North American Molecular Beam Epitaxy (NAMBE) organization has presented the first-ever MBE Innovator Award to David Miller at its recent annual meeting. The \$3,000 award, co-sponsored by NAMBE and Veeco Instruments, recognizes individuals whose innovations have significantly advanced the field of MBE.

Miller, an MBE consultant and adjunct professor with the Department of Electrical Engineering at Pennsylvania State University, was recognized for inventing arsenic capping and the valved arsenic cracker while he was employed at the Rockwell Science Center and later at Penn State.

"NAMBE's selection of David for the MBE Innovator Award is most appropriate, as his work contributed significantly to MBE becoming a critical enabling technology for developing and growing many of today's advanced telecom devices," said Marlin Braun, general manager of Veeco's MBE operations.

The NAMBE conference is the largest annual gathering of compound semiconduc-



The MBE Innovator award was presented to David Miller (second left) by Marlin Braun (left), Al Cho, retired vice-president of semiconductor research at Bell Labs (second right) and Charles Tu, from the University of California, San Diego (right).

tor researchers and manufacturers using MBE technology in North America.

The organization's purpose is to share the latest research discoveries in MBE and the new materials and devices based upon MBE, as well as progress in further developing MBE as a high-volume manufacturing technology.

ALSI ships laser dicing machine

Dutch company Advanced Laser Separation International (ALSI) has shipped its first machine capable of dicing GaAs-based wafers using a 40 W solid-state laser. The customer is described as a major manufacturer of optical components.

Using technology developed and patented at Philips, and subsequently transferred to ALSI, the company uses a multibeam concept in which between 3 and 14 laser beams are simultaneously directed at the wafer. This results in both a faster dicing speed and a narrower kerf width (the space between adjacent die) than can be achieved with conventional techniques, says René Hendriks, director of commerce with ALSI.

"For example, we were able to dice a 220 μm thick GaAs wafer with front and back

gold metallization with a kerf width of 17–18 μm ," said Hendriks. "The technique is 20–40 times faster than mechanical sawing."

As well as using multiple beams, the technique is notable because it doesn't use water on the wafer surface to focus the beam. "This is a melt and ejection process," explained Hendriks. "The material is melted by the tiny, high-energy laser spot, and the molten material is ejected by a high-pressure vapor pulse generated by the laser."

As well as increasing the dicing speed compared with other techniques, Hendriks expects that the new technique will improve the overall device yield in two main ways; by reducing the number of scrapped die and by allowing small die sizes to be achieved without reducing the wafer thickness.

FEI Company opens new HQ campus

FEI Company, a manufacturer of metrology equipment, has opened its World Campus and Headquarters in Hillsboro, OR.

The 27 acre campus consolidates the company's local Oregon operations at one site and features two buildings, one for offices and the

other for R&D and manufacturing.

The site also includes FEI's new Product and Technology Solutions Center, which will allow customers and researchers to access the company's latest products for managing advanced nanoscale research and technologies.

Surface Technology Systems loses its CEO

Surface Technology Systems, a UK-based company that sells process equipment into a variety of markets including photonics, wireless, data storage and MEMS, has announced that its CEO, Ian Smith, has resigned "by mutual agreement". Smith, the company's chief executive since late 2001, has resigned with immediate effect and is replaced by Mutsuo Mukuda, an STS director representing the company's majority shareholder Sumitomo Precision Products (SPP).

SPP, which owns around two-thirds of STS's shares, says that it will provide addi-

tional support and backing for the business and also wishes to be more closely involved in the recovery plan. Mukuda will become vice-chairman of STS and will move to the company's headquarters in Newport, UK, until a new chief executive is appointed.

In a statement, STS acknowledged that its markets have been very difficult and that it has made significant losses. "The board is committed to returning the business to profitability and good health and to building on the restructuring work already delivered," said the statement.

Mykrolis expands via Aeronex acquisition

Mykrolis Corporation, a manufacturer and supplier of liquid and gas delivery systems, components and consumables to the semiconductor industry, has signed an agreement to acquire the assets of Aeronex, a privately held manufacturer of gas purification products based in San Diego, CA. The terms of the acquisition have not yet been disclosed.

"The addition of the Aeronex gas purifier

technology is part of our strategy to expand our leadership in fluid handling products and subsystems that enable the semiconductor manufacturing process," said Jean-Marc Pandraud, president and COO of Mykrolis. "Aeronex is a market leader in gas purification, and it will dovetail well with our gas contamination control products, including our current line of Waferpure gas purifiers."

Equipment sales

● The **Ioffe Institute** in St Petersburg, Russia, has recently ordered another AIX 200/4 system from **Aixtron**. The system will be used for the R&D and production of epitaxial compound layer structures for solar cells to be used in satellites.

● **II-VI Incorporated** and **Penn State University** have each taken delivery of a COREMA (COntactless REsistivity MApping) system, manufactured by **SemiMap Scientific Instruments** in Germany under license from the Fraunhofer Institute. Both II-VI and Penn State University will use their systems for resistivity mapping of SiC substrates.

