

COMPOUND SEMICONDUCTOR

September 2002 Volume 8 Number 8

www.compoundsemiconductor.net



HETEROSTRUCTURES **Strained silicon, wafer bonding** **and SiGe beyond the HBT**

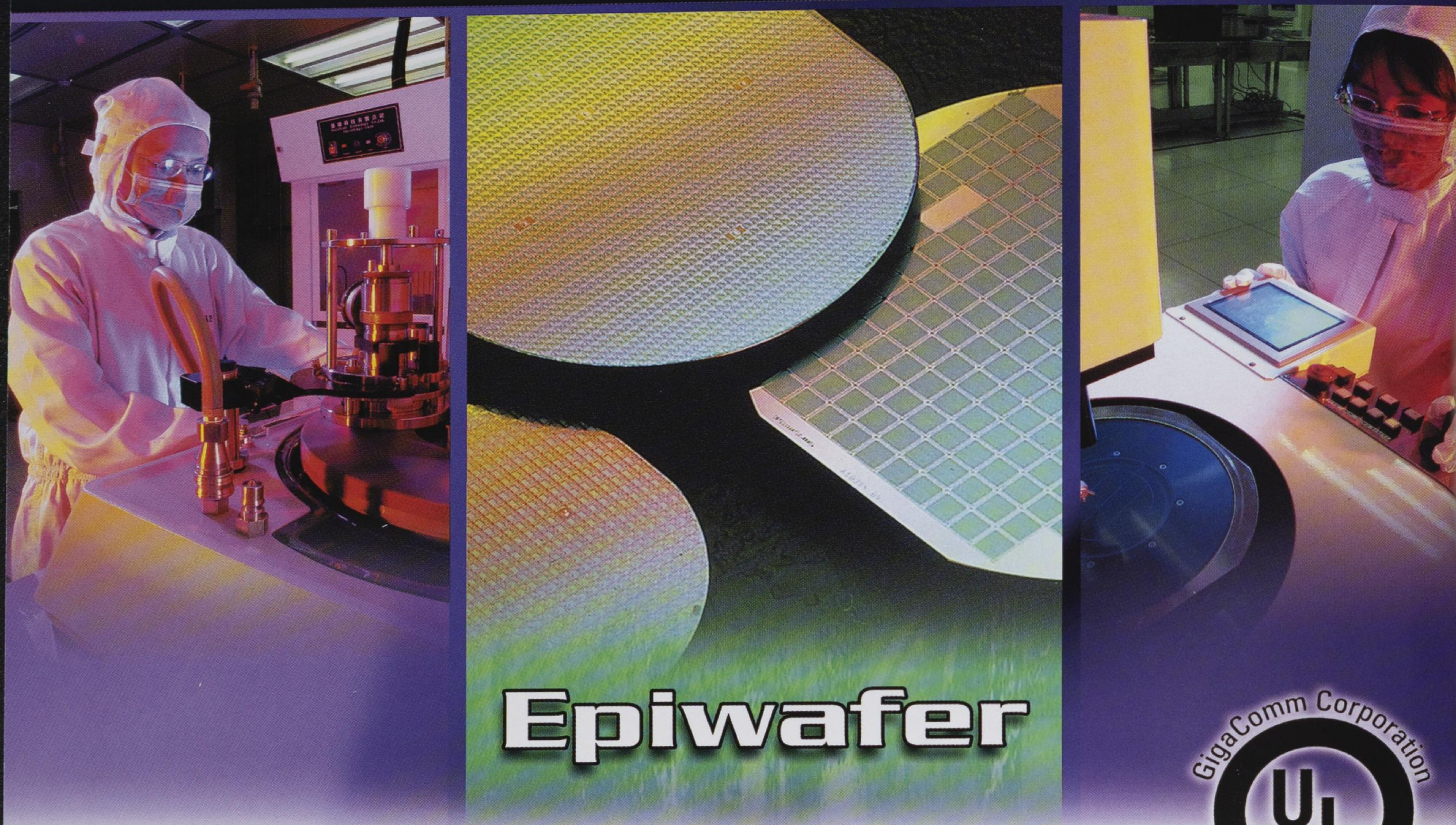
ALSO INSIDE

**Nichia and Toyoda
Gosei talk patents**

**Agere and ADC exit
opto business**

**What's on at
CS-MAX 2002?**

Custom epitaxial growth specialist— As efficient as your internal fab!



Epiwafer



- Ready to offer 850 nm VCSEL epiwafer and 1310 nm FP epiwafer
- InP & GaAs-based epi process capabilities
- Standard products provide device guarantee on every lot
- Specialized in custom epitaxial
- Short development cycle period and competitive cost

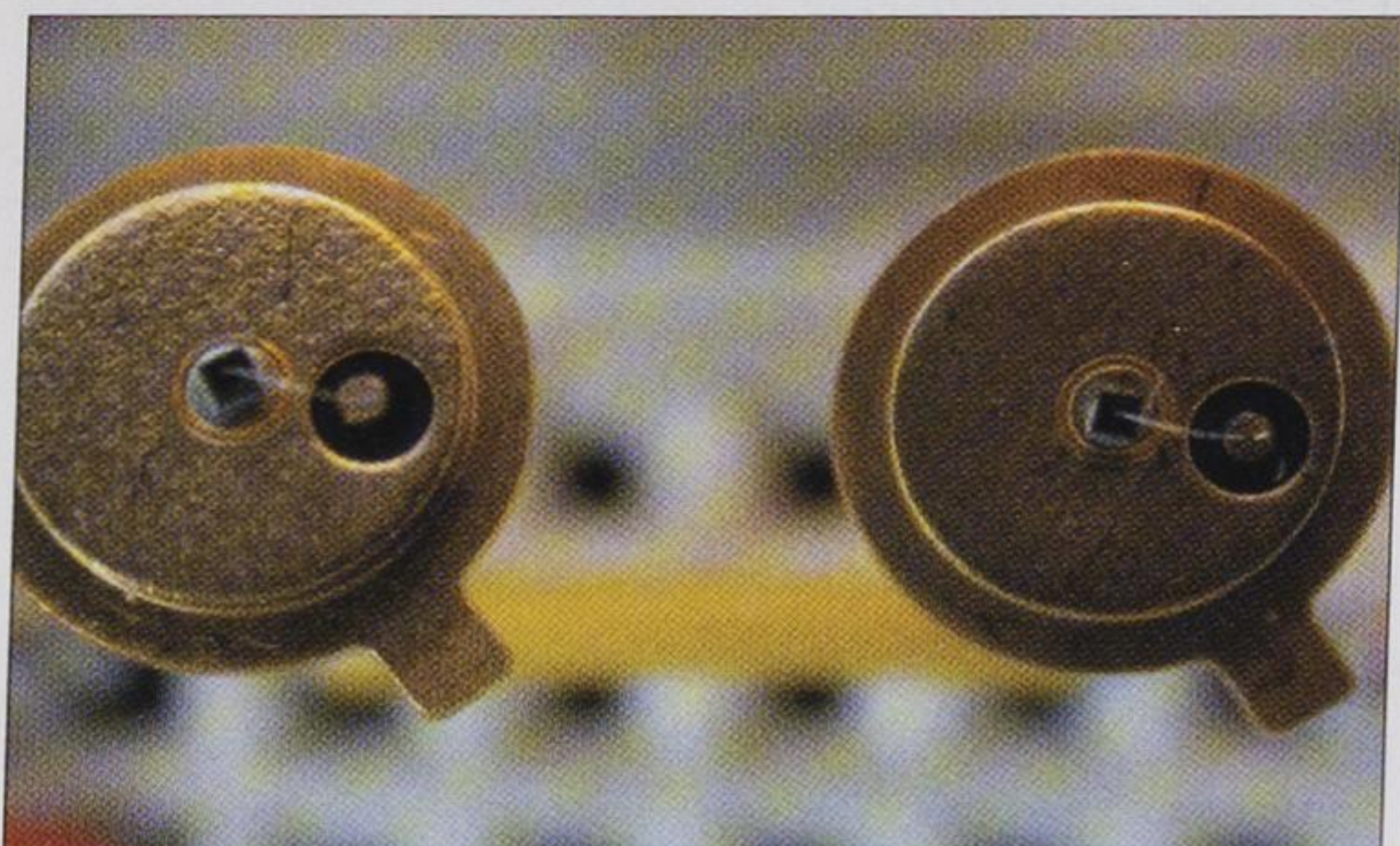


www.gigacommcorp.com

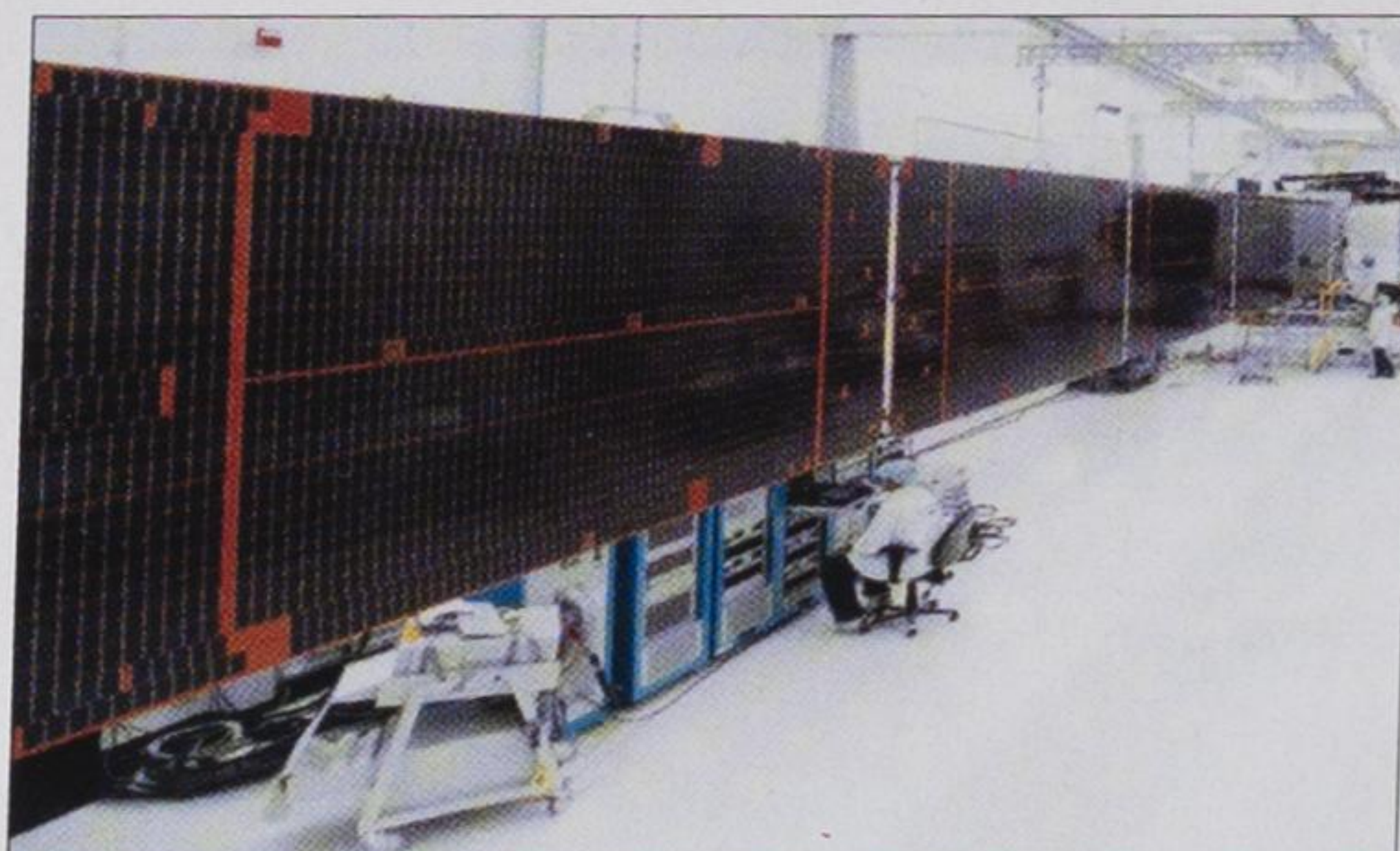


COMPOUND SEMICONDUCTOR

SEPTEMBER 2002 VOLUME 8 NUMBER 8



New bonding techniques are driving the performance of LEDs to new levels **p12**



Advances in solar-cell technology will boost efficiencies to more than 30% **p17**



Mobile-phone manufacturers are buying blue LEDs for use in their latest handsets **p25**

NEWS

- 3** **Headline News** Nichia and Toyoda Gosei talk patents...Agere and ADC exit the opto business...Skyworks restructures again
- 7** **GaAs News** RFMD leads the way in PA sales...Filtronic closes US fab and teams with Powerwave
- 11** **LED News** Kopin samples efficient CyberLite LEDs...AET develops GaN-based LEDs on GaAs
- 15** **Nitride News** European group grows InGaN lasers on silicon...SiXON set to build new SiC plant
- 17** **Opto News** Spectrolab celebrates millionth GaAs solar cell...JPL develops four-band QWIP...RSC wins contracts
- 21** **Fiber News** Agere axes its optoelectronics unit...Princeton Lightwave partners with Trumpf...Multilink to cut workforce by 45%
- 25** **News from Asia** Samsung increases blue LED orders...Sharp plans blue laser launch
- 27** **Market News** InP microelectronics sales to reach \$206 m by 2006...1310 nm transceivers to dominate 10 Gbit/s market...Nokia edges towards 40% market share
- 29** **Materials & Equipment** Aeronex to countersue SAES Getters...Accent acquires new product lines
- 32** **Silicon Compounds** Intel unveils strained silicon plans...Atmel closes 8 inch wafer fab

DEPARTMENTS

Index 2 **Research Review 37**
Product Showcase 56 **Portfolio 57**
Recruitment 60 **Advertisers' Index 60**

COVER STORY: HETEROSTRUCTURES

39 Strained silicon joins the drive to keep CMOS chips on course

The huge costs of scaling CMOS devices according to Moore's Law have left the silicon industry at a crossroads. AmberWave's Mayank Bulsara says that strained silicon will improve performance without a big investment.

45 The future of SiGe devices beyond HBT applications

The HFET is expected to be the next SiGe device to reach commercial markets. Thomas Hackbarth, Marco Zeuner and Ulf König of DaimlerChrysler discuss why they think the HFET will lead the race to higher speed devices.

49 Chip manufacturers look to wafer-bonding technology

As the demand for chip-level integration increases, the ability to bond materials onto a wafer is key. Shari Farrens, Viorel Dragoi, Paul Lindner and Bernhard Wieder of EV Group report on available techniques.

FEATURES

35 Silicon Update: CMOS gets ready for high-speed wireless LANs

While GaAs and SiGe are the obvious choices for manufacturing devices for 5–6 GHz WLANs, lower noise figures achieved through control of parasitics are keeping CMOS in the frame.

53 CS-MAX 2002 Preview: Compound Semiconductors come to Silicon Valley

The industry's largest event moves to San Jose, emphasizing manufacturing solutions for all types of III-V and silicon heterostructure devices. Marie Meyer previews CS-MAX 2002.

On the cover: strained silicon channels will advance the performance of CMOS without the need for big capital investment (picture courtesy of UMC) – see p39.

COMPOUND SEMICONDUCTOR

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

News editor Richard Dixon
rdixon@compsem.com
Tel. +1 617 666 1720

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

Features editor Rebecca Pool
rebecca.pool@iop.org
Tel. +44 117 930 1256

Contributing editor Robert Metzger

Managing editor Marie Meyer
marie.meyer@iop.org
Tel. +44 117 930 1034

Publisher Geraldine Pounsford
geraldine.pounsford@iop.org
Tel. +44 117 930 1022

Advertising manager Dan Huckle
dan.huckle@iop.org
Tel. +44 117 930 1032; Fax +44 117 930 1178

Advertising sales executive Joanna Hook
joanna.hook@iop.org
Tel. +44 117 930 1033; Fax +44 117 930 1178

Production Ruth Aspinall/Seth Burgess
Ad production Rachel Clark/Joanne Scriven
Circulation Laura Serratrice
Art director Andrew Giaquinto
Technical illustrator Alison Tovey
Publishing director Richard Roe

Subscriptions

All general enquiries: compsem@iop.org. US enquiries: tel. +1 215 627 0880; non-US inquiries: tel. +44 117 930 1018. *Compound Semiconductor* is available by free subscription for qualified individuals working at compound semiconductor fabs and foundries. For a subscription order form please visit our website at www.compoundsemiconductor.net. For other subscribers the individual annual subscription price is \$95 US; £61 foreign. Library rate: \$300 US; £207 foreign. Send payment to: Compound Semiconductor, WDIS Ltd, Units 12 & 13, Cranleigh Gardens Industrial Estate, Southall, Middlesex UB1 2DB, UK.

Editorial board

Colombo Bolognesi Simon Fraser University (Canada); **Steven DenBaars** University of California at Santa Barbara (USA); **Andrew Johnson** QinetiQ (UK); **Robert Metzger** Georgia Institute of Technology (USA); **Rodney Moss** Agilent Fiber Optic Components (UK); **Shuji Nakamura** University of California at Santa Barbara (USA); **Dwight Streit** TRW (USA); **Toby Strite** JDS Uniphase (Switzerland); **Jacob Tarn** Epistar (Taiwan); **Gary Tomkins** Nortel Networks (Canada); **Andreas Waag** University of Ulm (Germany); **Gary Wicks** University of Rochester (USA); **Peter Zory** University of Florida (USA)

©2002 IOP Publishing Ltd. All rights reserved.

US mailing information: *Compound Semiconductor* (ISSN 1096-598X) is published 11 times a year for \$95 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

Accent Optical Technologies	30	Microsemi	22
ADC Telecommunications	3	Motorola	7, 33
Advanced Epitaxy Technology	12	Multilink	22, 57
Aehr Test Systems	29	Nichia	3
Aeronex	29	North Carolina State University	11
Agere	3, 21, 33, 57	OEpic	22
Agilent	19, 57	Oki Electric	22
Air Products	30	Philips Analytical	30
Aixtron	15, 57	Picogiga	33, 57
Alcatel Optronics	57	Powerwave Technologies	7
AmberWave	39	Praxair	30
Anadigics	57	Princeton Lightwave	21
Anaren Microwave	9	RF Micro Devices	7, 9, 30, 57
Atmel	33	Riber	57
ATMI	57	Rockwell	19
Avalon Photonics	29	RWTH Aachen	15
AXT	57	SAES Getters	29
BAE Systems	7, 17	Samsung	25
Bede	57	Sharp	25
Bookham Technology	57	Sirenza Microdevices	9, 57
Celeritek	9, 57	SiXON	15
Chonbuk National University	37	Skyworks Solutions	4, 7, 57
Coherent	57	Soitec	32
Cree	57	Spectrolab	15
EADS	17	ST Microelectronics	33
ElectroniCast	27	Stanley Electric	25
Emcore	17, 29, 57	Strategy Analytics	27
Endwave	57	Stratos Lightwave	57
Epiplus	29	Surface Technology Systems	57
Epistar	25	Tegal	30, 57
ESA	17	Texas Instruments	32
EV Group	33, 49	Thermo VG Semicon	33
FEI	29	Thomas Swan Scientific Equipment	29
Filtronic	7, 57	Toshiba	35
Gartner Dataquest	7	Toyoda Gosei	3
Genoa	21	Trikon	57
Hitachi	7	TriQuint	30, 57
IEM Technologies	29	Trumpf	21
Inphi	22	Tyntek	25
Intel	32	UEC	12, 25
IntelliEPI	30	Unaxis	33, 45
IQE	30, 57	Uniroyal Technology	57
JDS Uniphase	32, 57	University of CA Santa Barbara	38
JPL	19	University of Illinois	38
Kopin	11, 57	University of New South Wales	17
Lucent	21	University of Sheffield	37
Lumileds	12	University of South Carolina	37
M/A-COM	7	University of Texas	38
Matsushita	7	Veeco Applied Epi	29, 57
Memscap	32	Vitesse	57

Nichia and Toyoda Gosei talk patents

By Tim Whitaker

The long-running patent dispute between rival Japanese LED makers Nichia and Toyoda Gosei concerning blue LEDs could at last be drawing to a close. The companies are to open negotiations aimed at ending the six-year feud, which has cost millions of dollars in legal fees. Since the dispute began in August 1996, each company has filed numerous lawsuits claiming that the other was infringing on its patents. The courts in Japan have also been occupied by their attempts to have their rival's patents declared invalid.

According to a joint statement, Nichia and Toyoda Gosei "have agreed, on technology of III-nitride semiconductors such as blue LEDs, to respect any and all patent rights etc which the other party owns". The companies will now "enter into negotiations to bring to an end any and all disputes and suits inside and outside Japan between the parties."

Nichia established a very strong position in the nitride LED market owing to its leading-edge technology and its extensive patent portfolio. The threat of litigation appears to have kept other Japanese competitors, such as Rohm, Stanley and Sharp, out of the market. Nichia consistently stated that it had no intention of negotiating a cross-licensing agreement with Toyoda Gosei or anyone else, but its firm policy of not working with other companies has softened considerably in 2002.

A change of policy

In January of this year, Nichia agreed to license its packaging technology for manufacturing white LEDs to Citizen Electronics; Citizen also agreed to purchase production quantities of blue LED chips from Nichia (*Compound Semiconductor* March 2002 p4). Even more significantly, in June 2002 Nichia and Osram Opto Semiconductors agreed to

Patent judgements in Japan			
	Japanese patent number	Japanese Patent Office decision	Tokyo High Court judgement
Toyoda Gosei			
	2,737,053	invalid (Oct 26, 1999)	valid (March 21, 2001)
	2,681,733	invalid (Mar 13, 2000)	valid (Oct 9, 2001)
	2,666,228	invalid (April 1999)	—
	2,658,009	invalid (Oct 1, 1999)	invalid (Apr 24, 2002)
	2,626,431	invalid (Feb 1, 2000)	valid (June 18, 2002)
	2,623,466	invalid (Aug 8, 2000)	valid (July 18, 2002)
Nichia			
	2,780,691	valid (Jun 16, 2000)	invalid (June 13, 2001)
	2,778,405	valid (Dec 6, 1999)	invalid (Oct 2, 2001)
	2,751,963	valid (Mar 27, 2001)	invalid (May 14, 2002)

TOYODA GOSEI

end their patent dispute and to cross-license all their patents relating to the manufacturing of white LEDs. Nichia filed an injunction in December 1999 to prevent Osram from selling white LEDs in Japan. After the complaint was dismissed in July 2001, Osram filed two lawsuits to try to prevent Nichia from selling its white LEDs in the US and Germany.

Speaking to the Japanese newspaper *Nihon Keizai Shimbun*, a public relations officer at Nichia said: "We now intend to share technology with companies that possess expertise that could complement our technology and firms that can be enlisted to jointly promote market growth."

Nichia has also been involved in a number of other lawsuits; its courtroom opponents have included Cree, Rohm and Shuji Nakamura, who authored most of Nichia's patents before leaving the company to join the University of California at Santa Barbara.

Although Nichia won two patent infringement cases against Toyoda Gosei in 2000, many recent rulings have not gone in Nichia's favor. Toyoda Gosei won two cases in February 2002 to the effect that it had not

infringed on two separate Nichia patents. Also a number of rulings made by the Japanese Patent Office (JPO) on the validity of patents have been overturned by the Tokyo High Court; with one exception, the high court ruled in favor of Toyoda Gosei (see table). Several Toyoda Gosei patents, which were rendered invalid by the JPO, have now been judged valid, while several Nichia patents have been rendered invalid.