● **Aixtron** is to install an AIX 2600G3 HT MOCVD system at **Samsung Electro-Mechanics Co, Ltd (SEMCO)** in Suwon-City, South Korea. The reactor will be utilized for the development and production of blue and white LEDs.

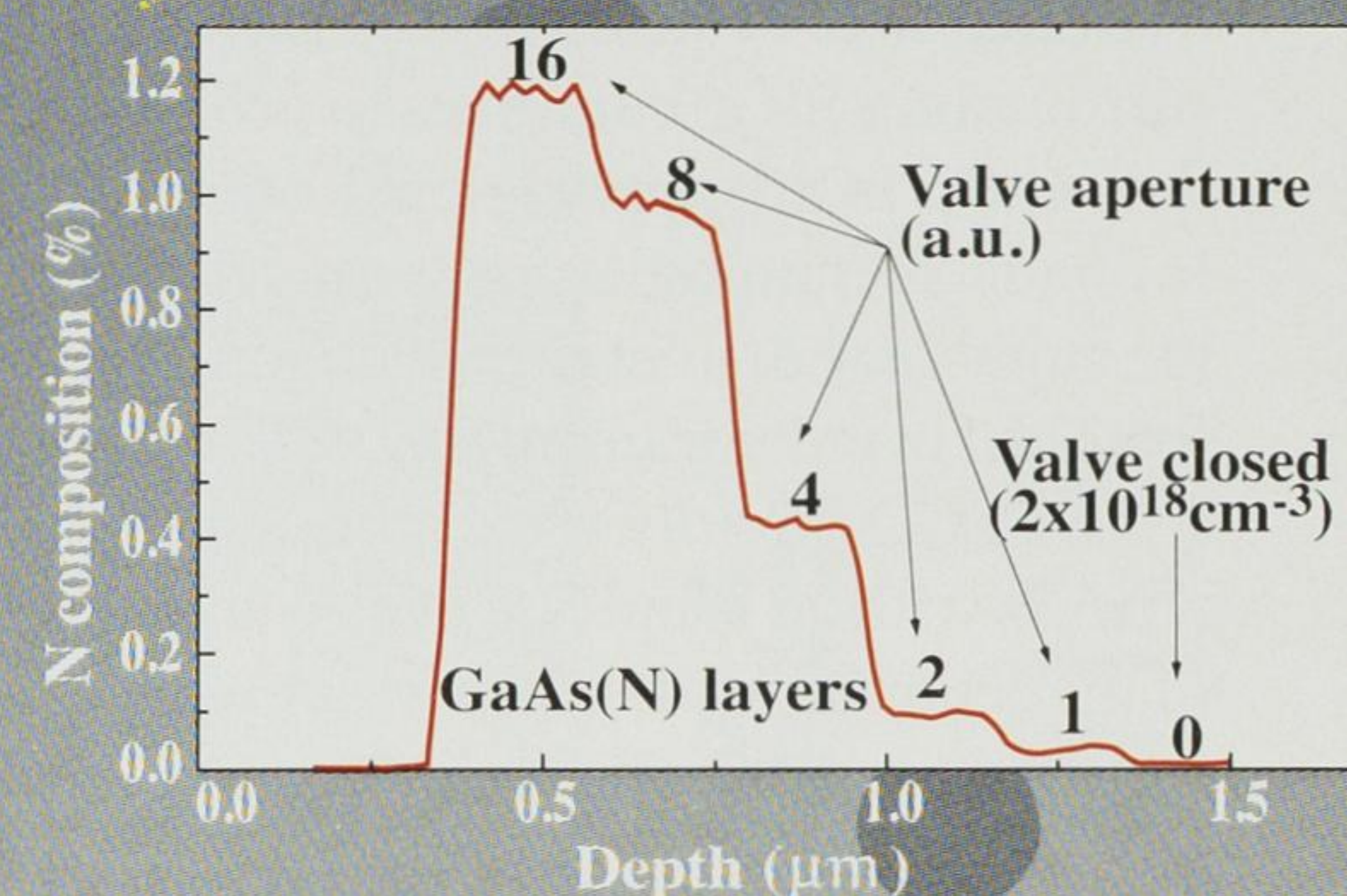
● **Samsung's Advanced Institute of Technology (SAIT)** has also taken delivery of an Aixtron MOCVD tool. Its AIX 2400G3 will be used for research and development of short-wavelength lasers for data storage.

● **DCA Instruments** will deliver another M600 MBE system to **Motorola Research Laboratories** in Tempe, AZ, by the end of this year. The machine is designed for metal and oxide epitaxy. DCA will also ship a UHV high-temperature treatment system to **Nokia Research Laboratories** in Helsinki, Finland, for process optimization.

● **Bookham Technology** has purchased a laser diode assembly cell from **Palomar Technologies** to complement its automated equipment used for high-volume precision manufacturing and new product development at its facility in Paignton, UK.

NEW PRODUCT FOR NITRIDES GROWTH! THE VALVED RF SOURCE PROVIDES RAPID AND REPRODUCIBLE FLUX MODULATION AND UNSURPASSED FLUX UNIFORMITY OVER LARGE WAFERS

- Allows a mechanical control over the useful range of N concentration in GaAsN while the source parameters remains constant.
- Permit to stop or to use the N species with no delay.
- Unsurpassed N uniformity.
- Permit to use a well degassed source at any time during the growth period.
- Models for Nitrogen, Oxygen, Ammoniac, Hydrogen ...
- Easy to install on a DN63CF (4") flange.
- Powered by standard customer and competitor electronics.
- Models for R&D and Production MBE systems.



Compared to a standard RF Plasma Source this New Source gives an easiness of control similar to an arsenic Valved Cracker Cell! See more results on Addon-mbe.com

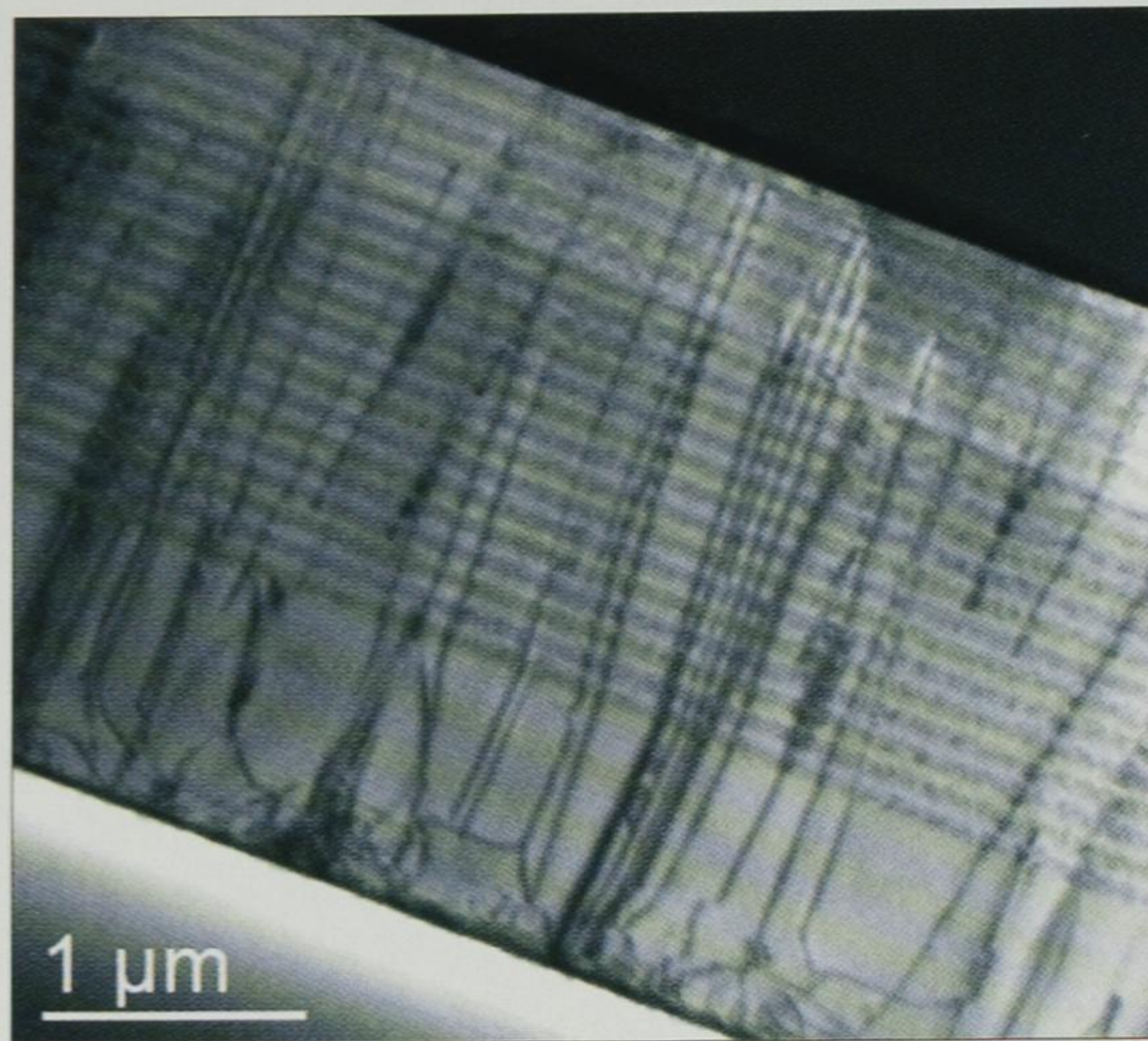
ADDON
Créative Epitaxie Equipement

Fax : 00 33 (0) 1 39 15 56 36
E-mail : mbecells@wanadoo.fr

AlInN/GaN mirrors for GaN devices

Bragg mirrors are key elements for the realization of components such as microcavity LEDs, resonant cavity photodetectors and VCSELs. In the nitride materials systems, such Bragg mirrors are generally made up of alternating quarter-wavelength GaN and AlGaIn layers. Because of the 2.5% lattice mismatch between GaN and AlN, the AlN content of the ternary material has to be kept low in order to avoid the generation of cracks in the layers. As a result, the index contrast between the layers forming the mirrors is also rather low, typically about 2%. This means that a large number of mirror pairs is required in order to reach a high reflectivity, and the width of the reflectivity stopband is quite narrow. One approach to overcome these problems is to grow the mirror on a strain-relaxed AlGaIn buffer layer whose lattice constant matches the average lattice constant of the AlGaIn/GaN Bragg mirror stack (*Compound Semiconductor* April 2003 p39). The presence of a relaxed buffer layer, however, degrades the quality of the material and may negatively impact the properties of the subsequent active layer growth.