Nichia's poor run of form in court has almost certainly been a factor in its decision to come to the negotiating table. Another factor is competition, as other companies seek ways around the patent minefield. Nichia and Toyoda Gosei use very similar InGaN-on-sapphire technology, while Japanese competitors are looking at alternative substrates such as SiC (Rohm, thanks to its tie-up with Cree), silicon (Sanken) and GaN (Mitsubishi Chemical, Sanyo and Sumitomo Electric).

Nichia and Toyoda Gosei should be in a much stronger position to face the challenge from these alternative technologies by cooperating rather than wasting time and money in court.

Agere and ADC exit the opto business

By Tim Whitaker

Two major players in the fiber-optic components industry, Agere Systems and ADC, have announced that they are to exit the optoelectronics business. Both are restructuring in the face of dire market conditions and will focus on core businesses. Agere is seeking a buyer for all or part of its optoelectronics business, which accounted for about 10% of total rev-

enue of \$560 m in the June 2002 quarter. ADC plans to sell or close all of its product lines for passive and active optical components, including tunable and pump lasers.

When the market was at its peak, the major component vendors – JDS Uniphase, Nortel, Lucent and Corning – scrambled to invest billions in expanding their facilities and acquiring new technology. Now Agere (a Lucent

spin-off) and ADC are just the latest companies to announce plans to get out of the business altogether. Nortel, once the clear market leader in optical components, announced at the end of May plans to realign its long-haul business, including the potential sale and/or resizing of its optical components business.

The reason for the exodus becomes clear when one looks at the overall component >>

market. According to market research firm RHK, the total market for optoelectronic components reached almost \$7 bn in 2000, but a figure of \$2.3 bn is now predicted for 2002.

"We believe the optoelectronics business has changed fundamentally and for the long term," said John Dickson, Agere's president and CEO. "Long-haul was the primary focus of efforts for Agere, but this area has declined steeply and continues to be weak. With the excess capacity in the core network, we don't see significant levels of buying for some years to come, with no major deployments of undersea or 40 Gbit/s systems before around 2004-2005."

In the nine months ended June 2001, Agere/Lucent recorded \$1.1 bn in sales of optoelectronic devices. This dropped to \$222 m for the nine months ended June 2002. Now Agere plans to discontinue its optoelectronics operations no later than June 30, 2003, and will focus on providing ICs for communications and computing. The company will sell or close its facilities in Reading and Breinigsville, PA; Dallas, TX; Alhambra and Irwindale, CA; and Matamoros, Mexico (p21).

Big spenders

ADC's decision to stop making components marks a direct reversal for the telecommunications equipment manufacturer, which some analysts have said should never have been in the components business in the first place. In the past few years, ADC acquired a large number of component manufacturers, including Spectracom, a 980 nm pump laser manu-

facturer located in Minnesota, and Altitun, a Swedish maker of tunable lasers. Spectracom was bought in June 1999 for \$400 m and Altitun cost \$872 m in May 2000. Both these businesses and their associated facilities are now on the market. Since its current financial year began in November 2001, ADC has closed 41 facilities worldwide and reduced its workforce from 12,500 to around 9200 - more closures and job losses are expected.

Agere is not confident that it will be able to find a buyer for its world-class technology.

ADC was not the only big spender in the components business in the last few years. Lucent, already a leading vendor, bought a number of companies including CATV component specialist Ortel for \$2.95 bn in February 2000. Among the purchases made by Nortel was tunable VCSEL maker CoreTek for \$1.43 bn in March 2000. Corning acquired pump laser manufacturer Lasertron for \$1.8 bn in November 1999, as well as Pirelli's optical components business (now Corning OTI) for \$3.6 bn in September 2000. In the summer of 2000, Corning and Nortel were involved in ultimately abortive talks over a \$100 bn merger.

A buyer's market

But the king of acquisitions was undoubtedly JDS Uniphase. The company, formed by the merger of Uniphase and JDS Fitel, acquired

IBM Laser Enterprise, Philips Optoelectronics, Epitaxx and SDL, among many others. JDSU was forced to sell its pump laser business to Nortel for competitive reasons after the merger with SDL, but now it appears to be jettisoning its less desirable businesses. JDSU's Cronos MEMS foundry, bought in April 2000 in a stock deal worth around \$550 m, was sold recently to Memscap for less than \$10 m (p32).

Elsewhere, Nortel and JDSU are among the companies that have auctioned off huge amounts of unwanted, and in some cases unused, equipment. In a current Internet auction, Corning OTI is selling manufacturing and test equipment for the fabrication of 980 nm pump lasers, including laser diode burn-in racks, bonders, optical spectrum analyzers and an unused MBE system.

With so many companies cutting back severely or trying to leave the opto business altogether, Agere is not confident that it will be able to find a buyer for its world-class technology and facilities. When pressed, Dickson said: "We are anticipating as a worst-case scenario that there will be no income from the disposal of the optoelectronics business."

JDS Uniphase, or even Intel, might step in to cherry-pick items of technology not in their current portfolio. Bookham Technology, which recently acquired Marconi Optical Components, is rumored to be looking at Nortel's optoelectronics business. But even if buyers are found, one thing is certain: there won't be any billion-dollar deals in the fiber-optic components industry for a long time.

Skyworks restructures again, shuts Sunnyvale fab

By Richard Dixon

Skyworks Solutions, the company formed by the merger of Alpha and Conexant's wireless operation, is taking further steps to make the most of its combined assets. Following other consolidation moves (*Compound Semiconductor* August 2002 p3), the company plans to transfer its InGaP HBT fabrication activities and key personnel from the former Alpha facility in Sunnyvale to Skyworks' Newbury Park facility, formerly Conexant's GaAs fab. The Sunnyvale fab will eventually be closed.

Acquired by Alpha in 1999 from NDI, the Sunnyvale facility manufactures devices using MESFET, PHEMT and InGaP/GaAs HBT processes. Over approximately one year, the 4 inch AlGaAs/GaAs HBT line at Skyworks' Newbury Park fab will switch to the

InGaP/GaAs HBT process, at which time the Sunnyvale fab will cease operations. Meanwhile, PHEMT and MESFET manufacturing requirements from Sunnyvale will be diverted to the former Alpha fab in Woburn, MA.

"As is the case in most mergers, there is an overlap in operations," said Kevin Barber, senior VP of operations at Skyworks. "The Sunnyvale facility represented an opportunity to consolidate operations by transferring products and technology to our Newbury Park and Woburn facilities. We can handle the transfer of the Sunnyvale product lines to Woburn using existing equipment capacity."

"We are also working closely with our customers to gain acceptance of the transfer and qualification of our product lines," added Barber. "This will end the restructur-

ing process, which we expect to be completed within a year."

GaAs manufacturing will also continue to be based on 4 inch wafer processing. Barber said, "We have done some work on 6 inch wafer processes so we understand the technology, but we don't see a need to move to 6 inch in the near future."

The restructuring targets operational losses at Skyworks, which has reported a revenue of \$113 m for the June 2002 quarter. The combined revenue of Alpha and Conexant's wireless business would have been \$137 m for the June quarter, with a \$19 m operating loss. Skyworks expects revenues for the September quarter to be \$150 m. The latest moves will dispose of around 100 jobs, reducing the company's total headcount to around 3750.

The CVD Engineering Company

IT'S A FACT

that no other MOCVD company in the world offers you the unique, versatile, and constantly high quality technology you're assured of from AIXTRON, whether you're producing LED's, Lasers, Detectors, HEMTs, HBTs, OEICs...

...And we can prove it!

FACT!

No other company in the world offers you a complete MOCVD reactor line, based on a proven scaling concept, from R & D up to full-scale production (1x2" up to 95x2" wafers or equivalent 3" 4" 6" wafers).

FACT!

AIXTRON is the only company in the III-V epitaxy field offering proven processes from mono layer thickness up to more than 200 $\mu\text{m}/\text{h}$.

FACT!

AIXTRON was the first MOCVD company worldwide to receive the ISO 9001 Certification the internationally recognized quality symbol.



WHAT BETTER GUARANTEE OF OUR

Commitment to AIXcellence

AIXTRON

European Headquarters Aachen · Germany
AIXTRON AG · Kackertstrasse 15-17 · 52072 Aachen
Phone: +49 (241) 89 09-0 · Fax: +49 (241) 89 09-40
E-mail: info@aixtron.com · www.aixtron.com

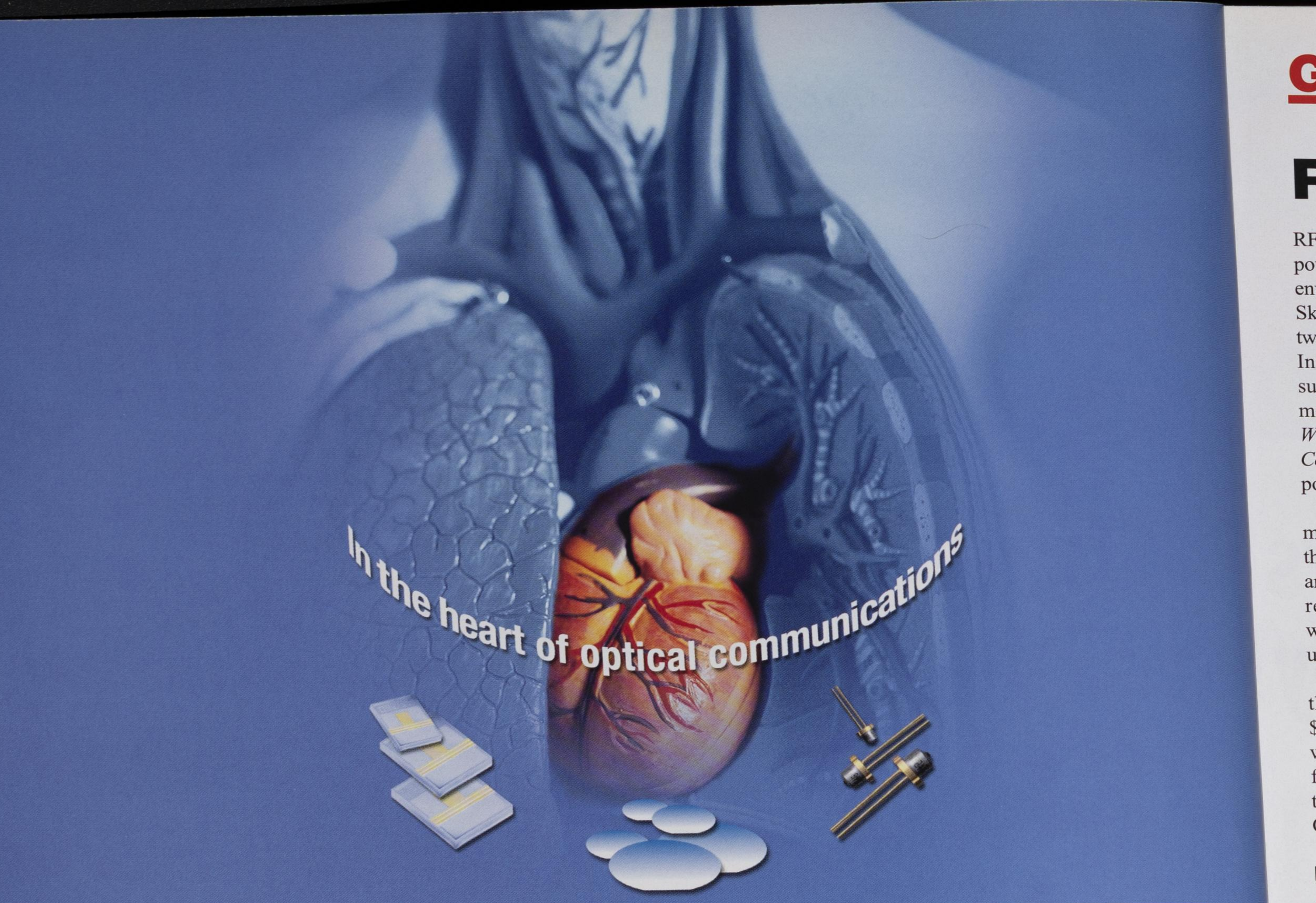
US Headquarters Chicago, IL
AIXTRON Inc. · 1670 Barclay Blvd. · Buffalo Grove · IL 60089
Phone: +1 (847) 215 - 7335 · Fax: +1 (847) 215 - 7341
E-mail: usinfo@aixtron.com

AIXTRON Korea AIXTRON cshs
4F, Korea Exchange Bank B/D · 358-1, Yatap-Dong
Bundang-Ku, Sungnam City · Kyoungki-Do, 468-828
Phone: +82 (31) 703 - 51 00 · Fax: +82 (31) 703 - 51 10
E-mail: koreainfo@aixtron.com

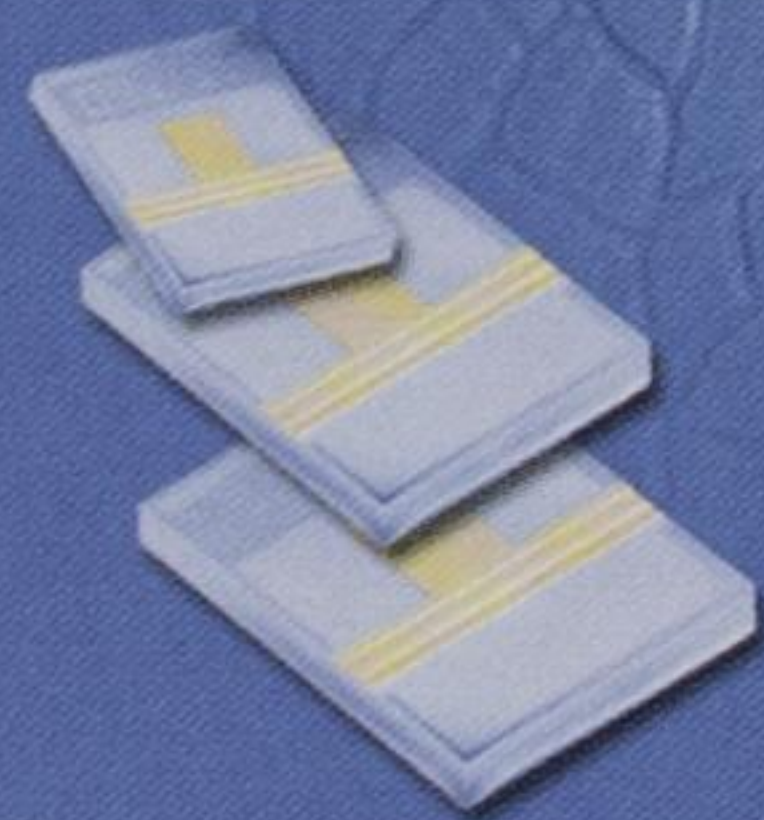
AIXTRON Japan Moritani & Co., Ltd · 8th Machinery Dept. · 1st Business Group
1-4-22 Yaesu, Chuo-Ku · Tokyo 103-8680
Phone: +81 (3) 32 78 - 61 31 · Fax: +81 (3) 32 78 - 60 03
E-mail: m8info@moritani.co.jp

AIXTRON Taiwan Challentech International Corp.
Pateh Road No. 1 · Lane 9 · Hsin-Chu, 300
Phone: +886 (3) 56 14 - 211 · Fax: +886 (3) 56 11 - 194
E-mail: hoton@challentech.com.tw

AIXTRON China AIXTRON AG · Shanghai Branch
Kuen Yang Building, Rm 1204
Zaojiabang Rd. 798 · 200030 Shanghai
Phone: +86 (21) 64 45-32 26 · Fax: +86 (21) 64 45-37 42
E-mail: chinainfo@aixtron.com



In the heart of optical communications



Exactly where you expected them to be

Advanced and high-quality compound semiconductor products for cost-effective optical communications systems.

- Epiwafers for telecommunication (LD, p-i-n, APD, etc.)
- Custom-designed epiwafers
- 1310/1550 nm Fabry-Pérot chips up to 10 Gb/s
- DFB laser chips
- TO-can packaged lasers
- Custom-modified chips and laser bars
- Special characterization to meet your needs
- Modulight's dedicated technical contact for after sales support



Modulight

Modulight, Inc.
P.O. Box 770
FIN-33101 TAMPERE
Finland
phone +358 3 3399 1200
fax +358 3 3399 1210
www.modulight.com
sales@modulight.com

Taiwan:
Gredmann Taiwan Ltd.
www.gredmann.com
Contact person: Mr. Winter Yen
phone +886 2 2719 3456
fax +886 2 2716 5500
email: winter@gredmann.com

United Kingdom:
Mi-Net Technology Ltd
www.mi-net.co.uk
Contact person: Mr. Mick Shropshall
phone +44 1628 783 576
fax +44 1628 784 671
email: ms@mi-net.co.uk

Korea:
Jinsan Scientific Co., Ltd.
www.jinsanco.co.kr
Contact person: Mr. Y. J. Shim
phone +882 578 4271
fax +822 578 4274
email: yjshim@jinsanco.co.kr

RFMD leads the way in PA module sales

RF Micro Devices was the leading supplier of power amplifier modules and MMICs by revenue in 2001, according to Gartner Dataquest. Skyworks Solutions, formed by a merger between Conexant's wireless business and Alpha Industries, was the number one PA module supplier and Motorola was the top PA MMIC manufacturer. The Gartner Dataquest report *Wireless Communications Semiconductor Competitive Market Shares for 2001*, puts total power amplifier sales for 2001 at \$869 m.

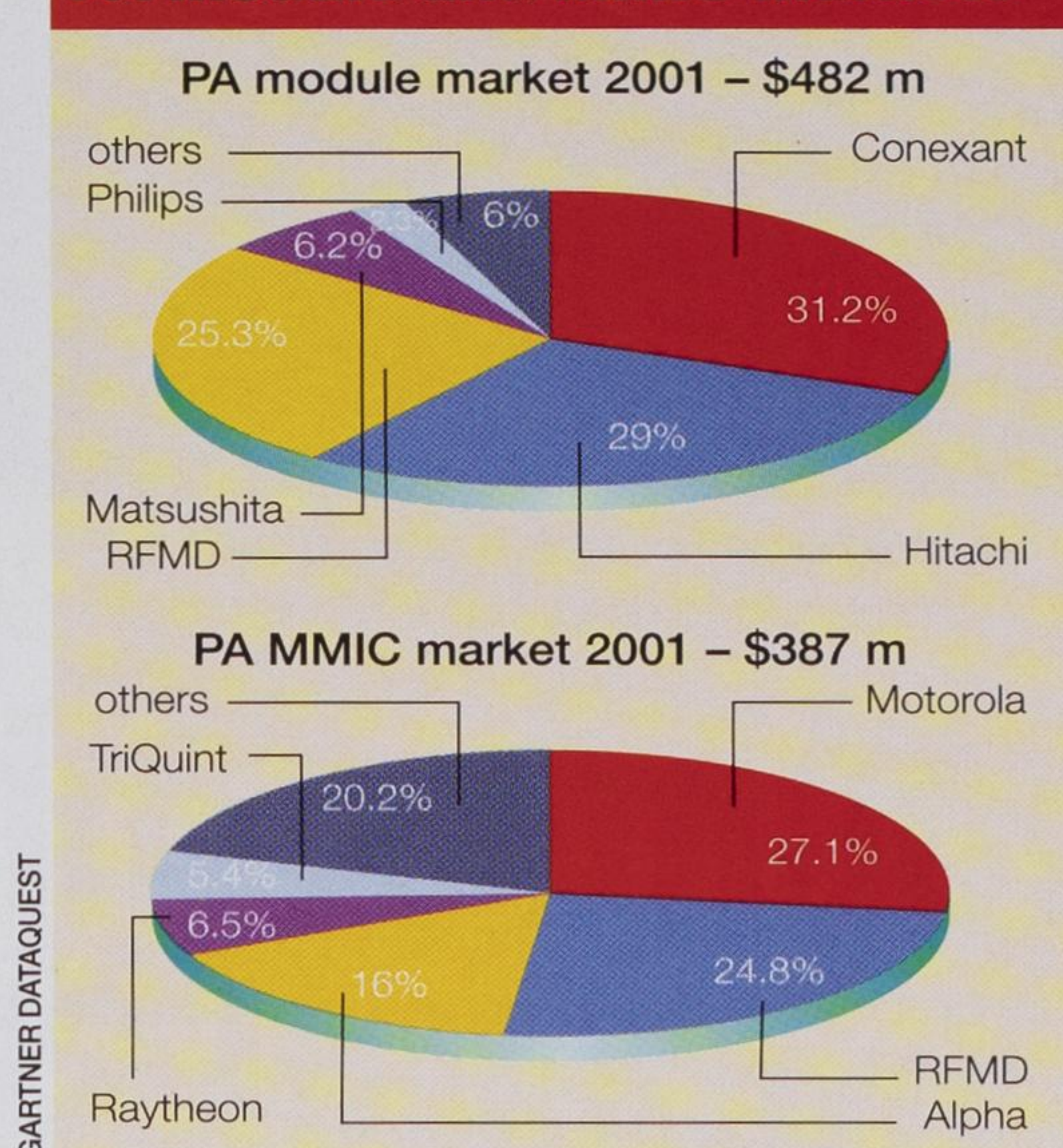
The report breaks the market down into PA modules and PA MMICs. Overall, RFMD led the field with \$218 m in combined PA module and MMIC sales. Combining the results of the recent Alpha/Conexant merger, Skyworks was very close behind, with combined module and MMIC revenues of \$212 m.

In the PA MMIC space, Motorola was the leader in 2001 with a 27% share of the \$387 m market, and RFMD was close behind with nearly 25% of the market. The market for discrete PAs consists primarily of GaAs transistors, passives and, in some cases, CMOS power controllers.

Power amplifier modules

According to Gartner's chief analyst and author of the report, Stan Bruederle, RFMD and Skyworks are currently the strongest suppliers of GaAs PA modules, a market which is becoming increasingly important to handset manufacturers.

PA module and MMIC markets



"Modules are rapidly becoming the power amplifier solution of choice for mobile terminals," said Bruederle. "Power amplifier module revenues grew from 34% to 55% of total PA revenues for mobile terminals between 2000 and 2001."

Conexant shipped more than 175 million PA modules, worth \$150 m out of a total 2001 market of \$482 m, making it the module leader with 31% of the market.

According to the report, Conexant's wireless business accounted for all of Skyworks' modules. Conexant had both GSM and GPRS

wins with Ericsson's T-28 handset, and is a major supplier (particularly for CDMA modules) to Samsung, which is Asia's leading handset maker.

Although Alpha did not figure in the module results before the merger with Conexant, it was third in the market for GaAs PA MMICs in 2001, with \$62 m in revenues.

Close behind Conexant was Hitachi, with 29% of the module market and \$140 m in sales. Hitachi is a leading GSM module supplier and uses discrete silicon LDMOS transistors. Hitachi was followed in the rankings by RFMD, Matsushita (which also uses an LDMOS design) and Philips.

Third-placed RFMD was the fastest growing module supplier, jumping from essentially no module revenues in 2000 to \$122 m for the company's GaAs HBT PA designs. This reflects the company's current strategic thrust (see *Compound Semiconductor* November 2001 p19).

Bruederle says that an important role is played by the module test and assembly functions. "Skyworks is in a very competitive position with a new test and assembly facility in Mexico." Bruederle also says small module size is a major advantage for handset designers, who are using increasingly complicated designs as phones migrate to 3G. Manufacturers, including Anadigics, Celeritek and Skyworks, have shrunk conventional 6 mm × 6 mm² packages to 4 mm × 4 mm² modules.