Recently, researchers from the Swiss Federal Institute of Technology in Lausanne have demonstrated an alternative approach based on



A TEM image of a 20 period $\text{Al}_{0.84}\text{In}_{0.16}\text{N}/\text{GaN}$ Bragg mirror with a reflectivity centered at 515 nm.

the growth by MOVPE of the ternary $\text{Al}_x\text{In}_{1-x}\text{N}$ alloy lattice matched to GaN (*Appl. Phys. Lett.* 2003 **83**(4) 668). By recording the reflectivity *in situ* during the growth of a Bragg mirror, the index contrast between GaN and AlInN was determined to be around 6.5% at the lattice-matched composition. When allowing for a 0.5% mismatch, which is sufficiently low to avoid the generation of cracks, the maximum index contrast achievable in the AlInN/GaN system is close to 8%, compared with a value of about 3% for the AlGaIn/GaN system. The researchers demonstrated the growth of a 20 pair $\text{Al}_{0.84}\text{In}_{0.16}\text{N}/\text{GaN}$ Bragg mirror centered at 515 nm exhibiting a reflectivity of just over 90% with a 35 nm full-width-at-half-maximum stopband. The resulting layers were mirror-like and transparent,

exhibited an X-ray diffraction rocking curve half width of 360 arcsec, close to the value for obtained for the GaN buffer layer, and were completely crack-free over the full 2 inch diameter wafer.

The researchers say that the growth of high-quality AlInN lattice-matched to GaN may represent a breakthrough in nitride optoelectronics, because it offers a high index contrast to GaN without the limitations in the design due to strain.

SiGe VCOs target the automotive radar market

While those with an interest in GaAs MMICs are looking at automotive radar to provide them with their next big market, the R&D effort surrounding SiGe continues to produce devices that could compete with GaAs in this application. Researchers from Ruhr University and Infineon Technologies in Germany have published work describing the suitability of a SiGe production technology for producing VCOs for 77 GHz radar transmitters (*Elec. Lett.* 2003 **39**(18) 1326).

The VCO circuits were fabricated using a 0.35 μm SiGe bipolar process with an f_t and f_{max} of 150 and 180 GHz respectively. The size of the reported VCO chip, which allowed the frequency range to be adjusted, was $0.8 \times 1.2 \text{ mm}$. At the chip's highest frequency range of

84.3–88.4 GHz (tunable with bias voltages from -2.0 to 1.3 V), the phase noise at 1 MHz offset frequency varied from -89.9 to 92.2 dBc/Hz . The power output in this frequency range dropped from 8.4 to 6.4 dBm. At the chip's medium frequency range of 75.3–79.6 GHz, for which the chip was optimized, and which is the range of interest for automotive radar, the phase noise was between -93 and -95 dBc/Hz at 1 MHz offset frequency, and the total available output power was 14 dBm. The authors say that this combination of frequency, phase noise and output power is the best yet reported for Si-based VCOs, and they expect to improve on these figures using design modifications currently being made.

AlGaIn/GaN HEMTs reach 4 W/mm at 35 GHz

There is a large research effort being directed towards AlGaIn/GaN HEMTs operating in the X-band, with power densities of over 10 W/mm now being achieved. There is also interest in bringing the benefits of AlGaIn/GaN technology to higher-frequency bands such as the Ka band for satellite communications and LMDS. Devices processed at TriQuint Semiconductor from AlGaIn/GaN structures grown on SiC at the University of South Carolina have yielded the best combination of power density, PAE and gain to date at 35 GHz (*Elec. Dev. Lett.* 2003 **24**(10) 616).

The epitaxial structure consisted of a 200 nm AlN layer, a 2 μm undoped GaN buffer and a 23 nm AlGaIn barrier layer, grown with a trace amount of indium that acts as a surfactant to improve interface

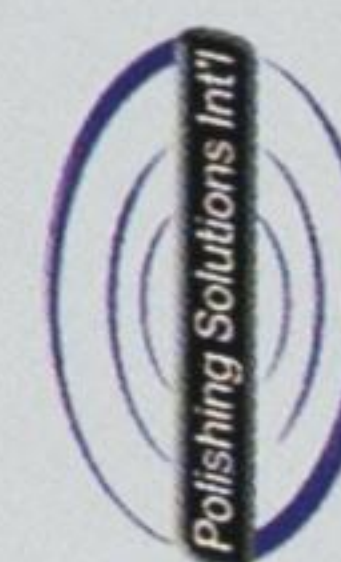
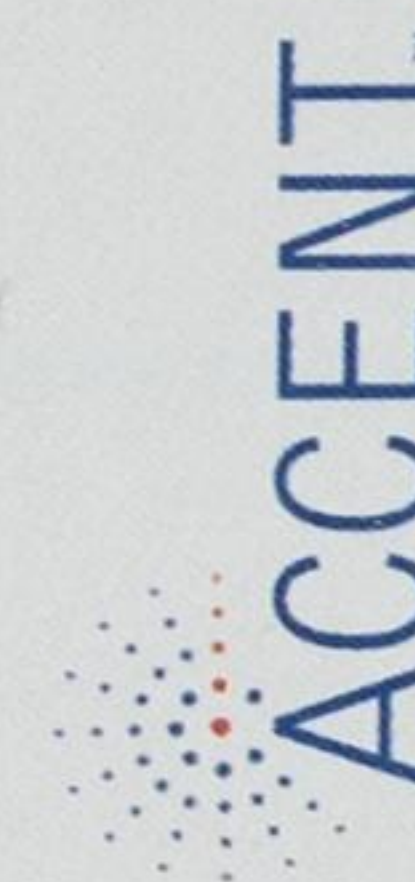
quality. Source and drain contacts were formed using Ti/Au/Ti/Au alloyed metallization. Pt/Au Schottky T-gates were centered in a 4 μm source-drain spacing. Silicon nitride was deposited to reduce the well known frequency-dependent current-lag phenomenon.

For devices with $200 \times 0.25 \mu\text{m}$ gates, the peak transconductance was 285 mS/mm at a gate bias of -2.9 V and a drain bias of 10 V, with over 200 mS/mm maintained across gate bias values from -3.5 to -1 V . The maximum saturation current at a V_{gs} of 2 V was 1.1 A/mm at an I_{ds} of 0.91 A/mm. Values of f_t for various 200 μm gate devices were 40–44 GHz at a V_{ds} of 10 V and V_{gs} of -3 V . At 30 GHz and at a V_{ds} of 30 V, without cooling, the device showed an output power density of 4.13 W/mm at a peak PAE of 23% with a linear gain of 7.54 dBm.

DEVICE PROCESSING EQUIPMENT

If you would like to advertise in future issues, contact Luke Neel (tel: +44 117 930 1264, fax: +44 117 930 1178, e-mail: luke.neel@iop.org).

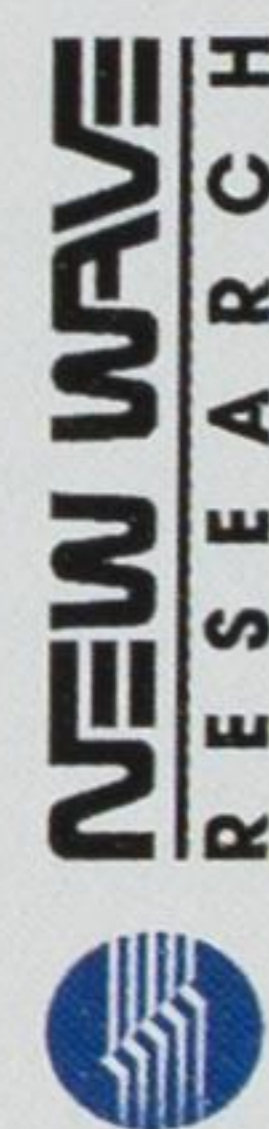
Device Processing Equipment Suppliers Guide				Selected suppliers of device processing equipment													
Company name	Web address	Telephone number	Contact	Materials characterization	Lithography equipment and services	Wet stations (etch, lift-off, cleaning)	Dry wafer-cleaning equipment	Sputtering, evaporation and metal-plating equipment	CVD systems	Ion-beam etch systems	Plasma-etch systems	Rapid thermal-processing equipment	Wafer handling and bonding	Wafer-thinning equipment and CMP	Wafer scribe/break/dice/polish	Process gas and purification equipment	Other process equipment
Accent Optical Technologies	accentopto.com	+44 1904 715500	Dale Page	•	•												•
Air Products	airproducts.com	+1 610 481 4911	Ed McKendry	•	•				•							•	•
Candela Instruments	candela-inst.com	+1 510 413 0900	Gale Lane	•													
CEVP Ltd	cevp.co.uk	+44 1273 515899	Ben Jensen					•	•	•	•						•
CVD Equipment Corporation	cvdequipment.com	+1 631 981 7081	Gary Dyal						•		•	•	•				•
EV Group	evgroup.com	+43 7712 53110	Anna Relter		•								•				•
J P Sercel Associates Inc	jpsalaser.com	+1 603 595 7048	Doug Pulfer														•
Leighton Electronics Inc	leighton.com	+1 610 377 5990	Matt Cordes	•				•						•			•
Loomis Industries Inc	loomisinc.com	+1 707 963 4111	Alex Loomis												•		
New Wave Research	new-wave.com	+1 510 249 1550	Michael Earley												•		
ORS Ltd	ors-ltd.com	+44 1248 672603	Kelvin Weeks	•													•
Polishing Solutions International	polishingsolutions.com	+1 602 426 0544	Mike Bowman											•	•		
SAES Pure Gas Inc	saesgetters.com	+1 805 541 9299	Chris Detrick		•			•	•		•	•				•	•
Surface Technology Systems plc	stsystems.com	+44 1633 652400	Carolyn Short						•								•
Total Fab Solutions	totalfabsolutions.com	+1 602 426 0544	Mike Bowman			•							•	•	•		
Unaxis USA	semiconductors.unaxis.com	+1 727 577 4999	Scott Craver				•		•		•						•
Unaxis Europe	semiconductors.unaxis.com	+49 89 7550 5205	Mark Hashemi					•	•			•					•
Veeco Instruments Inc	veeco.com	+1 516 677 0200	Fran Brennan					•		•							•