Filtronic closes fab and teams with Powerwave

Filtronic, the UK-based manufacturer of ceramic and GaAs-based components for wireless infrastructure and handsets, has revealed that it plans to close its GaAs fab in Santa Clara, CA. Filtronic bought the Santa Clara facility from Litton Solid State in 1998 and has used the site as a GaAs IC design and manufacturing center. Filtronic's sales and marketing activities in Santa Clara will continue and the GaAs IC design team will also remain at the site. The company is currently looking at options for the 3 inch fab, including a possible sale.

"With the current market conditions and a state of the art 6 inch fab in the UK, we decided that the Santa Clara fab was no longer required," Christopher Snowden, CEO of Filtronic Compound Semiconductor (FCS),

told *Compound Semiconductor*. "We can better serve our customers through the superb yield and quality that we are achieving in our modern fab in the UK."

Reporting its financial results for the year ending May 31, 2002, Filtronic said its overall sales fell 5.7% to £280.5 m (\$437.6 m). The FCS division continued to lose money, recording a loss of £16.2 m compared with £14.9 m in the previous financial year. Sales were also down to £7.5 m from £11.2 m in the previous financial year.

A new partner for Filtronic

FCS has extended its business model of collaborating with third parties to increase the utilization of its GaAs fab in Newton Aycliffe, UK. The company has formed a strategic

alliance with Powerwave Technologies (Santa Ana, CA) to jointly develop integrated RF power amplifier and conditioning subsystems for the 3G wireless infrastructure market. FCS also has agreements with M/A-COM and BAE Systems (see *Compound Semiconductor* September 2001 p12).

The new agreement combines Powerwave's RF power amplifiers, which are used in cellular, PCS and 3G base stations, with Filtronic's RF conditioning products. Powerwave's products include base-station PA modules and module racks covering all major air interfaces in the 800–2170 MHz range. Both companies will also consider including Filtronic's GaAs-based PA module in joint products and in selected future Powerwave products.

**Exhibitors at
CS-MAX 2002
will include:**

Accent Optical
Technologies
Air Products and
Chemicals
AIXTRON
APT/Telemark
ASML Special Applications
Axic Inc
Bede Scientific Inc
BOC Edwards
Compound Semiconductor
Corning Tropel
CVD Equipment Corp
Epichem
Evans Analytical Group
Gavish
Hologenix
IPAG - Innovative
Processing AG
IQE
JIPELEC
JMAR/SAL
Nanolithography
Kopin Corporation
Leighton Electronics
Loomis Industries
Matheson Tri-Gas
Mattson Technology
Maxwell Technologies
MicroChem
MKS Instruments
Modular Process
Technology Corp
Nippon Sanso Corporation
OSEMI
Oxford Instruments
Philips Analytical
Praxair Semiconductor
Materials
Riber
SAMCO International
Semicore Equipment
Spectrolab
Tegal Corporation
Temescal
Thermo VG Semicon
Thomas Swan Scientific
Equipment
Trikon Technologies
Trion Technology
Umicore Electro-Optical
Materials
Unaxis
Williams Advanced
Materials

Plan to attend

Compound semiconductors in the heart of Silicon Valley

McEnry Convention Center

San Jose, CA November 11–13, 2002

Dedicated to **high-volume manufacturing** of compound semiconductor devices

Technical sessions to include:

• **processing & characterization of VCSELs** • **laser diode packaging and reliability** • **fabrication of HB-LEDs** • **front-end & back-end processing of RFICs** • **arsine & phosphine handling & purification** • **high-volume III-V**

Comments from last year's attendees:

"It is refreshing to have a CS show, instead of always feeling lost at a Si show."

"Nicely balanced technical program, and I found the exhibit extremely useful."

"Very worthwhile, very efficient use of my time."

**COMPOUND
SEMICONDUCTOR**

www.cs-max.com



Celeritek to consider merger proposal with Anaren Microwave

Celeritek is to begin discussions with Anaren Microwave regarding Anaren's recent merger proposal (see *Compound Semiconductor* August 2002 p3). The merger proposition had originally seemed to draw a cool response from Celeritek, but in a recent press release the company said that its board had authorized Celeritek's management to arrange a meeting with Anaren Microwave "in an effort to better understand

Anaren's loosely defined overture".

Celeritek seems to have come under some pressure from its shareholders to negotiate a merger, though its board appears to be irritated at the way Anaren is presenting its desire for a merger. In the company's press release, Celeritek said that while it was looking out for the interests of all of its shareholders, it "will not be coerced by Anaren's public posturing".

Sirenza, RFMD open new sales offices

Sirenza Microdevices, a fabless supplier of RF components, has established a new sales office in Stockholm, Sweden, which is to be run by new appointee Sam Taban. In his new role as director of strategic accounts,

Taban will manage the company's business in Sweden and Finland.

RF Micro Devices has also expanded by opening a new Japanese sales and customer support office in Tokyo. RF Micro Devices' existing Japanese customer base includes companies such as Sanyo, NEC, Panasonic, Hitachi, Clarion, Alps, Toshiba, Sony and Sharp.

RFMD ships RFICs to top-tier handset manufacturer

RF Micro Devices has announced production shipments of five components to a top-tier handset manufacturer, for use in an Internet-enabled TDMA handset operating in the 800/1900 MHz band.

"These production shipments will enable us to expand our long-standing relationship with this customer, which we anticipate will grow in the September quarter," said president Bob Bruggeworth. "In addition to TDMA, we are also shipping into CDMA 1x handsets at this customer, and we are expecting to announce additional shipments into future handsets."

The shipments complement ongoing sales of power amplifiers and small signal devices across multiple air-interface standards to this customer, which represented more than 10% of revenues in the June 2002 quarter.

How About UV-LED?



We have started to provide 370nm GaN wafers and chips for LED.

Applications

- Deodorant: With photo-catalyst
- Light source for sensor etc.

Please ask

nitride@nitride.co.jp



NITRIDE
SEMICONDUCTORS
Co., Ltd.

115-7 Itayajima, Akinokami, Seto-cho,
Naruto-shi, Tokushima. 771-0360 Japan

TEL +81-88-683-7750
FAX +81-88-683-7751

<http://www.nitride.co.jp/>



A **MILESTONE** in SiGe

SiGe With the SIRIUS system, Unaxis became the world's leading supplier of UHV-CVD equipment for SiGe HBT production. Now Unaxis Semiconductors has secured the next milestone.

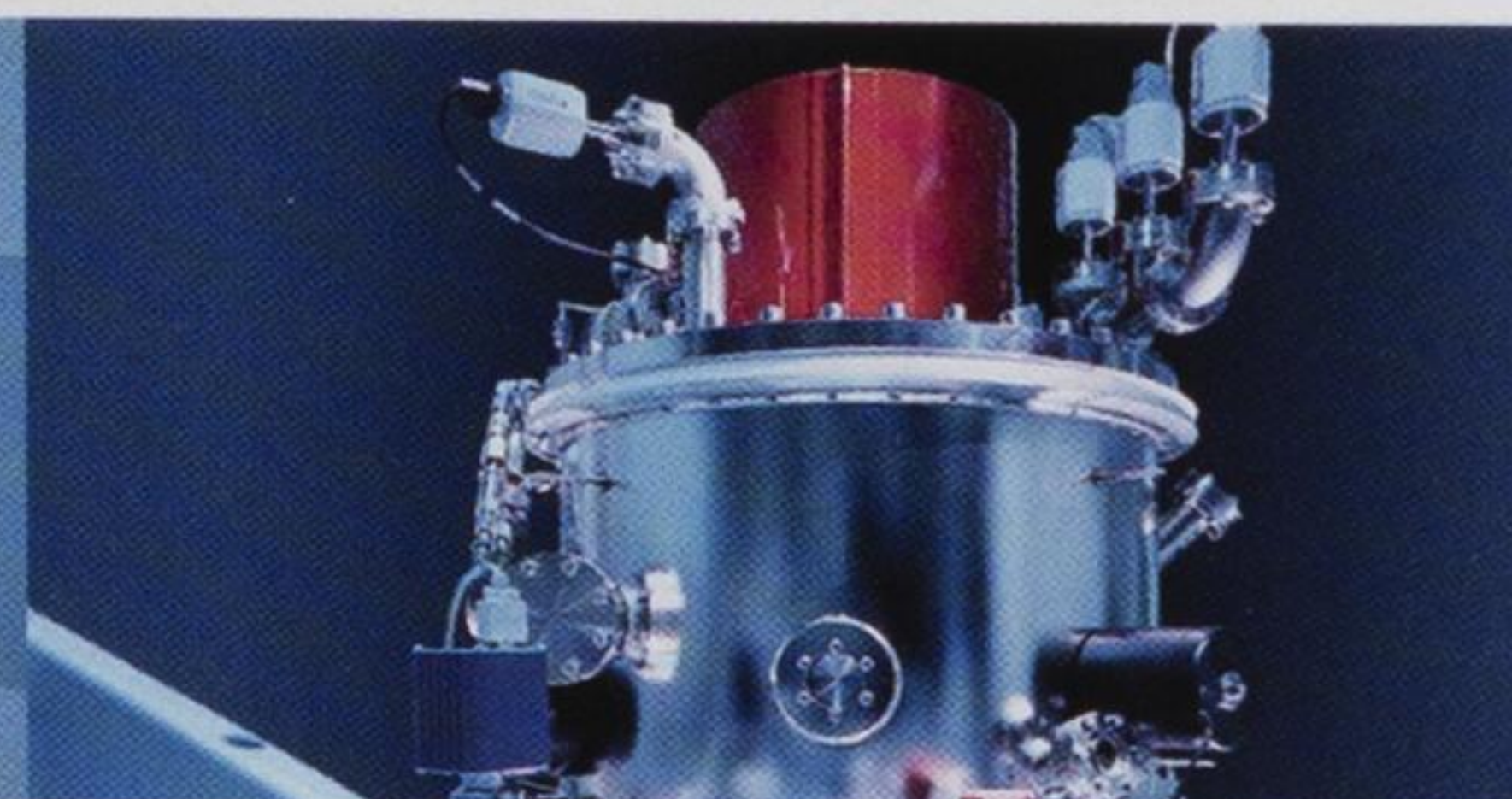
Revolutionary Low Energy Plasma Process know-how from Unaxis sets the benchmark in virtual substrate production by combining our «by factors» faster new Low Energy Plasma Enhanced CVD process with our dry Low Temperature Cleaning Process.

Set a new milestone in the SiGe-Market for your company now. Together we can shape the IT world of tomorrow.

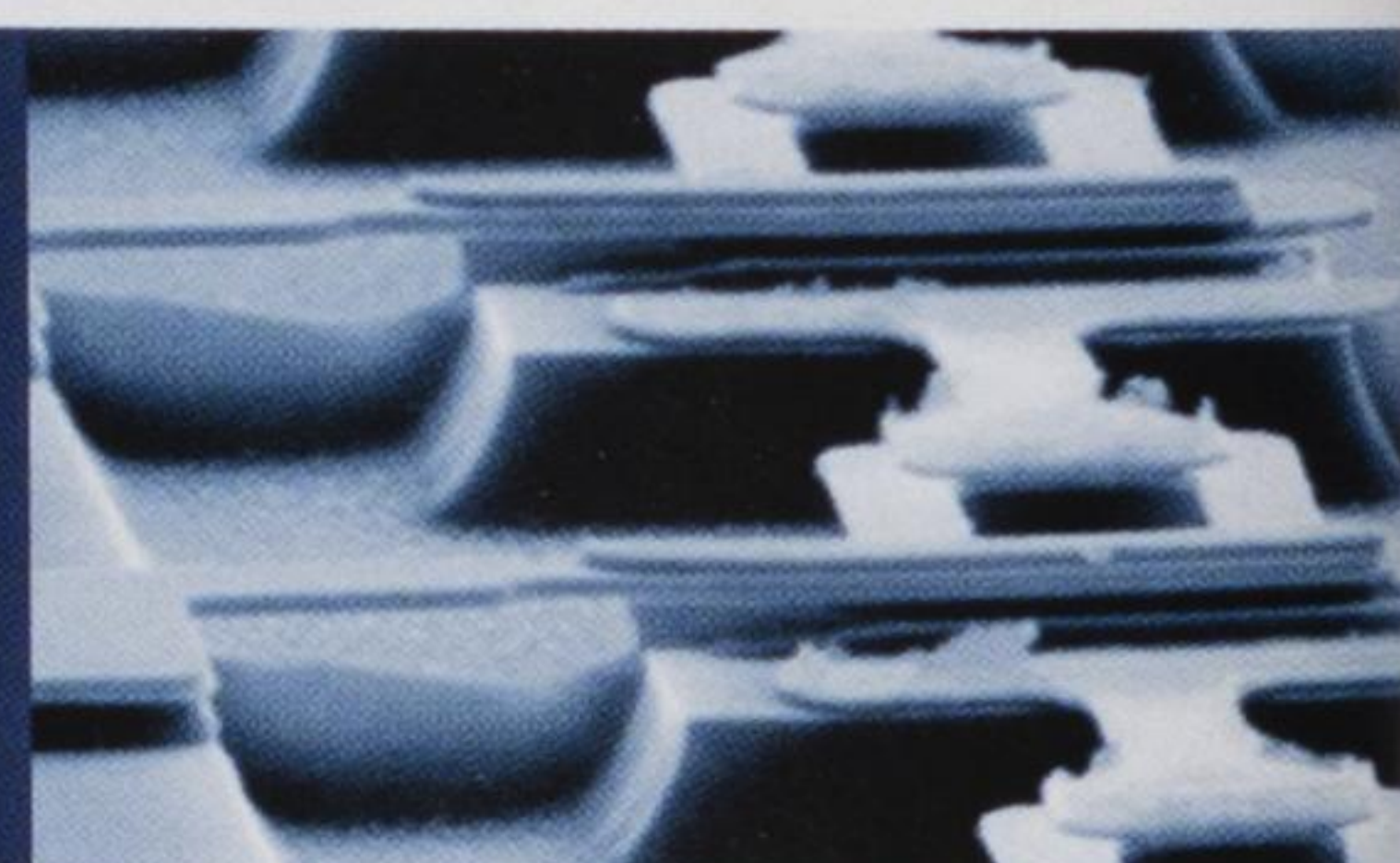
semiconductors.unaxis.com



LEPP 300 Loading Station



LEPP 300 Plasma Cleaning Module



SiGe Hetero Bipolar Transistor (HBT)

email: info.semiconductors@unaxis.com

USA	Tel. +1 727 577 4999
EUROPE	Tel. +423 388 6237
CHINA	Tel. +86 21 5057 4646
SINGAPORE	Tel. +65 6890 6288

KOREA	Tel. +82 31 708 8666
TAIWAN	Tel. +886 3597 7771
JAPAN	Tel. +81 3 3225 9020
OTHER MARKETS	Tel. +41 81 784 6237

Visit us at Booth 1072
Semicon Taiwan, Taipei

unaxis

making IT possible

Kopin samples efficient GaN blue LEDs

By Richard Dixon

Researchers from Kopin and North Carolina State University (NCSU) have demonstrated efficient InGaN/GaN-on-sapphire blue LEDs with low operating voltages. Efficiency gains have been made by inducing thickness variations called NanoPockets during InGaN QW growth. These NanoPockets provide regions for radiative recombination away from crystal defects. Kopin has applied for a patent and is now sampling the devices, known as CyberLites, to prospective customers. Kopin has been developing its GaN-based LED technology for about two years. The move to GaN and LEDs is a departure for the company, which manufactures display products and GaAs-based HBT epiwafers.

When driven by a standard forward current of 20 mA, the new CyberLites exhibit a drive voltage of 2.9 V. The majority of currently available devices operate at 3.3–3.5 V. The luminous intensity of the devices is 100 mcd.

“Getting below 3.0 V has been a scientific hurdle for nearly a decade,” said Kopin founder and chairman John Fan. “We believe that we can move CyberLites into large-volume production for the mass market. We have already begun shipping evaluation samples to prospective customers.”

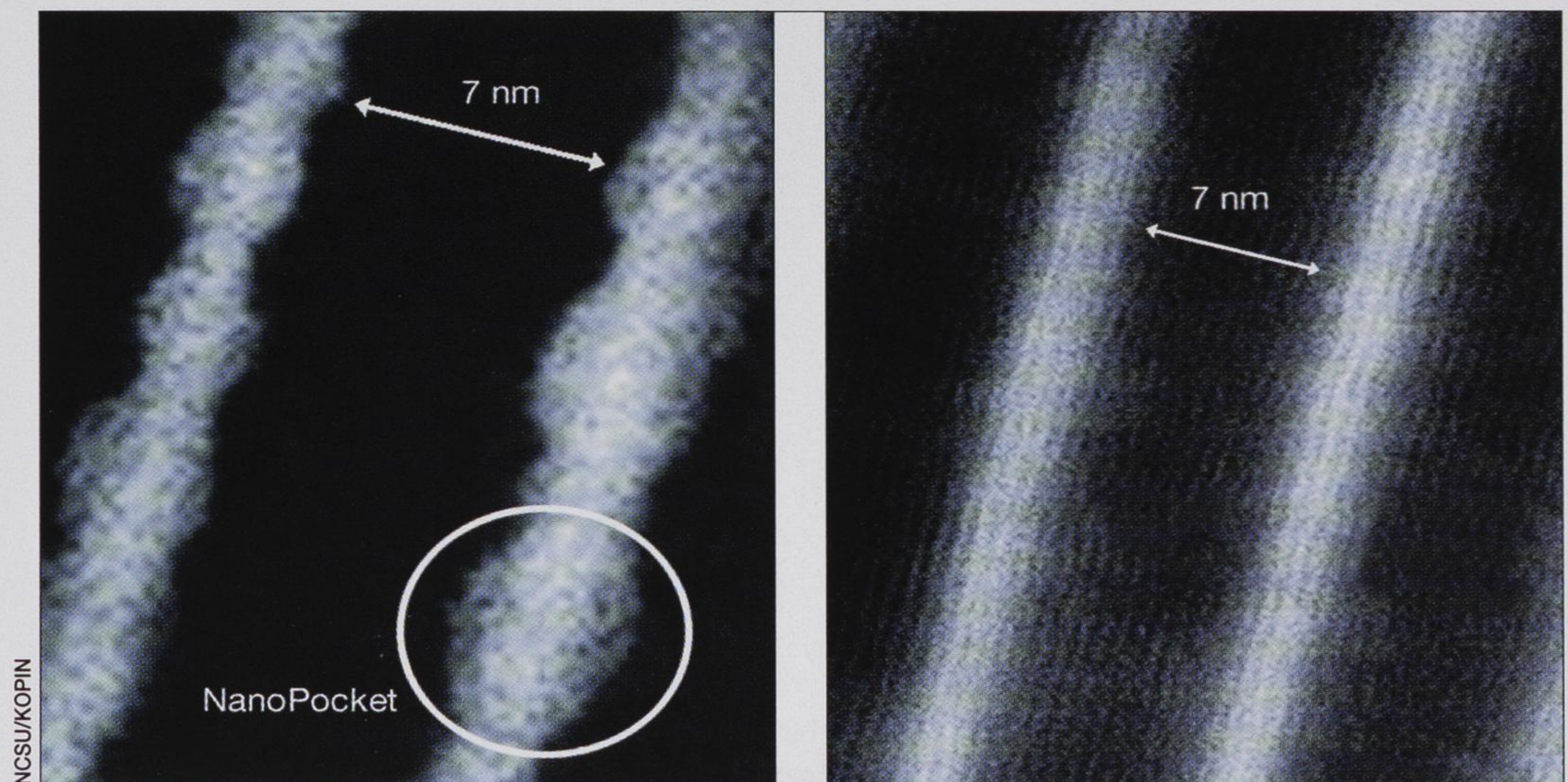
While Kopin is keeping quiet about the exact structure of the devices, the new blue chips feature peak wavelengths ranging from 450 to 470 nm, and have demonstrated a radiant power of 10 mW. The emitters also provide an excellent electrostatic discharge (ESD) resistance of over 4000 V, compared with 2000 V or below in other devices, although the exact mechanism for this is not yet fully understood. Kopin says the high ESD resistance is important for automotive applications.

Moving into production

Kopin will grow the new devices by MOCVD and process the wafers into chips for packaging by its customers. According to CTO Hon Choi, Kopin is aiming for commercial production by the end of the year, using its existing facilities in Taunton, MA.

CyberLite LEDs measure $350\text{ }\mu\text{m} \times 350\text{ }\mu\text{m}$ and have two top contacts, as typically used for GaN LEDs on non-conducting sapphire substrates. The finished chip is not subject to substrate removal or flip-chip mounting to improve light extraction.

Choi says Kopin has also been careful not



TEM images showing the variation in the QW thickness of an LED with excellent optical performance (left), and higher quality wells with much lower optical performance (right).

to fall foul of Nichia’s patent portfolio for blue LEDs, which could present a barrier to market entry. “We studied Nichia’s patents in detail, and we developed our own intellectual property,” asserted Choi. “We have also applied for our own patents.”

Optical efficiency

The new LEDs are described in detail in the July 29 edition of *Applied Physics Letters*. Researchers from Kopin and NCSU grew several InGaN/GaN-on-sapphire devices. Under certain growth conditions, the optical output could be dramatically increased. Devices with high optical efficiency were found to have thickness variations, or NanoPockets, in the InGaN QWs (see figure). This variation in thickness is the result of two-dimensional strain in the InGaN layer below its critical thickness. The strain energy in the layer increases as it grows, and so its thickness varies to minimize the free energy.

Previously, localized carrier recombination induced by variations in indium composition in the QWs has been used to explain the efficient light emission in InGaN LEDs with high dislocation densities. These variations in the indium composition are believed to separate regions of carrier recombination from regions containing dislocations that would otherwise quench the carrier recombination process. However, the Kopin/NCSU paper describes evidence that this explanation is circumstantial, with no direct observation of such compositional fluctuations having been

reported for thin InGaN layers.

The QWs grown by Kopin were characterized using TEM under conditions that gave diffraction and atomic-number contrast. This allowed both the crystalline quality and variations in the composition of the wells to be monitored.

Measurements showed that under certain growth conditions, QWs with short-range (3–4 nm) and long-range (50–100 nm) periodic variations in thickness were deposited. The long-range period is lower than the average dislocation spacing of approximately 100 nm. Atomic-number contrast imaging revealed only minor fluctuations in the indium content within the wells.

Devices fabricated from the material that contained long-range thickness variations demonstrated 8 mW of optical power at 20 mA, while comparable devices with planar InGaN layers showing little or no thickness or composition variation typically delivered less than 4 mW. The authors concluded that the long-range thickness variations were responsible for the higher optical efficiency.