Polishing Foundry Services
www.polishingsolutions.com



CMP ~ Metrology ~ Robotics
www.totalfabsolutions.com



Reversal of fortune complete as RFMD revenue beats JDSU

The September quarter yielded some interesting statistics as RF Micro Devices turned in higher revenues than Skyworks and both companies beat former super-earner JDS Uniphase.



After the general upward surge in revenue figures and meteoric rise in stock prices in the June quarter, things were looking a little more subdued as the September quarter's figures were published. However, they were still encouraging, with more positives than negatives in the portfolio table.

The companies manufacturing GaAs ICs for wireless communications reported a particularly buoyant September quarter. TriQuint Semiconductor reported revenue of \$78.8 m, a 10.9% increase compared with the year-ago quarter and an 8.2% sequential increase over the June quarter. Its revenue, gross margin and earnings per share were all above company guidance due to a very strong September, especially from its wireless handset products business, the revenue from which rose 30% sequentially. TriQuint's optoelectronics unit, which accounts for about 15% of its business, brought

in 7.6% more revenue than in the June quarter. Ralph Quinsey, TriQuint's president and CEO, described the outlook for the December quarter, traditionally the strongest for the wireless industry, as being bullish, with revenue expected to be \$80–83 m.

After a lackluster June quarter, RF Micro Devices (RFMD) had a strong September quarter with record sales of \$163.5 m. This is a 24% jump on the June quarter and a 36.5% increase on the equivalent period last year. Cost savings from RFMD's conversion from 4 to 6 inch wafer processing helped boost the company's net income to \$11.4 m for the quarter. This compares with \$6.5 m during the same period last year and the net loss of \$8.1 m it recorded in the June quarter.

RFMD is predicting double-digit growth to \$180 m in revenue for the December quarter. The company is anticipating further growth next year as it expects to gain new market share with its Polaris family of GSM/GPRS/EDGE transceivers, where it already has design wins with four of the top five handset OEMs.

Compared with the results from TriQuint's wireless business and RFMD, Skyworks Solutions looked a little disappointing. Its quarterly revenues have remained at about \$150 m for the last four quarters, meaning that its closest rival RFMD sailed past it in revenue in the September quarter. The company posted its first operating profit of \$0.5 m in the year-ago quarter, but in the September quarter it slid back into the red by \$4.8 m. It also took substantial charges in the quarter for its restructuring program, resulting in a net loss of \$42.9 m. Skyworks is expecting a better December quarter, forecasting 10% growth in revenues, and expects to make its first overall profit of 1 cent per share.

Decreasing revenues appeared again in the September quarter for JDS Uniphase. The figures were 11% lower sequentially at \$147.4 m, and the company says that the December quarter's income will be lower (at \$140–150 m) than originally estimated, sparking off further site closures and job losses.

Looking at the revenue figures, one sees that the two biggest GaAs IC manufacturers, Skyworks and RFMD, both have incomes above JDSU, something that would have been unthinkable two years ago when JDSU had revenues of \$3.2 bn. It will be interesting to see if this becomes the norm or if any upturn in the fiber-optic industry will reverse the situation.

September quarter's revenues

Company	Symbol	Closing price on Oct 30	% change since Aug 29	Sep quarter revenue (\$m)	% change over June quarter revenue
GaAs IC companies					
Anadigics	ANAD	5.32	6.8	17.8	-1.1
Celeritek	CLTK	8.02	3.2	7.1	7.6
Endwave	ENWV	8.50	91.0	8.2	-3.5
RF Micro Devices	RFMD	12.90	46.1	163.5	24.3
Sirenza Microdevices	SMDI	4.49	0.4	10.4	14.3
Skyworks Solutions	SWKS	10.74	-5.5	150.0	-0.1
TriQuint	TQNT	7.40	34.1	78.8	8.2
Opto companies					
Cree	CREE	17.65	11.6	66.2	10.0
JDS Uniphase	JDSU	3.51	1.7	147.4	-11.0
Avanex	AVNX	5.18	9.1	18.1	229.1
Semiconductor materials and equipment companies					
ATMI	ATMI	23.02	-17.6	58.1	1.0
AXT	AXTI	2.34	-12.7	8.5	-0.2
Kopin	KOPN	7.60	-12.7	17.5	-12.1
Trikon	TRKN	5.90	-6.2	8.4	40.0
Veeco	VECO	25.68	20.3	63.1	-14.0
European companies (share prices and revenues in €)					
Bookham	BHM.L	2.13	88.5	33.6	11.4
Riber	RIBE.LN	1.35	11.6	3.6	38.5
Soitec	SOIT.LN	4.70	-18.3	23.2	19.6
Unaxis	UNAXZN.VX	109.13	17.3	247.0	-1.6

EQUIPMENT

Global Phosphorus Solutions

■ **Innovative Reactors**

In 1982, Riber develops the industry's first phosphorus-dedicated MBE research system.