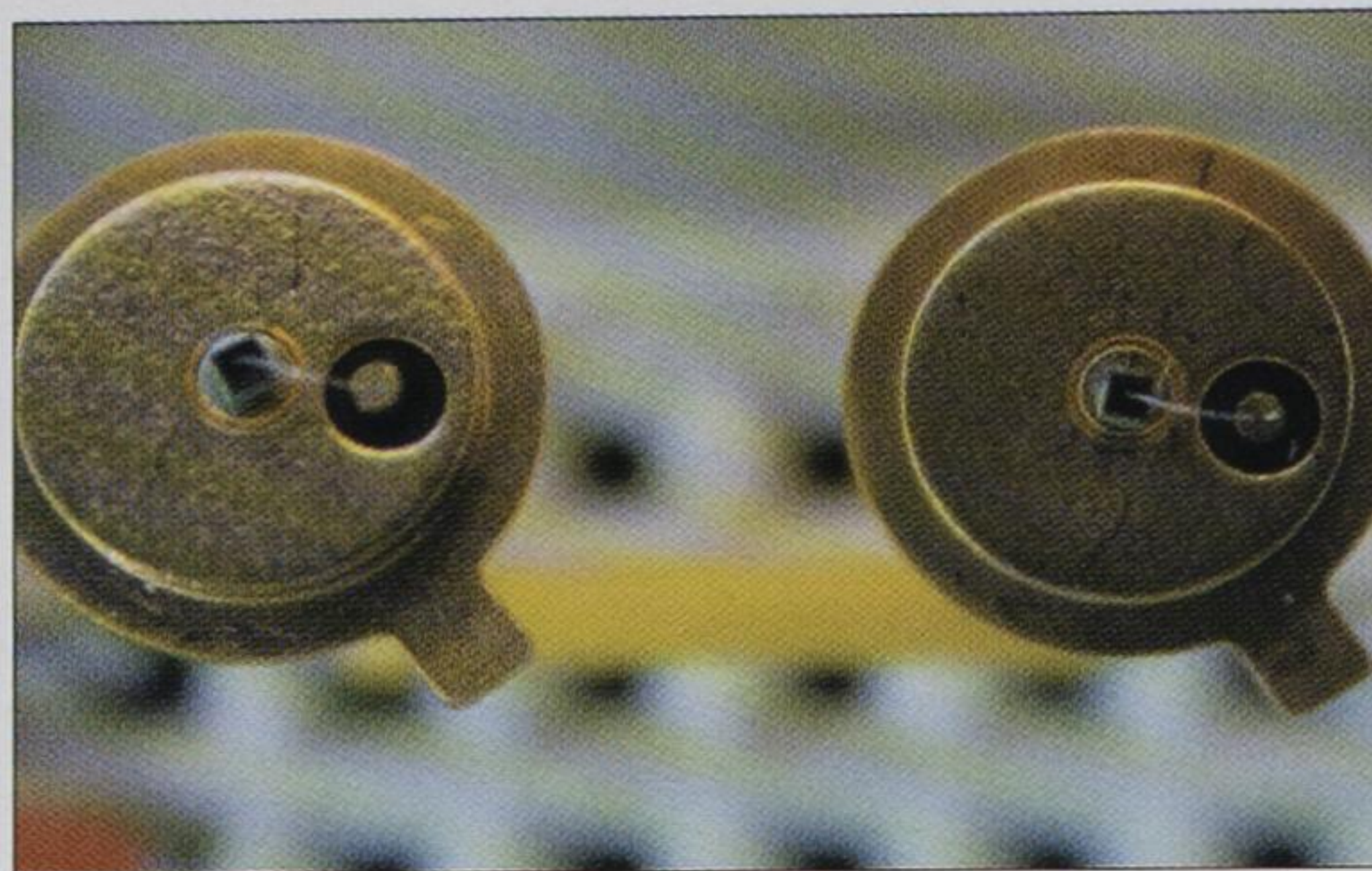
“Realizing that defects cannot be completely eliminated [from InGaN/GaN-on-sapphire LEDs], Kopin’s MOCVD growth provided confinements for the production of light away from defects, and inside these NanoPockets,” explained Jagdish Narayan of NCSU, a co-author of the Kopin/NCSU paper and director of the National Science Foundation Center of Advanced Materials and Smart Structures.

AET develops GaN-based LEDs on GaAs

Advanced Epitaxy Technology (AET) of Taiwan has developed a bonding technology, called virtual-chip bonding, which bonds LED wafers onto different substrate materials. The LED chip and epiwafer manufacturer has used its technology to fabricate vertically conducting, high-brightness blue LEDs on GaAs substrates.

According to vice president Jian-Shihn Tsang, researchers at AET have used the technique to bond a GaN-on-sapphire blue LED wafer onto a GaAs substrate. While details were not revealed, Tsang said: "Interfacial layers are used between the GaN-on-sapphire wafer and the GaAs substrate to bond them together."

The LED wafer is bonded to the GaAs substrate in a p-side-down arrangement. Once bonding is complete, the researchers remove the sapphire substrate to leave a vertically conducting LED. The final LED structure comprises the GaAs substrate, a p-GaN/AlGaInP layer, the GaN/InGaIn MQW



AET's blue LED chips require only a single wire bond. A semiconducting GaAs substrate allows a bottom contact to be used for the bonded vertical LED structure.

active region and an n-GaN layer.

AET selected the p-side-down structure to increase the effective conducting area of the electrode. P-type GaN is not very conductive, so the p-side-down configuration solves this problem by improving current spreading compared with wire bonding. "We also used a thick n-GaN layer as a window layer," said

Tsang. "The thick layer can extract [more photons] and enhance LED brightness." The concept of increasing the window-layer thickness to enhance light extraction has already been successfully demonstrated in AlGaInP LEDs.

The researchers claim that compared with conventional chips, the virtual-bonded blue LEDs have a lower operating voltage of only 3.3 V, and an output power of 2.5 mW. "The new LED chip is brighter under the same operating conditions," added Tsang. "This is due to more efficient current spreading and the thick window layer."

AET plans to manufacture 2.5 million chips a month by the end of the year and then to expand production to suit customer demand. "We have been aggressively working on virtual-bonding technology since 2001," said Tsang. "We will carefully seek partners to penetrate all sectors of the market and will expand chip production to accommodate customers' needs, be it 10 million, 20 million, or even more chips a month."

UEC bonding technology delivers high-power AlGaInP-on-Si LEDs

Taiwanese LED manufacturer UEC has developed a large-area, 10 W, AlGaInP LED that measures $2.5 \times 2.5 \text{ mm}^2$. While heat dissipation is usually a problem in high-power chips, UEC has patented a metal-bonding technology to bond the AlGaInP epiwafer to a Si substrate and prevent overheating.

As described in US patent 6,319,778, the LED uses an AlGaInP-on-Si vertical chip structure. AlGaInP-based LED layers are first deposited on a sacrificial GaAs substrate. Next, a Si substrate is coated on both sides with a low-temperature alloy solder such as

AuSn or PbSn, which serves as the ohmic contact as well as a bonding layer. To make the chips, the Si substrate is welded to the LED epitaxial layer at elevated temperatures. The light-absorbing GaAs substrate is then etched away to allow light emission. The metal bonding layer between the LED structure and the Si wafer acts as a reflector, stopping light from reaching the Si substrate where it would otherwise be absorbed.

According to UEC, the chip has a total flux of more than 200 lumens and operates above 5 A without saturation. The company has

already sampled the chip to a number of LED packaging manufacturers in Taiwan and plans to start mass-production by the end of the year. The chips will be available in three sizes: $0.3 \times 0.3 \text{ mm}^2$, $1 \times 1 \text{ mm}^2$ and $2.5 \times 2.5 \text{ mm}^2$.

UEC also hopes to improve the high-power performance of these LEDs by enhancing the metal-bonding technology in order to increase heat removal. The company intends to bond AlGaInP LED epiwafers to metal heatsinks such as aluminum and copper, and will release metal LED samples later this year.

UEC has also recently developed a 650 nm AlGaInP resonant-cavity LED for home networking applications. It has a typical output power of 1.5 mW, a bandwidth of 120 MHz at 20 mA drive current and an operating voltage of 2 V.

TIR, Lumileds supply lighting system to BP

TIR Systems, a manufacturer of solid-state lighting systems, has received a CDN \$9 m (\$5.76 m) order from BP, one of the world's largest gasoline retailers, for its ChipStrip lighting product. The ChipStrip is fabricated by Lumileds using its high-brightness LEDs, and is sold by TIR under a marketing agreement between the two companies

that was signed in March 2002.

BP is currently involved in a reimagining program and will install the ChipStrips at 850 of its service stations.

TIR has also developed an RGB colorwash fixture using Lumileds' high-power Luxeon LEDs. The Destiny Colorwash Luminaire has a light output that can match that of its halogen and metal halide lamp rivals, while the LEDs can be mixed to create any color, including white.

The new fixture contains 60, 1 W Luxeon

red, green and blue emitters, each with an output of 5–40 lm. TIR has designed new optics, as well as power conversion and control technology, to produce light distribution, color mixing and programmability that is comparable to conventional wall-washing systems.

"Lumileds' technology is enabling us to meet the market demand for a colorwash alternative that combines a high light output with lamp longevity, energy savings and other solid-state lighting benefits," said Grant Harlow, director of marketing at TIR.



RealTemp

**He's Not the Only One
Who Can Accurately Control
High Temperatures**

RealTemp™ from EMCORE - Standard on all EMCORE Tools*
Now You Can Master the Art of Wafer Temperature Control

RealTemp™ enables epitaxial materials manufacturers unprecedented control of wafer surface temperatures, improved yield and less downtime. Exclusively offered by EMCORE, RealTemp™ enables users to improve the quality of highly sensitive materials and facilitates a more efficient, accurate, and cost-effective production process.

RealTemp is not yet available for GaN MOCVD Tools.



For more information, please contact sales at EMCORE - 732.271.9090

Making Our World Brighter

We are a leading materials science solutions provider in research, manufacturing and marketing of high quality, large diameter, single-crystal sapphire and other advanced technology materials.

Our Chicago based growth, fabrication and polishing facilities provide the highest quality substrates with unparalleled service at the lowest price.

Maximize Brilliance and Yield In Your Blue LED and LD Processes

Rubicon's KYR-Plus SAPPHIRE SUBSTRATE provides high transmission, very low EPD

With Rubicon's unique combination of Kyropoulos growth technology and state-of-the-art manufacturing and quality facilities you get the optimal basis for efficient blue LED and LD fab—greater brightness and higher yield.

- 2, 3, and 4 inch C-plane wafers in development and production quantities
- Precision offsets and other orientations available
- As cut and epi ready surfaces
- Flexible product specification
- Material Science Engineering services

www.rubitech.net

3000 Lakeside Drive, Suite 105N
Bannockburn, Illinois 60015 USA
Tel 847.295.7000
Fax 847.295.7555

Employment opportunities available



RUBICON
TECHNOLOGY

European group grows InGaN lasers on silicon

A European GaN research consortium has demonstrated low-threshold, optically pumped blue laser chips on silicon substrates. Based on an InGaN/GaN material system, the chips could lead the way to cheaper production methods for blue/green LEDs and blue lasers, as well as HBTs and HEMTs.

The chips were jointly developed by German MOCVD equipment supplier Aixtron, and research institutes RWTH Aachen in Germany and the Stepanov Institute of Physics in Belarus. Each device comprises two buffer layers; one to absorb thermal expansion mismatches between silicon and GaN, and a second to allow the growth of high-quality GaN/InGaN layers.

"The structure contains a [strain reduction] buffer that is designed to allow the growth on (111) silicon and a 600 nm GaN undoped buffer layer," explained Michael Heuken, vice-

president of R&D at Aixtron. These buffer layers are deposited on the silicon substrate, followed by an active layer. The active region consists of 10 InGaN/GaN QWs and is capped with 50 nm undoped GaN.

The chips emit at 447 nm, with operating temperatures as high as 420 K. Output powers ranged from 8–10 mW and power densities reached 270 kW/cm². The researchers say that these performance characteristics nearly match those of InGaN-based lasers and LEDs that are currently manufactured on more expensive, small-diameter SiC and sapphire substrates.

"The investigation presented here shows the outstanding performance of our equipment and will open new markets," said Heuken. "All our patents are open to our customers to fabricate the devices and this is a good way to educate more people in MOCVD technology."

SiXON set to build new SiC plant

SiXON, a SiC substrate manufacturer based in Kyoto, Japan, is planning to build a new 2500 sq. m plant in April of next year, in a bid to double its capacity for 2 inch SiC substrate production, reports the Japanese news source Nihon Keizi Shimbun (NKS). The new fab will cost the company up to ¥300 m (\$2.6 m).

SiXON currently manufactures about 1000 2 inch 6H-SiC and 4H-SiC substrates a month.

These substrates contain micropipe densities of less than 100/cm². According to NKS, with the opening of the new plant, SiXON will relocate all of its existing operations to the factory and double production to 2000 substrates a month.

The company also plans to start shipping 4 inch wafers as the new plant opens, and hopes to increase the capacity to 10,000 substrates a month within two years.

Equipment funding win for Rubicon

Chicago-based Rubicon Technology has received \$2.25 m in equipment financing. The company, which is a manufacturer of exotic optical-grade materials, will use the funding to develop its epi-ready sapphire-substrate polishing technology.

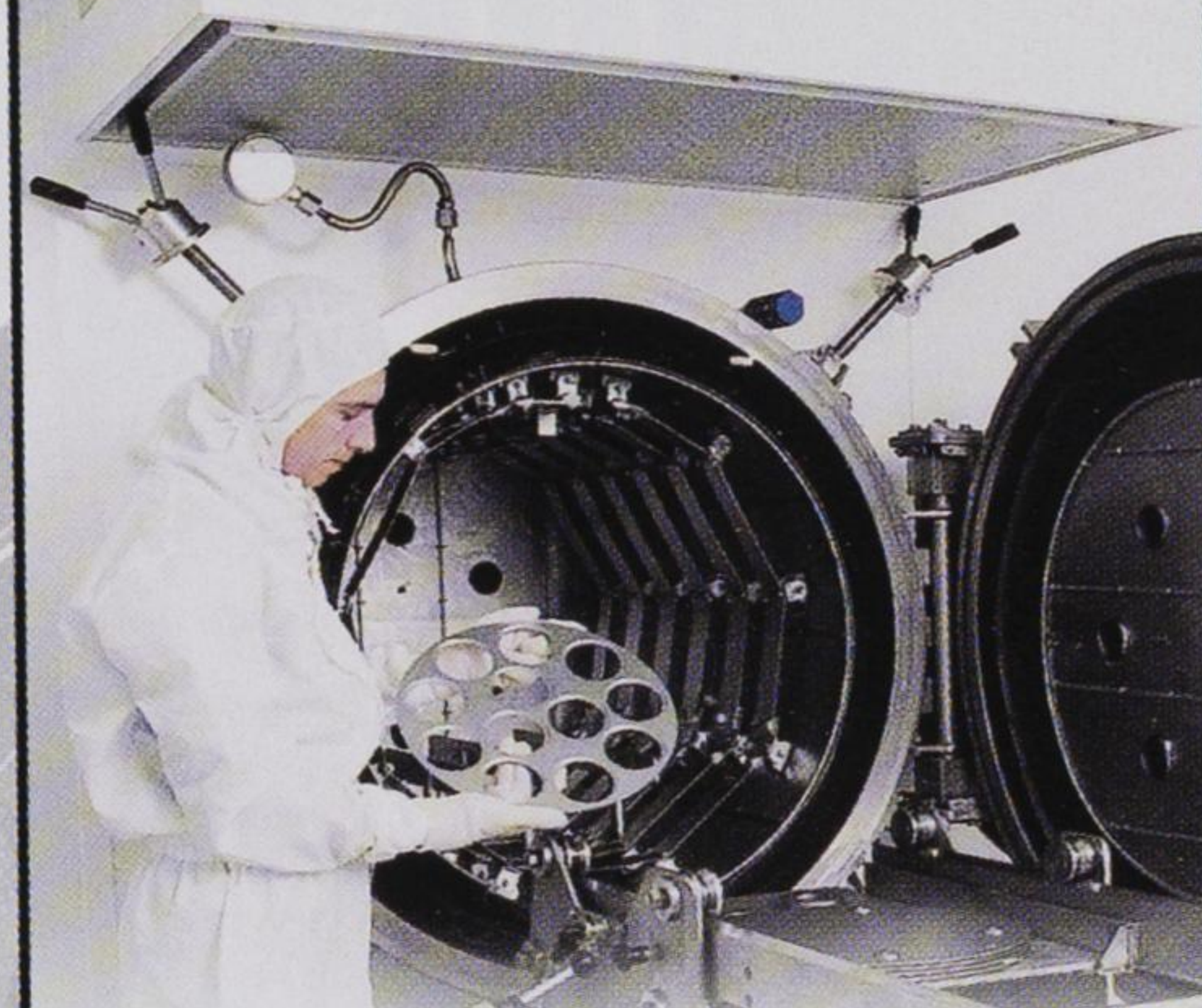
"The investment [supports] our strategy

to acquire the equipment and technology to vertically integrate into epitaxial polishing," said Chris Moffitt, CEO of Rubicon.

The latest cash injection follows the \$9.5 m that Rubicon won in its second round of funding in July of this year (see *Compound Semiconductor* August 2002 p15). The company is using this investment to develop larger diameter sapphire substrates and exotic materials, as well as extend its production of single-crystal sapphire substrates.

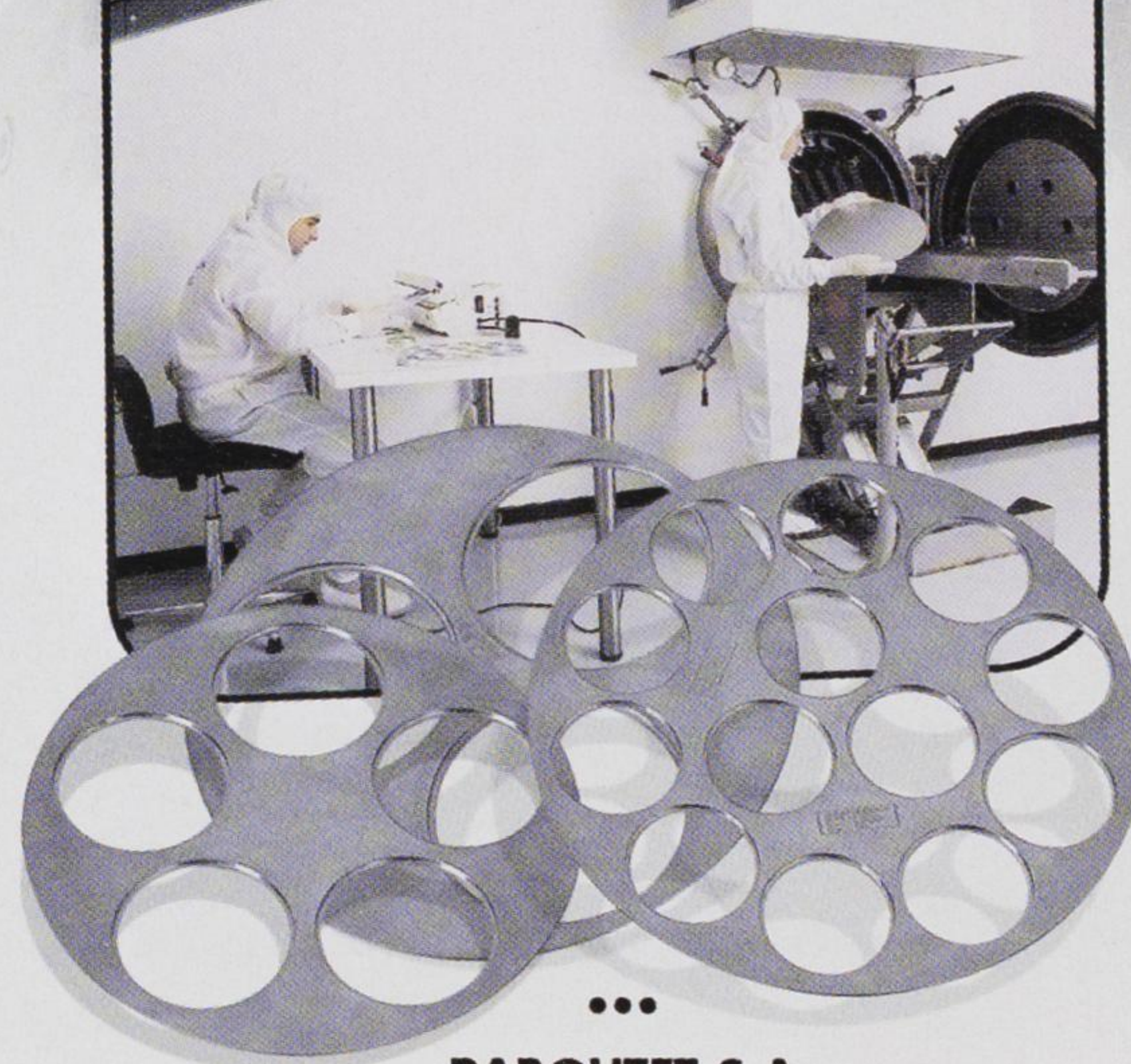
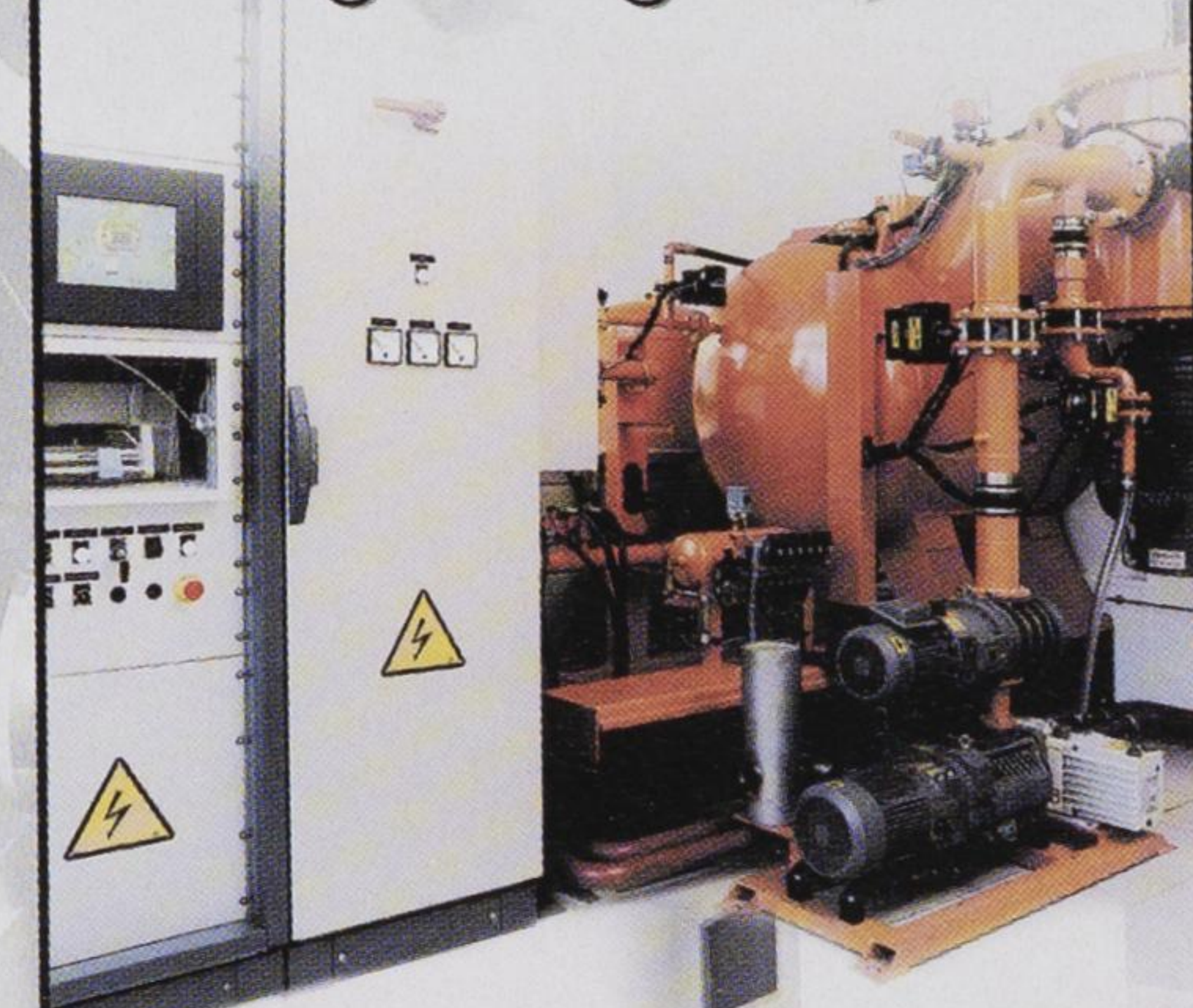
Sign up for our free weekly email NewsAlert service at

www.compoundsemiconductor.net/articles/news



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

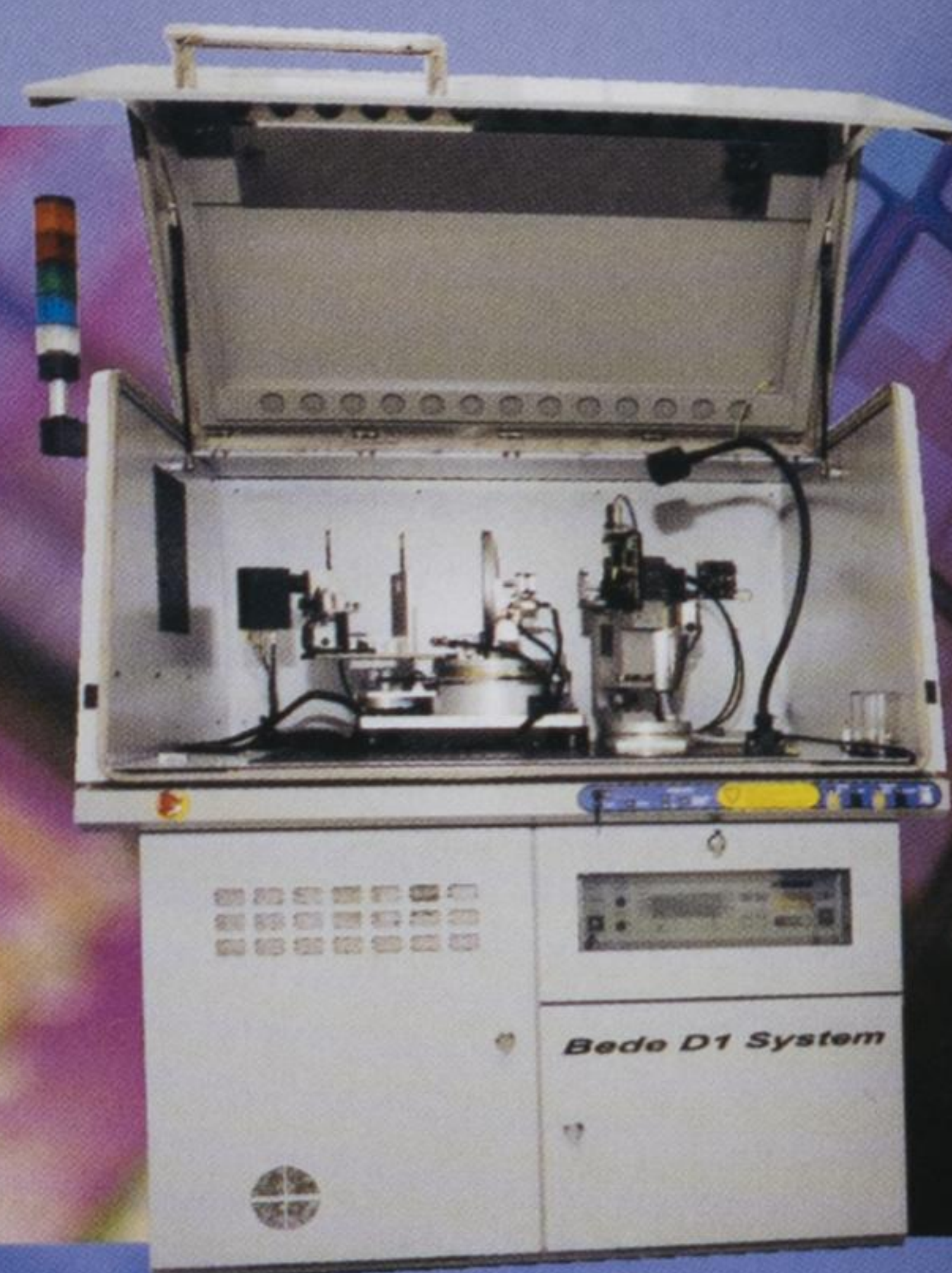
from the lab to the fab™



Bede QC200™



Bede FAB300™



Bede D1

A range of X-ray solutions for R&D and quality control environments

Bede X-ray tools non-destructively determine key parameters of most important advanced materials automatically, quickly and safely:

- Silicon and compound semiconductors
- Si, SiGe and SOI device structures
- GaAs, InP and GaN epitaxial device structures
- Thin films including:
 - High-k dielectrics
 - Low-k dielectrics
 - Diffusion barriers
 - Damascene copper
 - SiO₂ and oxynitride
- Metallic & magnetic multilayers
- Ceramics
- Polymers

Solutions for each stage of Si semiconductor production:

- Process development in the R&D lab
- Pilot lines
- Full-scale production in a fab
- Suitable for high capacity compound semiconductor foundries

Solutions for the general purpose high resolution X-ray research lab:

- Ultimate performance and versatility for semiconductor, pharmaceutical and other applications
- Widest possible range of techniques
- Used worldwide in industrial, university and government research laboratories

solutions
partnership
expertise

bede

a bede plc company

UK

T +44 (0)191 332 4700
F +44 (0)191 332 4800
E info@bede.co.uk

USA

T +1 (303)790 8647
F +1 (303)790 8648
E sales@bede.com

Asia

T +86 (0)21 64594811
F +86 (0)21 54867218
E info@bede-asia.com

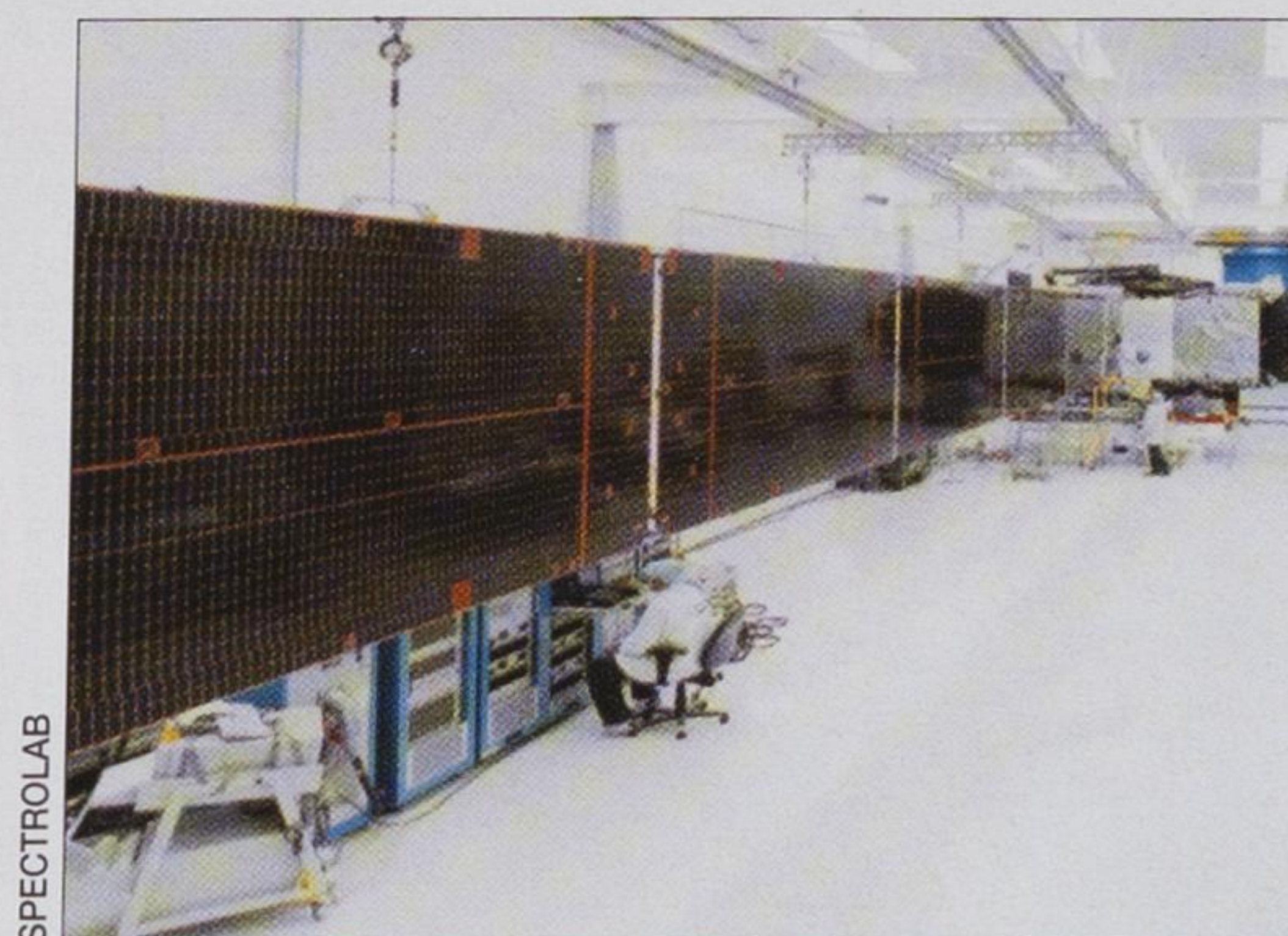
www.bede.com

Spectrolab expands solar-cell portfolio

Spectrolab, a unit of Boeing based in Sylmar, CA, has celebrated the manufacture of its one-millionth multi-junction GaAs solar cell. Multi-junction cells increase collection efficiency by using each junction to convert a different portion of the solar spectrum. They provide up to twice the power of conventional Si solar cells and have been used on numerous flight-proven satellite designs.

Spectrolab's solar-cell portfolio includes a combination of dual-junction, triple-junction and what the company describes as improved triple-junction solar cells. The dual-junction cell made its debut five years ago and provides a beginning of life (BOL) efficiency of 21.5%, while the triple-junction solar cells, first produced in 1999, deliver 24.5%.

In 2001 an upgraded triple-junction device was designed with 26.5% BOL efficiency, and this cell now represents more than 20%



The Galaxy IIIC satellite was launched on June 15, 2002, and is powered by Spectrolab's improved triple-junction solar cells, which have a BOL efficiency of 26.5%.

of multi-junction cells produced to date. Grown by MOVPE, the cell features a monolithic GaInP/GaAs/Ge structure and is a two-

terminal triple-junction cell interconnected with two tunnel junctions.

Spectrolab says it will now begin manufacturing a new device – the ultra-triple-junction solar cell – during the fourth quarter of 2002. The cell is currently undergoing rigorous space qualification and targets greater than 28% conversion efficiency. Cells capable of more than 30% efficiency are also under development and are expected around 2004.

"I am proud of our team's accomplishment in delivering over one million advanced solar cells, and the 0.25 MW of power the cells provide to operating spacecraft using this technology," said David Lillington, the president of Spectrolab. "This is a direct reflection of our ability to continuously improve our technology and to provide our customers with high-quality, competitive, power-system design choices."

Photons double up for solar power

Researchers at the University of New South Wales in Australia have proposed a photon down-conversion system to boost the efficiency of semiconductor solar cells towards 40%. The down-converter proposed by Martin Green and Thorsten Trupke can be applied to the front face of a Si- or GaAs-based solar cell to convert the high-energy photons that are normally wasted into two photons of an energy that can be used by the cell (*J. Appl. Phys.* 2002 **92**(3) 1668).

In a normal solar cell only photons with an energy close to the cell material's bandgap can excite carriers into the conduction band. Any photon with an energy above the cell mater-

ial's bandgap does not add to the photocurrent.

The proposed converter has a bandgap twice that of the cell material, and an impurity level in the middle of the gap. An incident photon with an energy more than twice the cell's bandgap will excite an electron across the bandgap of the converter. The electron then returns to its ground state via the mid-gap impurity level, emitting two photons of an energy roughly equal to the bandgap of the cell material. In this way, one high-energy photon is converted into two photons with an energy that can be used by the cell. Compounds such as GaP, InAs and ZnSe could possibly be used as down-converters for semiconductor solar cells as they have approximately twice the bandgap of Si and GaAs.

"Our calculations show that the efficiency boost due to a down-converter is largest for

solar-cell materials with bandgaps of around 1.1 eV," Trupke told *Compound Semiconductor*. "Si cells are therefore ideal candidates."

Currently, the most efficient semiconductor solar cells are InGaP/GaAs/Ge triple-junction cells (see Spectrolab article above). Trupke sees the down-conversion system as an alternative to the triple-junction method for raising efficiency. Using a down converter with a multi-junction cell would not make the cell any more efficient.

"The nice feature of this approach is that we can take a [single junction] cell and stack it with a suitable luminescence converter," said Trupke. "The cell itself does not need to be modified. Also, the solar cell and converter are electrically isolated. Therefore we do not have the problem of current matching as in two-terminal multi-junction cells."

Emcore awarded major satellite design contract

Emcore is celebrating its first major contract for satellite solar arrays since acquiring Tecstar's Applied Solar business, which is now part of Emcore's PhotoVoltaics division (Albuquerque, NM). The contract is for the design and development of a solar array to power the CryoSat satellite being built by Astrium, a joint venture company between BAE Systems and the European Aeronautic Defense and Space Company (EADS). CryoSat is being built for the

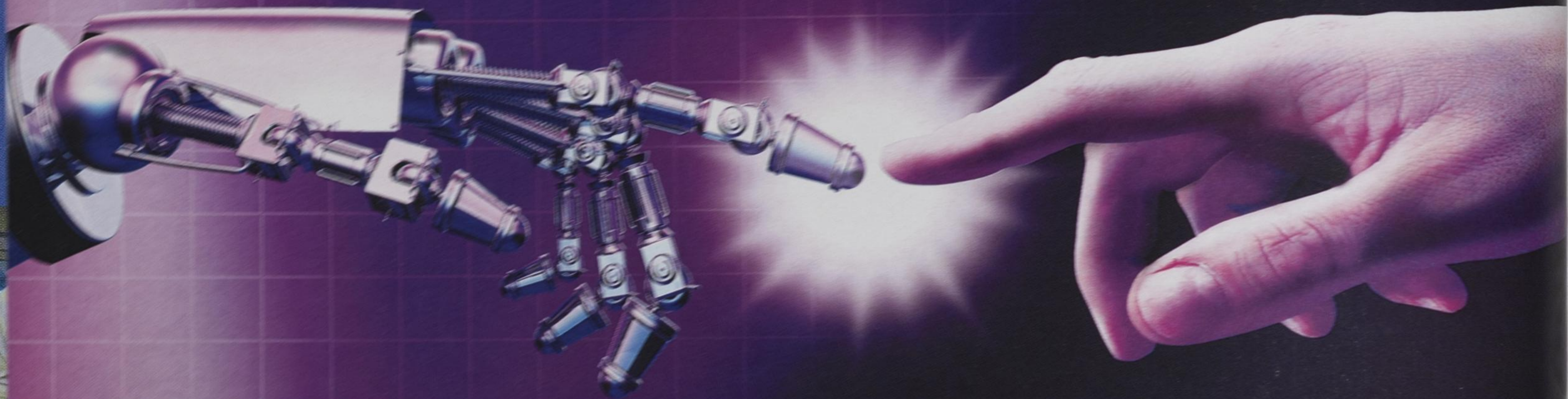
European Space Agency (ESA).

The CryoSat satellite is the first in a series of Earth explorer missions sponsored by the ESA's Living Planet program. The satellite will monitor land and marine ice-mass fluxes in order to improve the understanding of climate change.

Under the terms of the contract Emcore will partner with EADS, which will provide the mechanical design, while Emcore will lead the array project and provide electrical

designs. The arrays will use Emcore's triple-junction solar cells, which typically offer a beginning of life efficiency of 26% at 28 °C.

"Satellite success is highly dependent on the solar array's performance and reliability as a key component of the satellite's power supply," said Uwe Mallow of Astrium. "The combination of Emcore's high-efficiency triple-junction solar cells and the successful flight heritage of Tecstar's solar-array programs were key factors in our decision."



Partners in growth

Materials Outsourcing is the key to leveraging the most from your IP.

With more than 14 years experience in wafer outsourcing, IQE can help you deliver world-class products for next generation applications.

For all your semiconductor materials needs from III-V substrates to III-V and Si based epiwafers, ***make IQE your partner to take you into the future.***



USA: +1 610 861 6930

Europe: +44 2920 839 400

Japan (E&M): +81 797 34 6655

Korea (K1): +82 2 597 3961

Taiwan (Conary): +886 22 509 1399

info@iqep.com

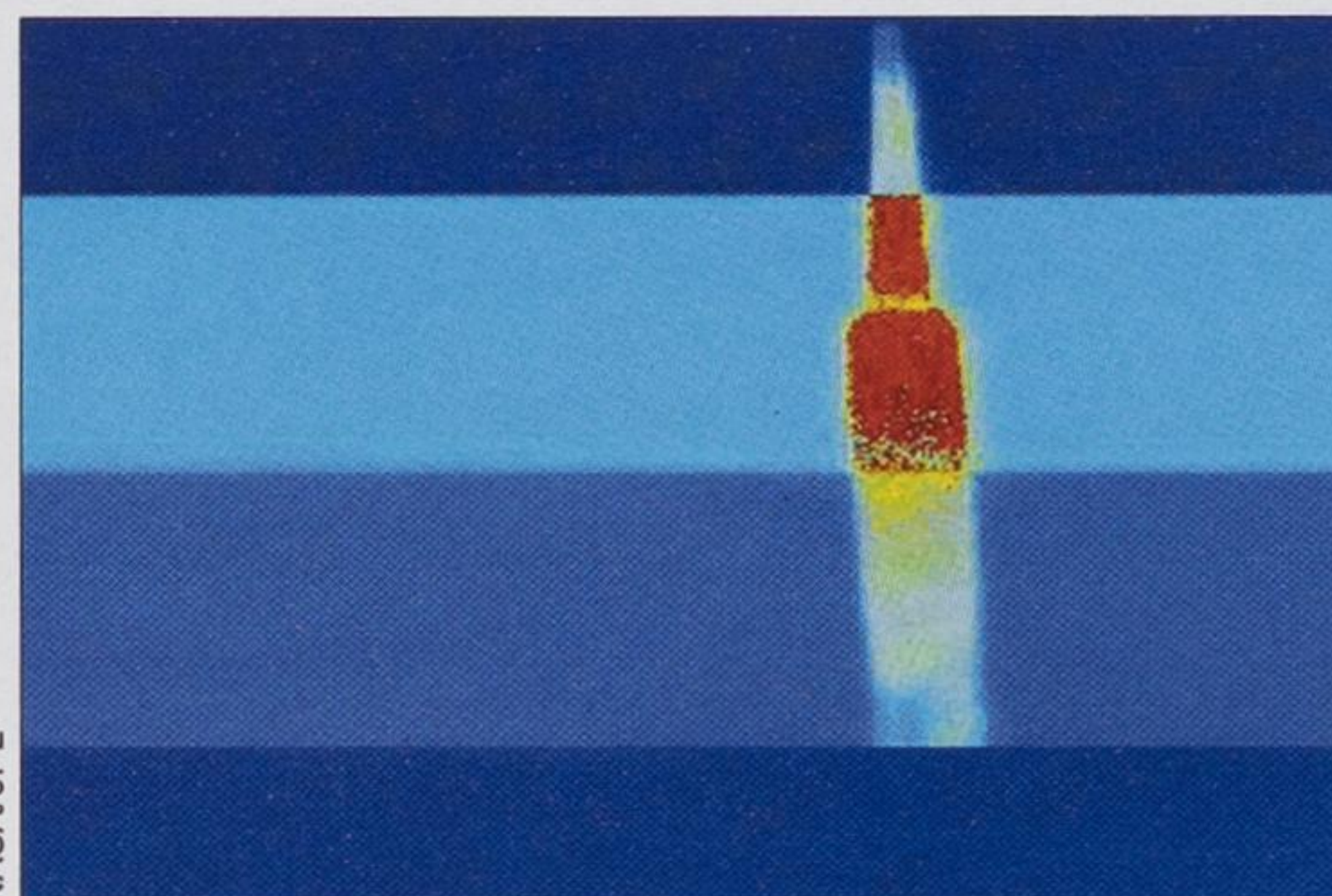
www.iqep.com

JPL leaps ahead with new four-band GaAs/AlGaAs QWIP array

Researchers at NASA's Jet Propulsion Laboratory (JPL) have pushed infrared imaging technology into a new dimension with the development of a GaAs/AlGaAs quantum-well infrared photodetector (QWIP), which is capable of imaging in four bands in the infrared. The new infrared focal-plane array (IRFPA) can detect in the 3–5, 8–10, 10–12 and 14–15.5 μm bands. So far only two-band IRFPAs have been manufactured using GaAs/AlGaAs QWIP technology, or any other competing technology.

The four-band 640×512 pixel IRFPA is grown monolithically by MBE on a semi-insulating GaAs substrate. The layer structure contains four different GaAs/AlGaAs QW regions, one for each IR band. A deep-trench etch process is used to define the pixels, and the unwanted spectral bands in each pixel are eliminated by a short-circuiting process.

As might be expected, fabricating a four-band detector is considerably more complicated than fabricating a standard single-band QWIP array. The new array requires 12 levels



An image of a soldering iron that was taken with the four-band QWIP array. Each quarter of the image represents one IR band.

of photolithography, compared with three for a single-band device. However, pixel yield and detector performance are impressive. "The detector's pixel uniformity and operability is greater than 99.9% thanks to the maturity of GaAs/AlGaAs compound semiconductor processing technology," JPL senior research scientist Sarath Gunapala told *Compound Semiconductor*.