■ **Patented Phosphorus Sources**

In 1992, Riber introduces the zero-burst valved phosphorus cracker cell design that is now used by all major component manufacturers.

■ **Full-Service Application Lab**

In 2002, Riber inaugurates the industry's first indium phosphide application lab to accompany you from start up through full production of phosphorus-containing compound semiconductor materials.

If you want to visit our application laboratory and find out more about our global phosphorus solutions for growth, characterization and maintenance, please contact us today at:

RIBER

133, bd National

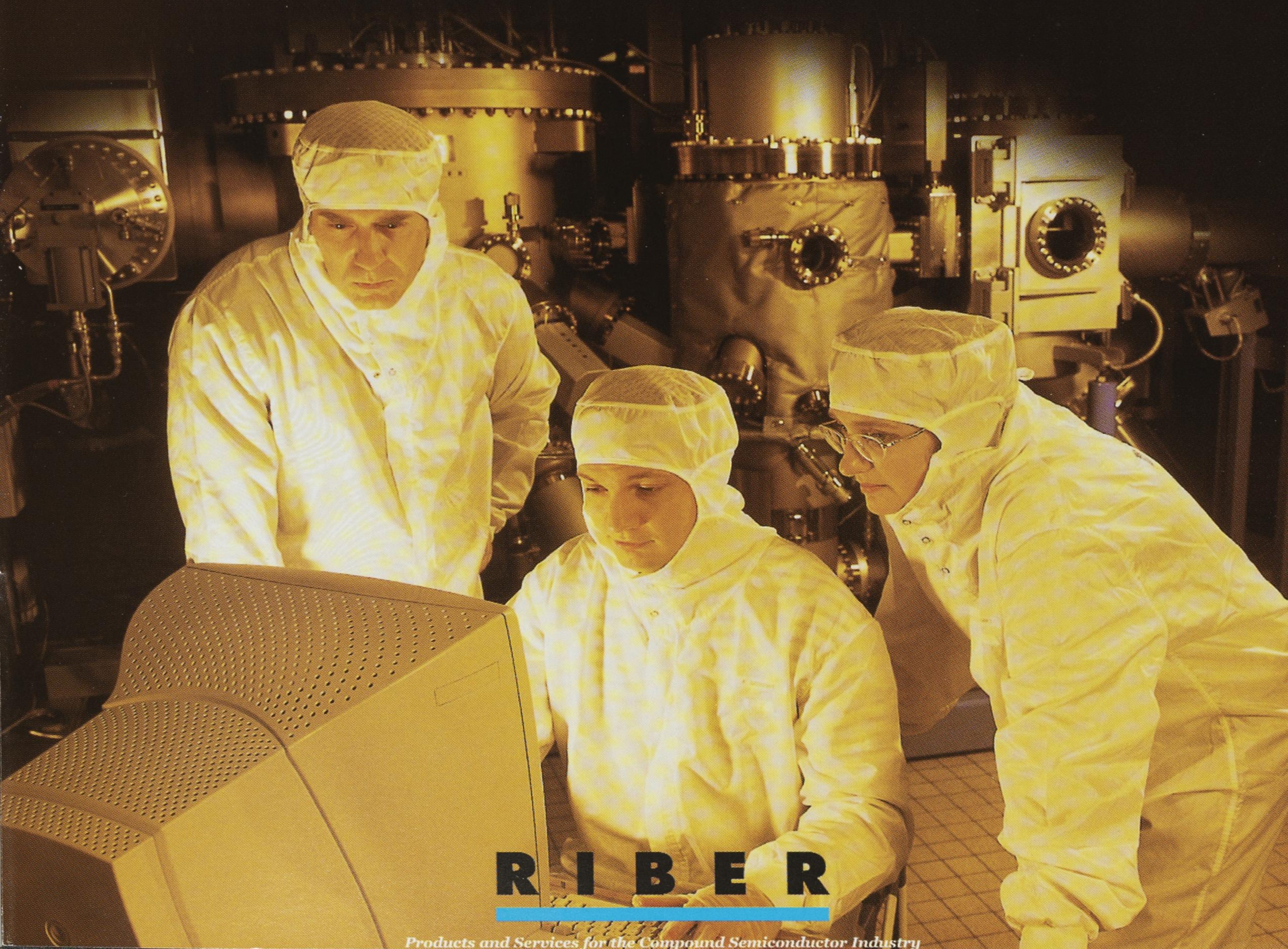
92503 Rueil-Malmaison Cedex / France

Tel: +33 (0) 1 47 08 84 35

Fax: +33 (0) 1 47 08 32 39

e-mail: info@riber.com

Web site: www.riber.com



R I B E R

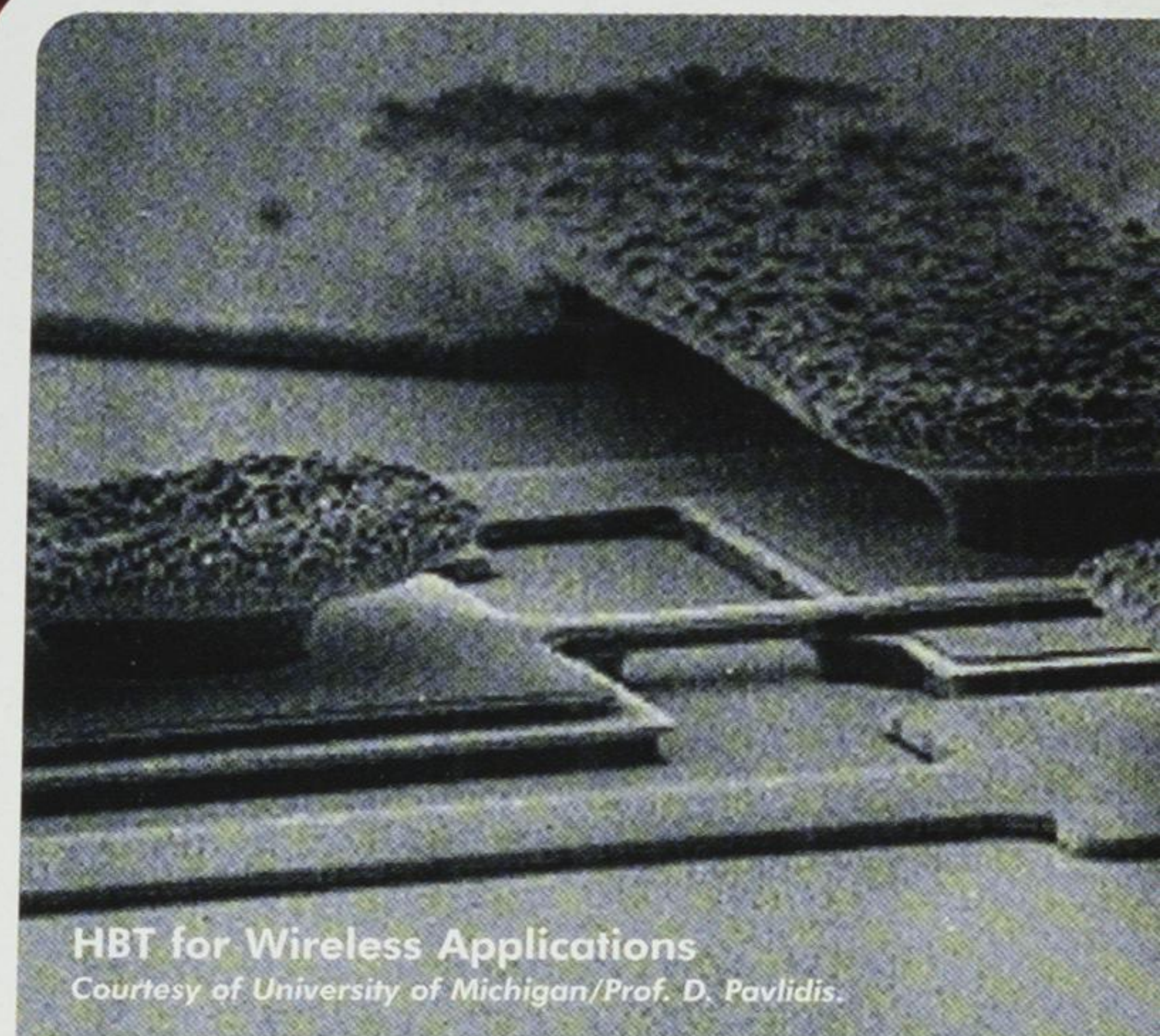
Products and Services for the Compound Semiconductor Industry



Think big. Work small.

**Veeco helps you visualize, measure,
and create nanoscale features.**

Veeco provides the metrology and process equipment solutions that help make today's—and tomorrow's—advanced semiconductor devices faster, smaller, and more cost-effective. Solutions like the only non-destructive 3D measurement technology for 100nm and below. MBE for the production of compound semiconductors. Ion beam deposition and 3D AFM for photomask production and metrology. To find out more, visit www.veeco.com/semi or call 1.888.24.VEECO today.



HBT for Wireless Applications
Courtesy of University of Michigan/Prof. D. Pavlidis

Atomic Force Microscopy
Atomic Force Profiling
Optical Profilers
Stylus Profilers
Ion Beam Deposition
Ion Beam Etching
Molecular Beam Epitaxy

Solutions for a nanoscale world.

Veeco