RSC awarded contracts for large IR arrays

Rockwell Scientific Company (RSC) of Thousand Oaks, CA, has won two contracts totaling \$4.4 m to develop 2048×2048 pixel IRFPAs for ground-based infrared astronomy. The two contracts with the Canada–France–Hawaii Telescope (CFHT) and the Gemini observatory will see RSC develop MBE-grown

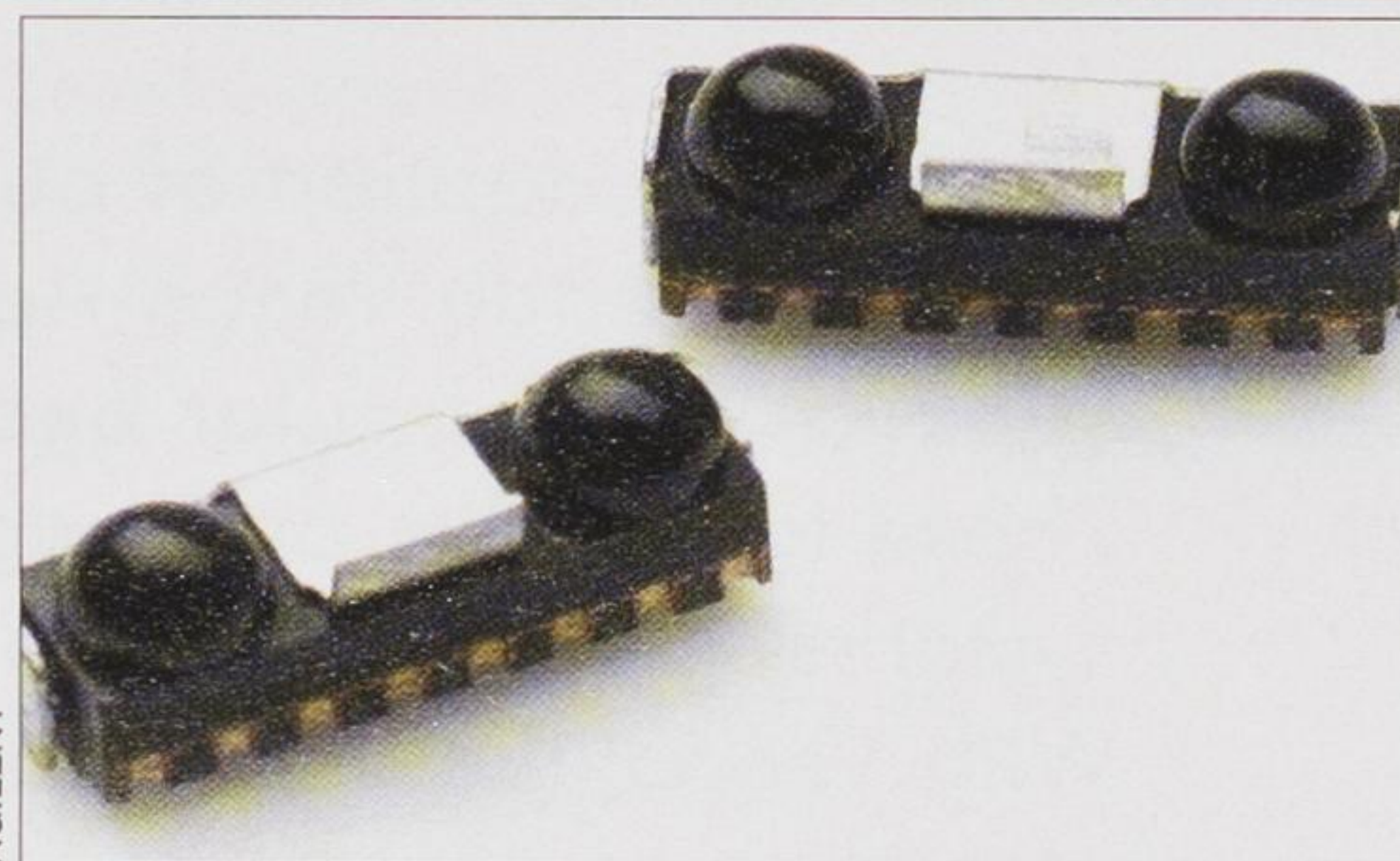
HgCdTe short-wave infrared sensors and tile them to produce a 4096×4096 pixel array.

The first IRFPA will be installed on the CFHT wide-field infrared camera in Hawaii. The second array will go to the adaptive optics near-infrared imager on the Gemini South telescope in Chile.

Agilent's transceiver targets handsets

Agilent Technologies has developed the first infrared transceiver supporting the IrDA serial transceiver control (STC) bus used in ultra-slim cellular phones and PDAs. The STC interface provides a common *pin* layout for designers to add new features and accommodate future transceivers, and is expected to simplify design efforts and reduce time to market.

The HSDL-3210 features an AlGaAs LED and Si *pin* photodiode. The transceiver delivers data at 1.15 Mbit/s over short distances, based on the IrDA's low-power link specification of 20–30 cm. The unit includes



Agilent's new infrared transceiver draws only 10 nA of current when in shutdown mode, and 300 μA when in standby mode.

a power feature that prolongs battery life by lowering the optical power when the link distance is shorter. The new device is now available in volume.

Gallium Arsenide

Indium Antimonide

Indium Arsenide

Indium Phosphide

Gallium Antimonide

Gallium Phosphide

Silicon Carbide

Sapphire

Silicon

Zinc Oxide

wafer technology

High purity MBE source material

High purity indium metal

High purity gallium metal



Wafer Technology

USA: +1 928 468 2204

UK: +44 1908 210 444

Germany: +49 451 59 6500

Scandinavia: +46 8 571 62640

Japan (E&M): +81 797 34 6655

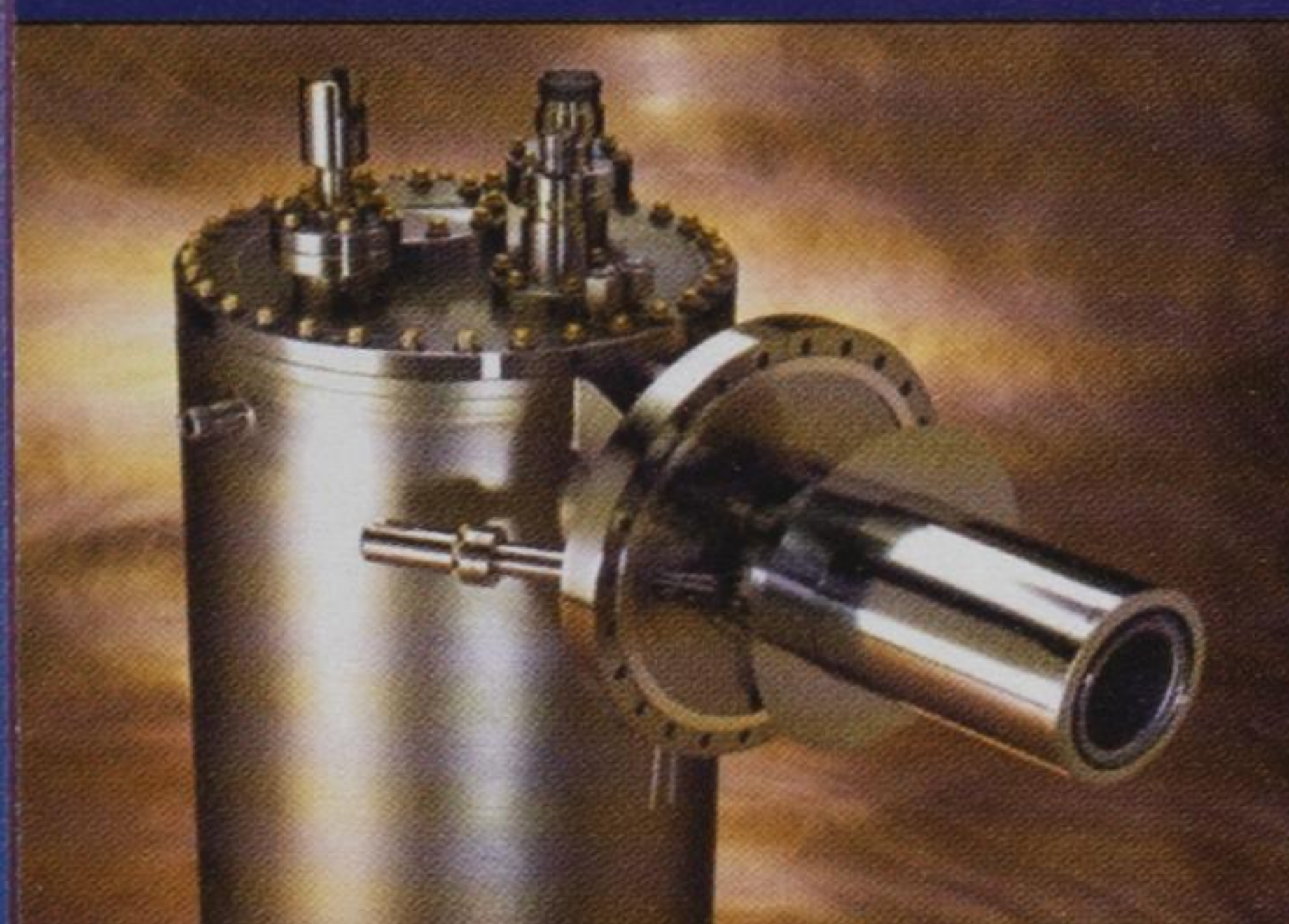
Korea (Semivac): +82 2 573 3786

Australia (M.M.R.C): +61 3 9885 1752

www.wafertech.co.uk

Wafer Technology is part of IQE plc

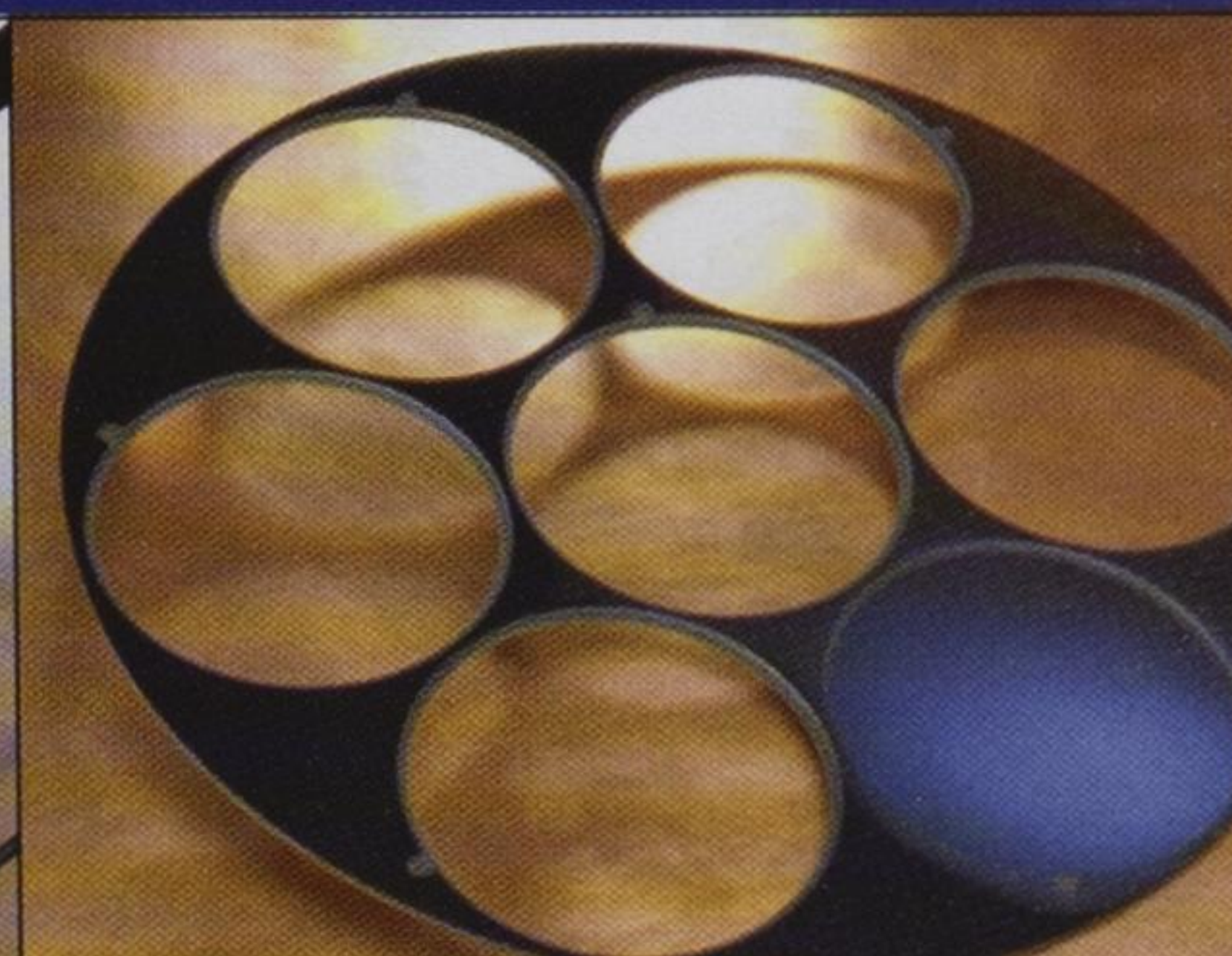
Many claim leadership in MBE. **Veeco-Applied Epi proves it.**



**World's leading
MBE sources**



**Today's preferred
R&D systems for MBE**



**Only production-proven
7x6" wafer tools**



**Expanded global
service with Veeco**

Veeco-Applied Epi. The new leader in MBE.

The rapid adoption of our GaAs-Silicon Style production tools has made Veeco-Applied Epi the world's leading supplier of molecular beam epitaxy (MBE) equipment. These tools, plus our long-proven MBE sources and R&D systems, give you the broadest MBE product portfolio. With Veeco, we now also have the financial muscle and global reach to ensure your success.

Find out why the MBE industry prefers Veeco-Applied Epi for all its equipment needs. We have the proof.



www.appliedepi.com
1.651.482.0800

Veeco Applied **Epi**

Agere axes its optoelectronics unit

Only months after announcing a major restructuring plan in an effort to cut costs (*Compound Semiconductor* March 2002 p3), Agere Systems now plans to leave the optoelectronics market altogether. The company, which estimates that it has a 12% share of the market for optoelectronic components, will discontinue its optoelectronics operations no later than June 30, 2003, and will focus on providing ICs for communications and computing applications.

Agere is seeking a buyer for all or part of its optoelectronics business, which accounted for about 10% of its total revenue of \$560 m in the June 2002 quarter. Its workforce will be slashed from around 11,200 to 7200 by the end of December 2003; 2500 of these job losses are related to optoelectronics.

Agere will sell or close its facilities in Dallas,

TX; Alhambra and Irwindale, CA; and Matamoros, Mexico. Also the company will no longer need to carry out its former plan, announced in January, to transfer its manufacturing operations from facilities in Reading and

Agere will slash its workforce from around 11,200 to 7200 by the end of December 2003.

Breinigsville, PA, to Allentown, PA. The company intends to sell the Reading and Breinigsville properties once it discontinues those operations. The facilities feature state-of-the-art automated manufacturing lines for the optical sub-assemblies used in lasers, transceivers and transponders for the fiber-optic market.

The changes do not end there. Agere will move its remaining IC wafer fabrication line in Allentown to Orlando, FL, consolidating all of its US manufacturing operations in one facility. Agere hopes to sell its Orlando plant as an ongoing operation, allowing the company to continue sourcing products from this facility. It plans to leverage foundries for standard process technologies, continue its IC assembly and test operations in Singapore and Thailand, and maintain its wafer manufacturing venture with Chartered Semiconductor.

Agere's central campus will remain in Allentown, where the company's two sites will house R&D, operations, marketing, sales and other corporate functions. The company's target is to reduce its quarterly operating income break-even point from \$700 m to \$500 m by the second half of next year.

Princeton Lightwave partners with Trumpf and goes fab-lite

Princeton Lightwave (PLI), a manufacturer of high-power laser diodes for telecom applications based in Cranbury, NJ, has entered into a strategic partnership with the Trumpf Group, a German company which is one of the world's largest producers of laser systems for industrial applications.

Trumpf, based in Ditzingen, Germany, has acquired PLI's major assets, including its production facilities and its portfolio of relevant patents, along with a substantial number of highly qualified staff. Trumpf has formed a wholly owned subsidiary, Trumpf Photonics, with 20 employees initially. Financial details of the deal were not revealed.

However, PLI will continue to exist as a supplier to the fiber-optic market. As PLI's general manager and CTO John Connolly explains, the deal allows PLI to operate as a "fabless or fab-lite" organization.

"PLI will continue to make and sell lasers for the fiber market and Trumpf Photonics will manufacture optoelectronics components for PLI," said Connolly. "Under the terms of the partnership, PLI will retain its extensive optoelectronics device design capabilities, characterization, reliability testing, fiber-optic packaging and application support facilities."

The fab-lite model is consistent with the growing maturity of the optical systems busi-

ness, and reflects changes at organizations such as Agere Systems and Nortel Networks as they adapt to the sales decline in the optoelectronics component industry.

"Operating without a fab permits PLI to diversify and invest in the R&D of new technologies," said Connolly. "It will enable us to work more effectively with our telecommunications partners and other customers during the market recovery."

Such a strategy also enables significant cost savings since PLI benefits from a reduction in its capital infrastructure. "Most of the component companies that emerge successfully from the telecommunications downturn will do so using this business model," he said.

PLI spun out of Sarnoff Corporation in the spring of 2000 with venture capital backing. In 2001 the company launched several products, namely high-power pump lasers, broadband gain chips and advanced source lasers, and also reported a power level of 1 W from single narrow-stripe 1480 and 14xx nm pump laser chips (*Compound Semiconductor* July 2001 p51).

A spokesperson said that Trumpf is currently evaluating which markets it will seek to address with its new laser diode manufacturing capability – but the fiber-optic market is unlikely to be considered at present.

In brief...

Agere to supply Raman pump modules to Lucent

Agere Systems is to supply Raman pump modules containing InP-based 14xx nm lasers to Lucent for use in its LambdaXtreme DWDM system. Although Agere is to quit the optoelectronics business (see stories on this page and p3), the company says it will honor its commitments to its customers for optoelectronic products until at least mid-2003.

Genoa wins US patent for the integration of an LOA

Genoa of Fremont, CA, has been issued a US patent, number 6,347,104, covering the integration of its linear optical amplifier (LOA) with a signal power-monitoring capability. Genoa's amplifier is based on a 1550 nm InP-based VCSEL that pumps excess photons into a gain medium, amplifying all wavelengths in the same way that EDFAs currently amplify WDM signals.

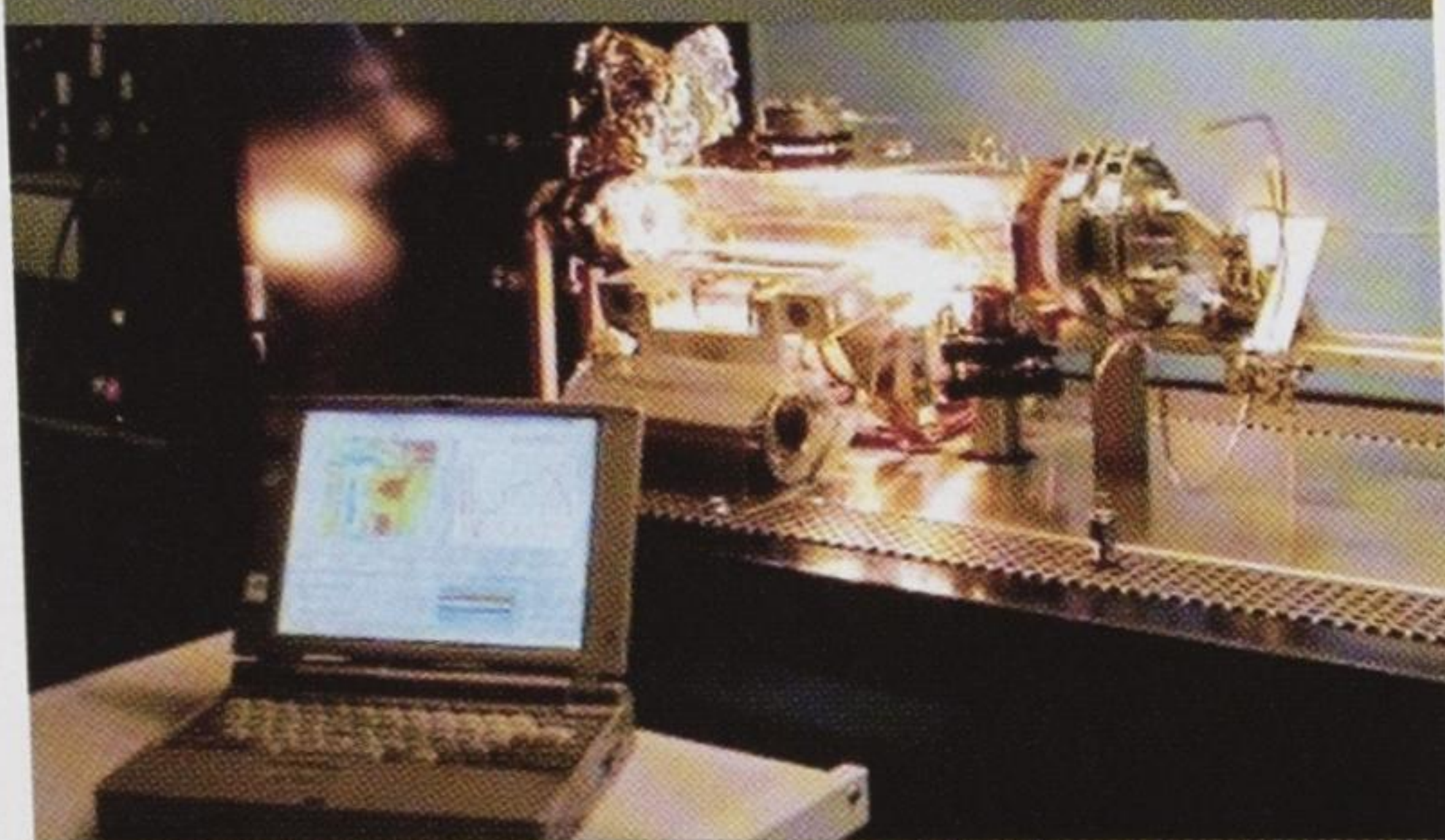
In Genoa's design, the amplifier and signal-monitoring functions are integrated and the signal does not need to be redirected for monitoring purposes, while the laser directly and continually corrects variations in the optical signals.

If you need
answers
not surprises



Cutting edge
technology demands
cutting edge control.

With our EpiRAS series of epitaxy monitoring sensors, LayTec offers the world's first full spectroscopic real-time monitoring tool. It analyses in-situ growth rate, composition, true wafer temperature and doping level of complete semiconductor device structures.



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!

Multilink to cut workforce by up to 45%

Multilink Technology, a fabless supplier of digital and mixed-signal ICs, transponders and modulator drivers, has joined the growing ranks of companies that are resizing in response to the current state of the fiber-optic components market.

The cuts will reduce the company's 329 staff worldwide by up to 45% by the end of the year. In addition to its headquarters in

Somerset, NJ, the company has a west-coast design center, and operations in Israel and at several locations in Europe.

Jobs will go throughout the company. Multilink will close certain locations, and reduce activity at others. The company expects to record restructuring charges of approximately \$13–15 m during the quarter ending September 2002.

Oki forms optical components subsidiary

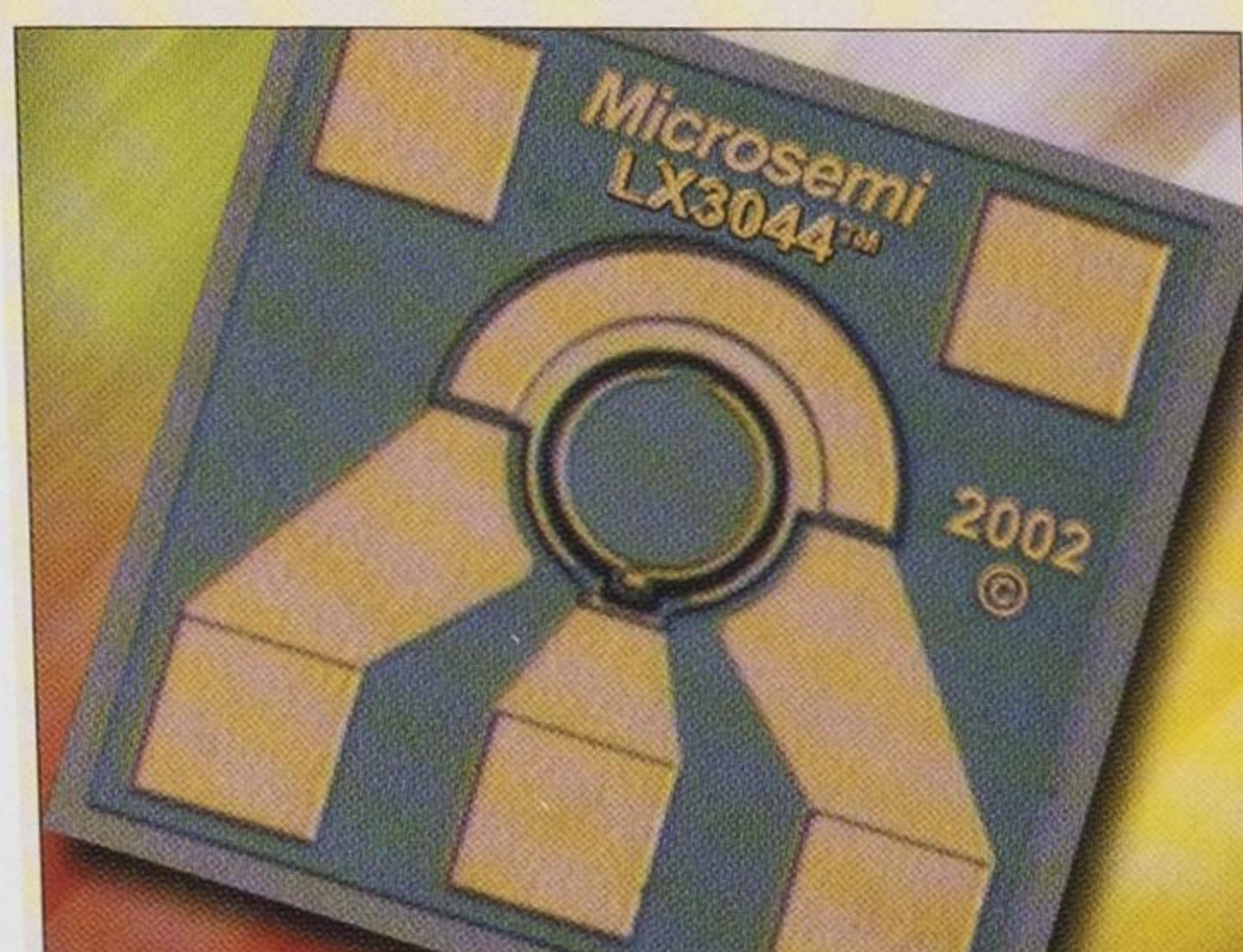
Oki Electric has formed a subsidiary to support its North American sales activities. Headquartered in Mt. Laurel, NJ, Oki Optical Components complements the company's existing sales office in California's Silicon Valley, and will help Oki to support its optical customer base.

Oki Optical Components has also released a new electroabsorption optical modulator

and integrated InP DFB laser. The OL5155M features a modulation voltage of 3 Vpp and is suitable for 40 Gbit/s very-short-reach (less than 2 km) applications. The device can operate over medium and long-reach spans with NRZ or RZ modulation schemes, and features a modulation bandwidth of more than 30 GHz, a dynamic extinction ratio of 10 dB and fiber output power of 3 dBm in CW mode.

New devices from Microsemi, OEpic and Inphi

● **Microsemi Corporation** has introduced three families of photodetectors for optical networks. The MXP4000 is a series of five InGaAs photodetectors operating at 1310 and 1550 nm and provides a typical responsivity of 0.95 A/W. Two of the detectors suit power-monitoring applications, and feature 200 and 300 μm apertures and respective dark currents of 0.8 and 5 nA. The other devices have 75, 40 and 20 μm apertures, and operate at 3.125, 10 and 12.7 Gbit/s respectively.



The new LX3044 single GaAs photodiode from Microsemi detects at 850 nm.

The new LX304x and LX305x series of photodetectors are designed for 1 and 10 Gigabit Ethernet, Fibre Channel, Infiniband, VCSEL and SONET/SDH

OC48 and OC192 systems. Operating at 850, 1310 and 1550 nm and at data rates of 3.125, 10 and 12.7 Gbit/s, the photodiodes feature 75 $\times$ 75 μm^2 anode and cathode pads for faster self-alignment during flip-chip and wire-bond assembly.

● OEIC manufacturer **OEpic** has introduced an integrated 10 Gbit/s front-end receiver chipset for intermediate and long-reach applications. The 1310 nm receiver chipset comprises a *pin* photodetector and TIA and is available as a bare die or packaged in a TO-46 can. The *pin* device has a responsivity of 0.7 A/W at 1310 nm and a bandwidth of up to 18 GHz. The TIA is made with an InGaP HBT process and has a differential transimpedance of 2200 Ω , 9 GHz bandwidth and power consumption of 125 mW. The receiver has a conversion gain of 1200 V/W and optical sensitivity of -17 dBm.

● **Inphi** has added an NRZ–RZ converter to its product portfolio. The GaAs-based IC electronically converts NRZ input signals to RZ output signals, which are fed into a modulator driver for transmission over a network. The 13705RZ supports data rates of up to 12.5 Gbit/s with sufficient overhead for forward-error correction.

Everything must go at Siros – even the phones

VCSEL manufacturer Siros Technology is closing its facility in San Jose, CA, and selling everything, including its phone system. The company has authorized the auction house DoveBid to conduct a complete facility closure. The equipment on sale includes a scribe and break machine and a wide range of test and measurement equipment, as well as office furniture and PCs.

As recently as March 2002, the company received a funding round of \$17 m from a number of venture and corporate investors, bringing the company's total funding since inception to \$32 m.

Details of what the company was working on are very sketchy. The company claimed to have developed a new high-power VCSEL-based component that could be reliably produced in volume at a fraction of the cost of

As recently as March 2002, the company received funding of \$17 m from venture and corporate investors.

other solutions. The product, thought to have been a long-wavelength (1310 or 1550 nm) device, was to have been offered in an industry-standard package for rapid integration.

According to Siros' website, its high-power VCSELs "combine proven wafer fabrication technology with an innovative, highly-integrated design that delivers the performance needed to support any metro or long-haul networking application at a fraction of the cost of existing products".

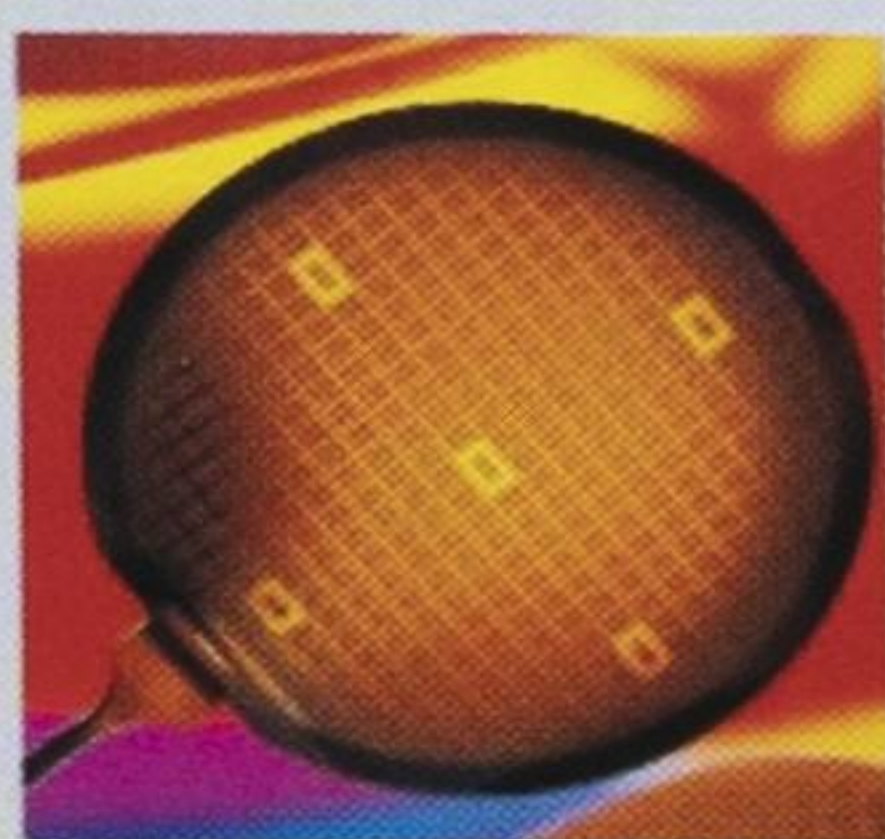
JGKB wins funding for GaAs modulators

JGKB Photonics, a spin-off from the University of British Columbia making optical modulators, has won \$4.3 m in its first round of financing. JGKB has already sampled prototypes of its GaAs-based 40 Gbit/s modulator, and will use the new money to deliver demonstration units to customers and to develop the business.

The Mode Converter technology exploits the electro-optic properties of compound semiconductors to modulate light by affecting its polarization state. JGKB says that this requires a significantly lower modulator drive voltage than Mach-Zehnder and electro-absorption modulators. The GaAs modulator operates at 1520–1620 nm across a 40 GHz bandwidth, with an insertion loss of 6 dB.

"Mode Converter will deliver the market-critical requirements of low-power, ultra-high bandwidth and long-distance performance," said JGKB's president and CEO, Alan Guest.

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

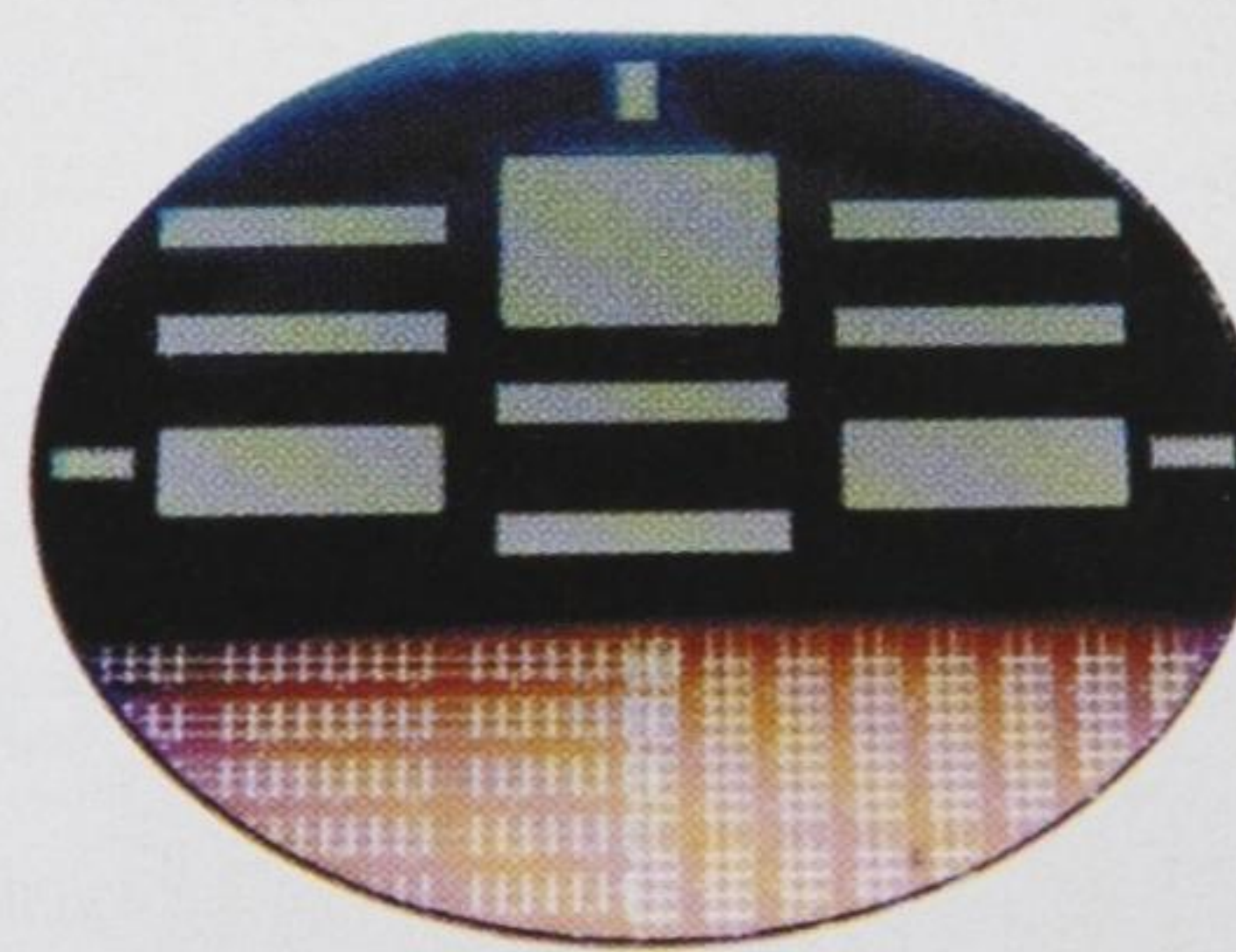
www.bandwidthsemi.com

(603) 595-8900

Epitaxial and Foundry Inquiries: sales@bandwidthsemi.com

EOE M/F/D/V

Custom Epitaxial Solutions



QinetiQ offers custom epitaxial growth and characterisation solutions for today's fast-changing environment. We can supply epitaxial layers to stringent specifications, and offer layer design and device fabrication if required.

- Custom wafer growth with no minimum order
- High quality, with 20 years of expertise behind us
- Full in-house characterisation (SIMS, X-ray, CV, Hall, PL)
- GaAs/AlGaAs, InP-based, InSb/InAlSb, GaN/AlGaN, CdTe/HgCdTe, SiGe, dilute nitrides
- MBE, CBE and MOCVD
- Custom device fabrication and assessment
- Layer design and modelling

Tel. +44 1684 89 5365

Fax. +44 1684 894311

electro-optics@QinetiQ.com

www.electro-optics.co.uk

QinetiQ was formerly DERA, the UK's
Defence Evaluation and Research Agency

QinetiQ

St. Andrews Road, Malvern, UK

Some just talk ...
... we innovate

invent

**# 1 in delicate wafer and thin
substrate handling**

innovate

**Automated temporary bonding
and debonding**

implement

**Backside lithography for
vias processing**

EVG provides proven technology for automated temporary bonding and debonding of fragile and ultra-thin wafers for compound semiconductor manufacturing. Our precision alignment systems solve the most critical lithography processes and achieve the ultimate in handling safety and reliability.

Wafer Bonders – Precision Alignment Systems – Resist Processing Systems – Wafer and Mask Cleaners – Integrated Systems
SOI – MEMS/MOEMS – Compound Semiconductors – Advanced Packaging – Power Devices – www.EVGroup.com



EVG
E-mail: CS@EVGroup.com
Europe: +43 7712 5
US East: +1 401 784
US West: +1 602 437
Japan: +81 45 438

Samsung increases blue LED orders

Samsung Electronics, the world's third-largest mobile-phone manufacturer, recently started a second wave of procurement of blue LEDs in Taiwan. The company purchased blue LED chips for the first time in Taiwan at the beginning of this year. It is estimated that Samsung will purchase around 30 million blue LED chips per month over a period of more than half a year, creating a demand for 180 million chips worth around NTD 720 m (\$21 m). These will be supplied by Epistar, United Epitaxy and two other chip makers.

According to Lee Ping-Chieh, general manager of Epistar, Samsung plans to use a large number of high-brightness blue LEDs in its phones. Other mobile-phone makers are likely to follow suit, and further demand for LEDs will come from applications such as car lighting and outdoor signs.

Agilent has also increased its orders for blue LEDs from manufacturers in Taiwan.



Samsung has placed orders in Taiwan for around 30 million blue LEDs per month, to be used in mobile phones such as the N600.

The US company uses the blue chips for a wide variety of applications, and is currently buying around 30 million devices per month from Taiwan. The overall demand for blue

LED chips from Taiwan is estimated to be around 80 million per month.

At present, both Epistar and United Epitaxy can deliver around 20 million blue LED chips per month, so the combined requirements of Samsung and Agilent will put a strain on both companies. United Epitaxy intends to expand its productivity to around 40 million chips per month by the end of this year. Epistar recently installed a new MOCVD and plans to add another in September, hoping to reach a level of around 30 million chips per month.

The discrepancy between supply and demand, which is as high as 40–50%, has forced the Taiwanese suppliers to raise their prices, a move that has already been approved by Samsung when placing its new orders. In addition, when customers have relatively strict requirements on brightness and wavelength specifications, the price can be around 20% higher than normal.

Sharp plans blue laser launch

Sharp is aiming to begin mass production of blue lasers for high-capacity, next-generation optical storage systems in late 2003. The company's president, Katsuhiko Machida, made the announcement at an opening ceremony to mark the completion of Sharp's new laser fab in Hiroshima prefecture, which will produce the blue lasers. At present, the new plant and Sharp's older factory in Nara prefecture produce red and infrared lasers for DVD and CD systems. Sharp holds about 50% of the global market for such lasers, and produced about 15 million units per month in the April–June period this year. Production is now being

trimmed by 5–10% in response to a slump in sales of PCs; about half of Sharp's lasers are used in the optical drives of PCs.

Sharp also announced that it plans to transfer assembly and packaging operations for semiconductor lasers to a wholly owned subsidiary in Indonesia. Since production volumes of these products tend to fluctuate widely, Sharp will try to stabilize costs by shifting the assembly work to the Indonesian plant where many employees are contract workers. The factory is also closer to customers that make audiovisual equipment and PCs in other Southeast Asian countries and China.

Tyntek offers grind and polish service

Tyntek, one of the leading LED chip makers in Taiwan, plans to increase the percentage of blue and AlInGaP high-brightness LEDs that it produces. According to Tyntek's vice general manager, Chen Tu-Hung, the company hopes to increase its productivity of blue LEDs to 10 million per month during the third quarter, from 2 million per month in July, and also plans to make 80–100 million AlInGaP LEDs per month.

The relatively high technological barrier to

manufacturing blue LEDs and the low yield of the process contribute to the situation in Taiwan at present, where supply is unable to meet demand. Chen Tu-Hung explains that blue LED epiwafers are generally grown on sapphire substrates, which have a high hardness and are difficult to grind and polish.

"Because of this, we have recently started to offer Tyntek's grinding and polishing service to other LED makers," said Chen. "United Epitaxy and other chip manufacturers have appointed Tyntek to carry out grinding and polishing processes to a certain extent, and the gross profit rate is estimated at around 10%."

Stanley equips cars with white LEDs

Stanley Electric has started to mass-produce white LEDs for use in two luxury Japanese cars to be launched this fall. Around 20 white LEDs will be used in each car to provide back-lighting for instrumentation panels. Stanley is producing white LEDs at its plant in Yamagata prefecture at a rate of around 1 million units per month, using a novel phosphor down-converter that does not infringe on other companies' patents. Stanley says it will try to reduce production costs in an effort to target non-luxury vehicles in future, and is also looking at using white LEDs in car headlights.

LED makers eye Olympic opportunity

Taiwanese companies have increased their level of investment in mainland China, looking to some of the opportunities that will arise when China hosts the Olympic Games in 2008. Many large-scale public works such as airports, hotels and shopping centers will be built, creating a strong demand for LEDs. After expanding surface-mount LED productivity in its Taiwan factory, Harvatek now plans to invest \$3 m in Yuan-Hong Technology of China. OPTO Tech also plans to invest \$6 m in China.

Palladium Cell Replacement

AERONEX Infinity GPS[®] Provides the Solution to Palladium Cell Troubles

INFINITY GPS

No Damage Due to Power Outages

Low Pressure H₂ Operation

Low Operating Costs

Performance

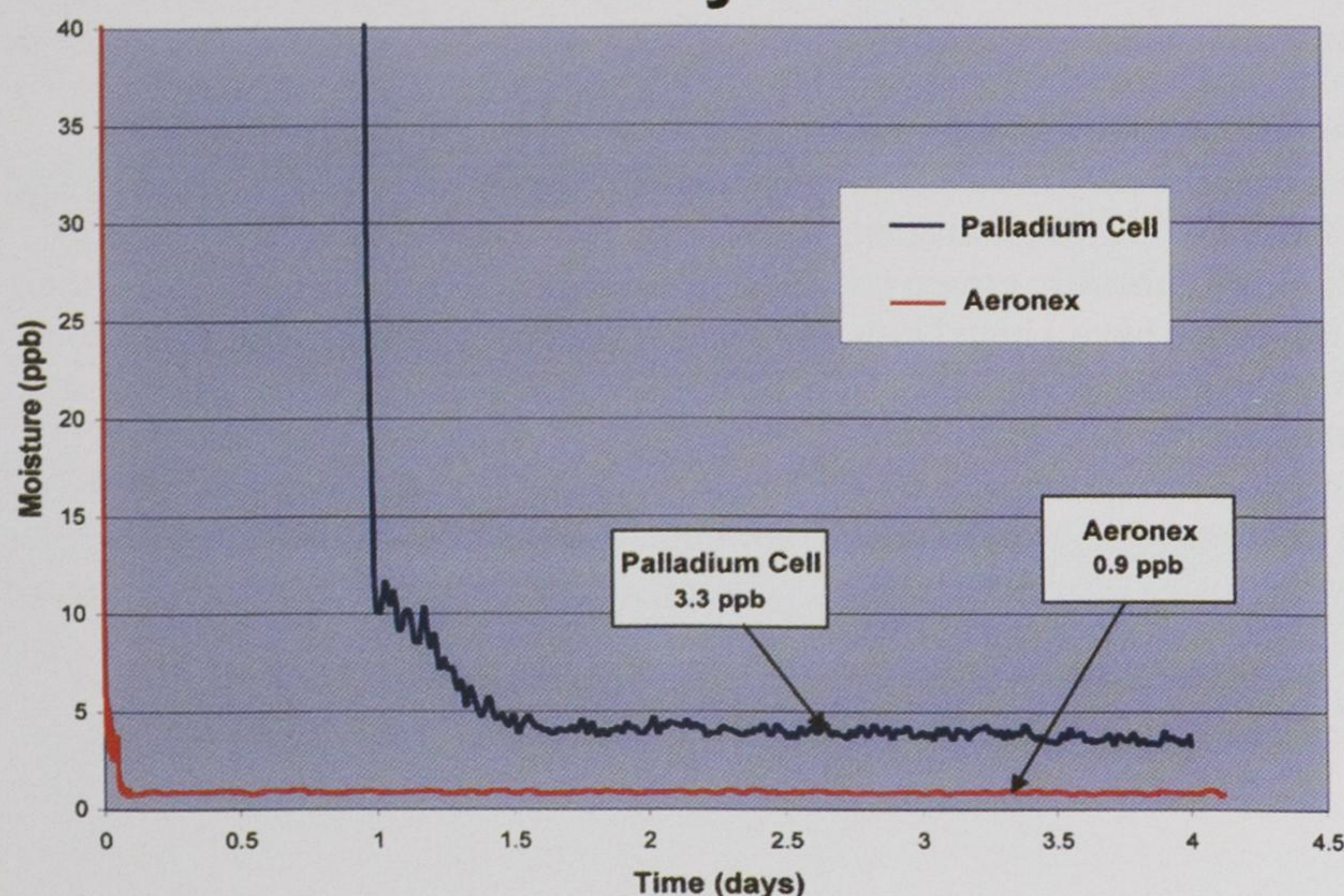
The Infinity GPS provides less than 1 ppb (part-per-billion) outlet purity for removal of O₂, H₂O, CO, CO₂, and hydrocarbons with very low pressure drop at high flows, regardless of source gas pressure.

Value

The Infinity GPS enables savings through the use of liquid H₂, lower utility requirements, and its robust reliable design. All of which translate into a lower cost-of-ownership than palladium cells.



Fast Dry-Down



More Gas Purification
Solutions for
NH₃, AsH₃, PH₃, and N₂
Complete purifier packages for
GaN and GaAs tools

AERONEX
The Source for Gas Purification

www.gaspurifier.com

+1 (858) 452-0124
(800) 511-9761 Toll Free in U.S.
6975 Flanders Drive • San Diego, CA 92121

InP microelectronics waits for fiber-optic recovery

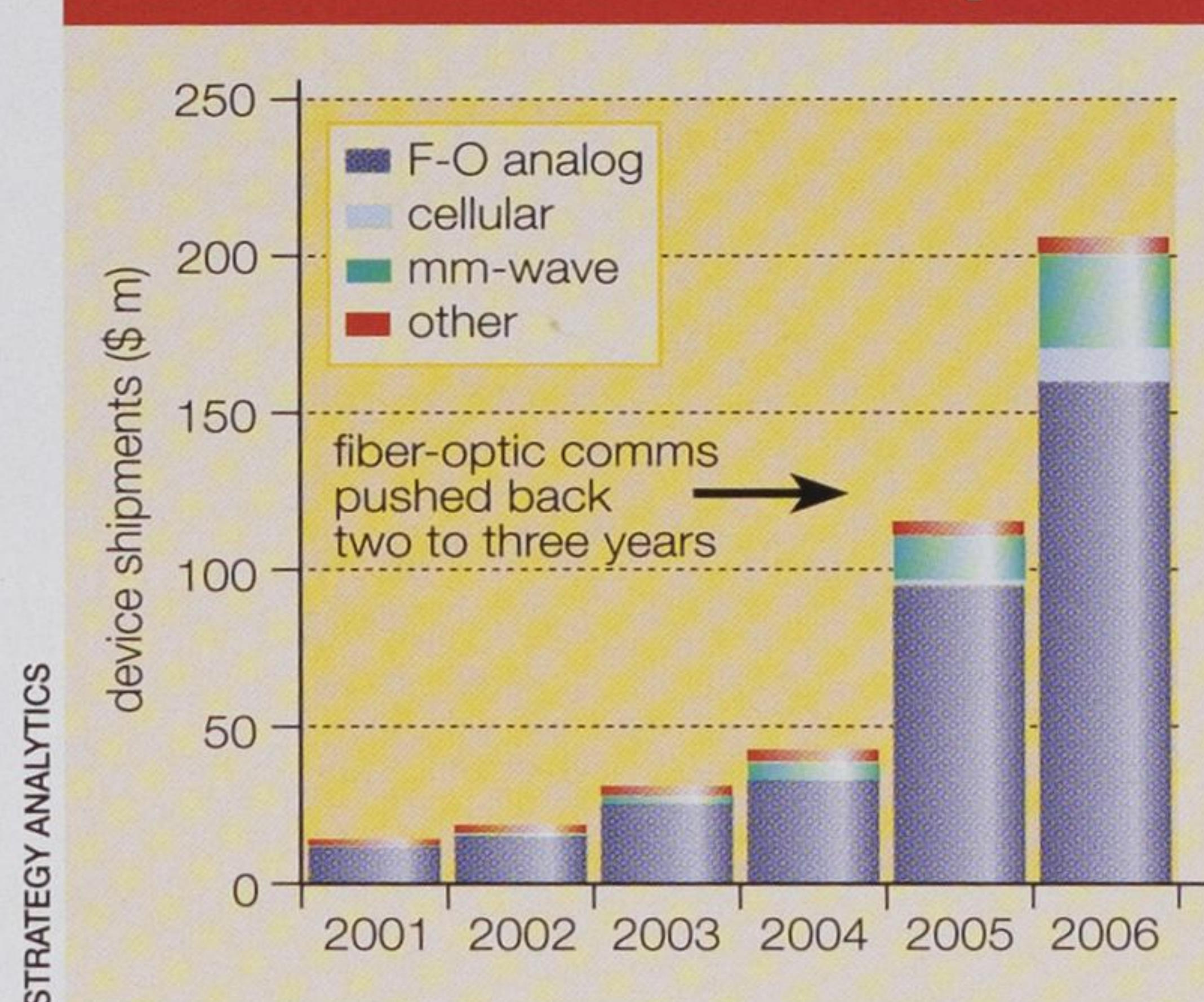
Shipments of InP microelectronic devices will be worth \$206 m in 2006, with analog InP ICs for fiber-optic networks accounting for \$160 m. That's according to a report that will be published by Strategy Analytics (SA) later this year. In contrast, the whole market was worth \$13.4 m in 2001.

The report breaks the market for InP microelectronics into application areas, and forecasts the total value of shipments each year. The collapse of the telecom infrastructure market and the resulting delay in the uptake of 40 Gbit/s technology will push back high-rate growth in the market for InP microelectronics by two to three years.

"Fiber-optic telecoms has got to be the application that kick-starts the market," said Stephen Entwistle, the program manager for SA's GaAs and High Speed Circuits Service. "But we've really had to push that back two to three years from now. Existing volumes are in space and military projects."

Entwistle says that the current position of InP-based microelectronics is similar to that of GaAs-based HBTs several years ago, when companies such as TRW developed devices and manufacturing processes for demanding but low-volume military and space applications. TRW then invested in equipment for high-volume manufacturing to enable the company to reach a price-point where the

InP electronics market split



technology would be acceptable for commercial applications such as mobile phones.

The report also forecasts that InP may play a role in millimeter-wave applications such as automotive radar. Such applications should account for nearly \$30 m of the total InP microelectronics market by 2006. "Automotive radar may come along before the fiber-optic market revives, initially making it the volume application," said Entwistle. "However, realistically that is still two to three years away."

The new report forms part of the company's syndicated research services and has the working title *Indium Phosphide Microelectronics Market Developments*.

Growth set to return in GaAs substrates

Strategy Analytics has released a report on the market for semi-insulating GaAs substrates. Although the report predicts a CAGR of 26% through to 2006, the equilibrium between supply and demand will not return until 2003.

According to the report, the excessive inventory in 2000 was built primarily on expectations of continuing demand through 2001, and fears of a 6 inch wafer shortage. The decline in demand for products manufactured using SI GaAs wafers left some users with inventory levels equivalent to 10 months' supply, resulting in a 40% decline in the merchant market for semi-insulating GaAs substrates in 2001.

"While the merchant market for GaAs substrates will show growth through to 2006 of around 26%, GaAs substrate vendors will have to wait until 2003 to see the level of merchant sales that were observed in 2000," said Asif Anwar, senior analyst at the company.

Markets for SI GaAs Substrates: 2001-2006 is available from Strategy Analytics. See www.strategyanalytics.com.

Report shows Nokia edging towards a 40% market share

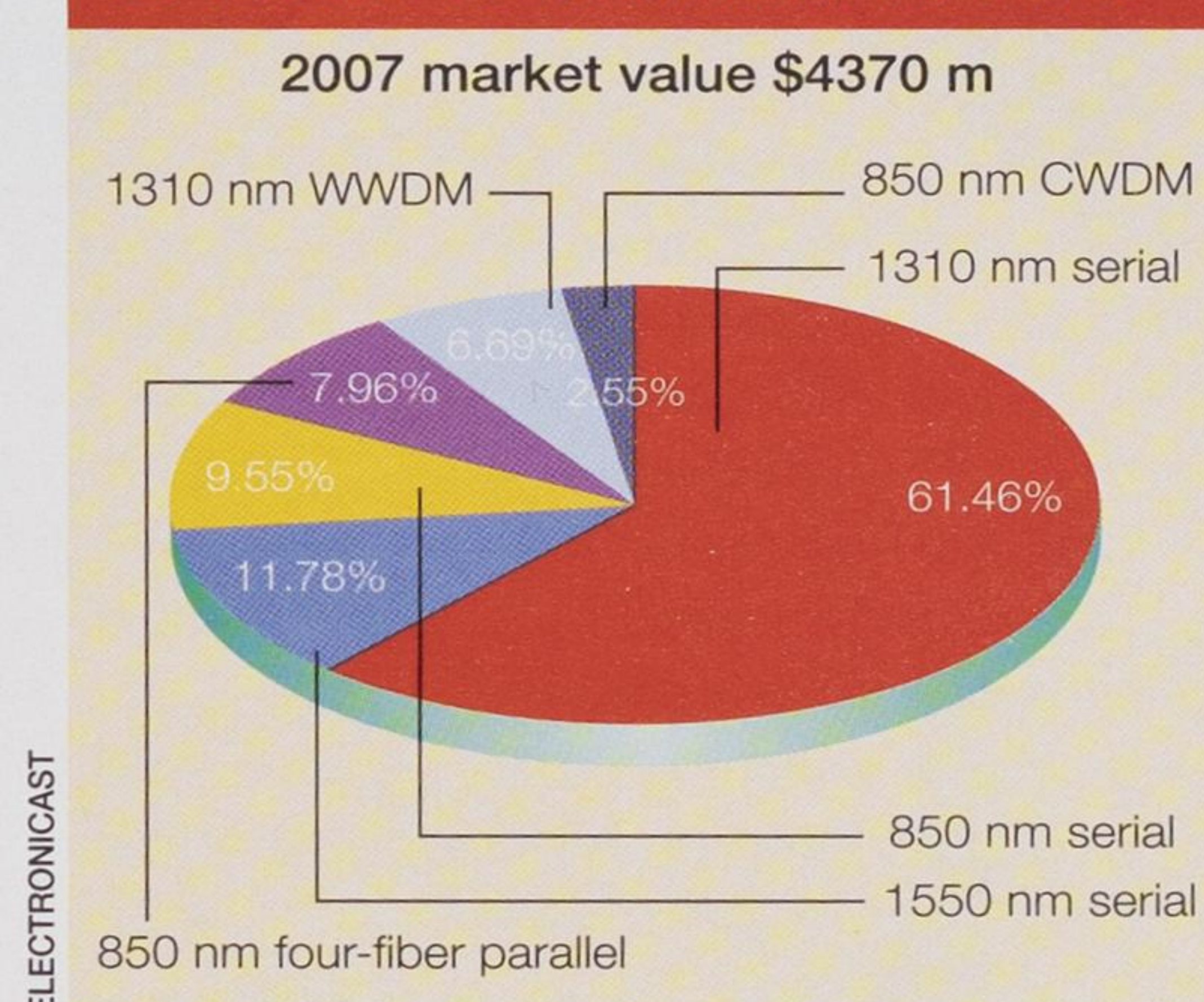
Market analyst firm Strategy Analytics has published data for global mobile-phone shipments in the second quarter of 2002, showing Nokia extending its lead over its rivals. According to the figures, Nokia shipped 37.2% of the 96.7 million handsets produced globally in the second quarter. In the first quarter Strategy Analytics put Nokia's share at 35.4%. The research firm reiterated its forecast for 417 million units in 2002, up from 393 million last year.

Despite rising competition from vendors in China and the Pacific Rim nations, the top-five vendors in 2001, namely Nokia, Samsung, Motorola, Siemens and Sony Ericsson, maintained their control of the handset market in the second quarter, accounting for 78% of global shipments. Strategy Analytics also noted that Motorola, Samsung and LG have all increased their market shares by delivering innovative handset designs and features in order to satisfy increasingly demanding customers.

1310 nm transceivers will dominate the 10 Gbit/s market

Fiber-optic components market forecaster ElectroniCast is predicting that 1310 nm serial transceivers will remain the dominant form of 10 Gbit/s datacom transceiver until 2011. In 2001, 10 Gbit/s 1310 nm serial transceivers held a 93.5% share, or \$64.25 m, of the market for 10 Gbit/s transceivers. ElectroniCast predicts that 10 Gbit/s links are poised for a rapid 116% growth per year, from \$68.7 m in 2001 to \$3.26 bn in 2006, and up to \$10 bn in 2011. By 2011, 1310 nm serial transceivers will account for 44.5% of the market by value. The next-largest segment in 2011 will be 1550 nm serial transceivers. These should enter the market in 2005 and account for about 25% in 2011.

10 Gbit/s transceiver market



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

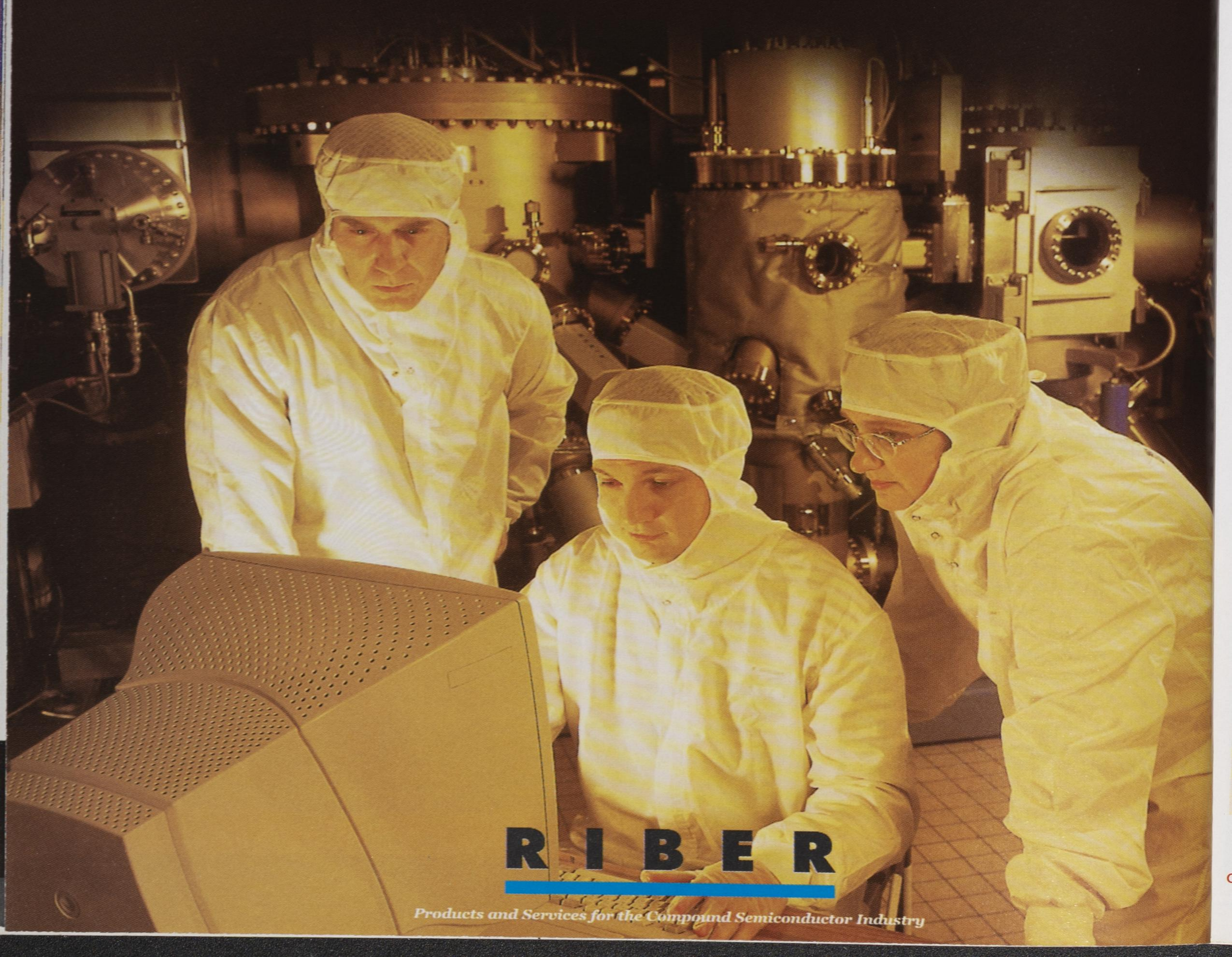
92503 Rueil-Malmaison Cedex / France

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



RIBER

Products and Services for the Compound Semiconductor Industry

Aeronex to countersue SAES Getters

In a new twist on a patent lawsuit between SAES Getters and Aeronex regarding ammonia gas purifiers, Aeronex intends to combine a countersuit against SAES for patent infringement together with the original lawsuit brought by SAES.

Late last year, SAES Getters of Milan, Italy, filed a lawsuit against rival gas purifier manufacturer Aeronex of San Diego, CA, claiming that Aeronex had infringed on a SAES patent (US patent number 5,716,588) relating to ammonia purification technology. The lawsuit was then amended, in April this year, to include claims against Aeronex for false advertising and unfair competition (see

Compound Semiconductor June 2002 p25).

In a surprising reversal, Aeronex is now claiming that SAES is using an ammonia purification technology that does not follow SAES' own patent, but instead infringes on Aeronex's US patent number 6,241,955.

When gathering evidence for the lawsuit, Aeronex claims to have discovered that neither of the ammonia purifiers made by itself or SAES uses technology covered by SAES' patent 5,716,588. This patent describes the use of metallic iron and metallic manganese on a high-surface-area substrate such as a zeolite or an inert silicate. Aeronex claims that composition testing of SAES' product PS11-MC1-

NH reveals a combination of iron oxides and manganese oxides without a separate supporting substrate, and therefore the product does not follow SAES' patent. Instead, Aeronex claims the SAES product uses technology described in Aeronex's patent 6,241,955.

Aeronex notes that its product contains a higher ratio of manganese oxide to iron oxide compared with the SAES product, which contains more iron oxide than manganese oxide. "Manganese oxide is highly aggressive at binding water in an ammonia stream and is superior to iron oxide in our development tests," said Dan Alvarez, director of new technology at Aeronex.

FEI buys campus site in Oregon

FEI Company has acquired a new campus in Hillsboro, OR, to consolidate its local operations at one site and provide room for expansion. The 27 acre site will feature two buildings covering 180,000 sq. ft, including offices and 112,000 sq. ft of R&D and manufacturing space. FEI will begin moving its operations, currently housed in five separate buildings throughout

Hillsboro, to the new site later this year. Investment in the site, which was bought from Tokyo Electron, will be around \$23 m.

Earlier this month the company announced that it was to be bought by Veeco Instruments, making Veeco FEI the third-largest US metrology company and the sixth-largest US supplier of semiconductor equipment.

Aehr, Avalon qualify VCSEL burn-in tool

Aehr Test Systems of Fremont, CA, has completed the development and successful qualification of its FOX full-wafer VCSEL burn-in system. The qualification results from a development partnership between Aehr and Avalon Photonics of Zurich, Switzerland. The joint development project included the testing and confirmation of successful burn-

in of VCSEL wafers in Aehr's WaferPak full-wafer burn-in cartridge.

The WaferPak cartridge was used with the FOX system to demonstrate successful full-wafer contact to more than 10,000 densely packed VCSELs using Aehr's nanospring contacting device. "We decided to use wafer-level burn-in and test, with its obvious advantages for time and cost," said Karlheinz Gulden, Avalon's CTO. "With this qualification we have the confidence to implement the technology in our manufacturing process."

Equipment sales

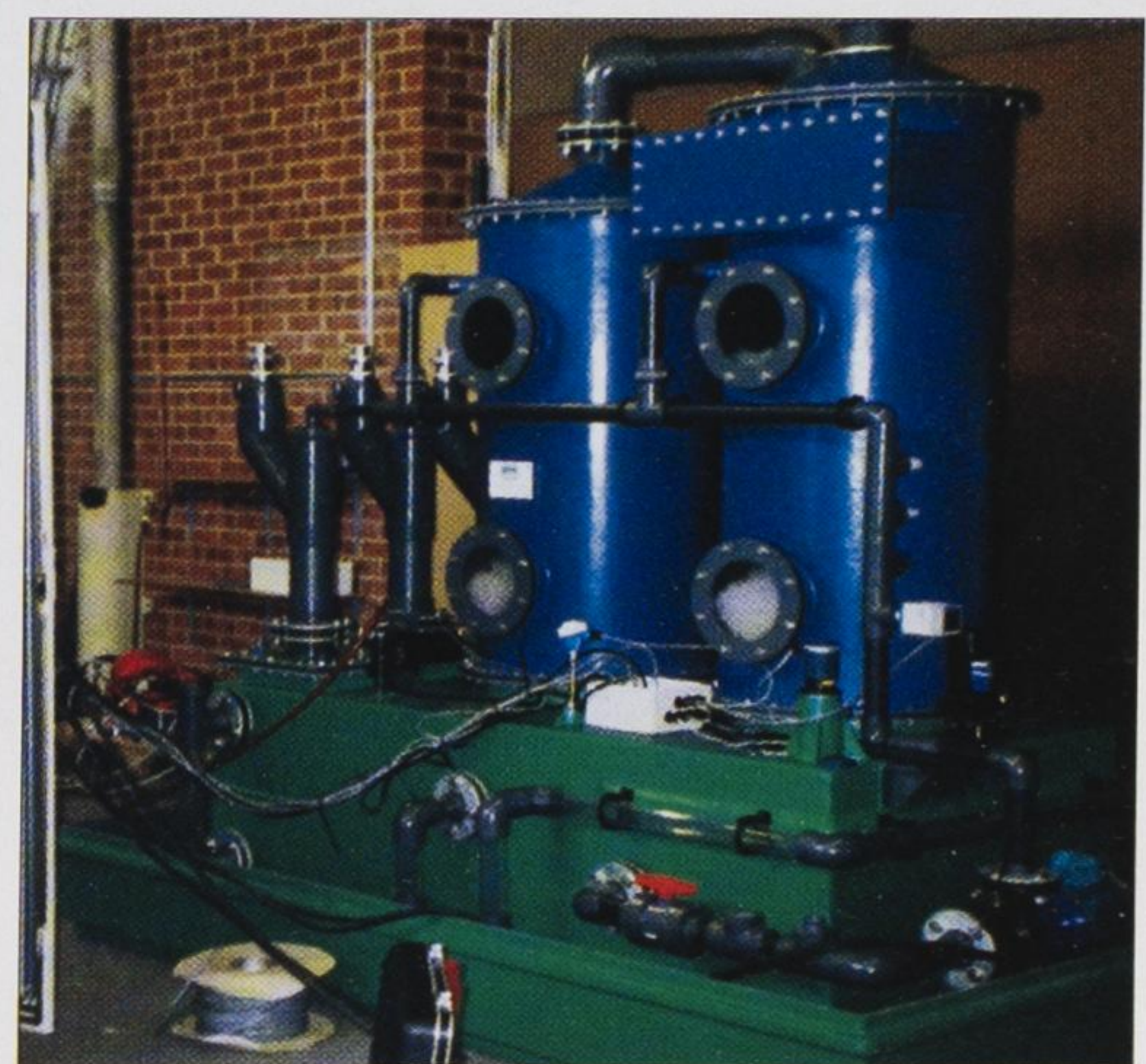
● **Veeco-Applied Epi** has shipped a gas-source GEN III MBE system to **OEpic**, a manufacturer of advanced optoelectronic integrated circuits based in Sunnyvale, CA. The GEN III has a capacity of 1 × 4 inch or 3 × 2 inch wafers for the low-volume manufacture of optoelectronic devices.

● **Emcore** has sold the first of its new Enterprise 300 laser-diode machines to **JVC Japan**. The system will be used to produce lasers for CD-ROM and DVD-ROM applications.

● Korean epiwafer manufacturer **Epiplus** has installed a 19 × 2 inch

MOCVD system from **Thomas Swan Scientific Equipment**. The system will be used for high-volume GaN LED production, and the installation is part of a co-operation between the two companies to develop MOCVD processes for GaN on a 19 × 2 inch platform.

IEM signs distributor deal with US firm GTI



IEM's Gemini system treats the hazardous waste gases from MOCVD systems.

IEM Technologies of Bridgwater, UK, has signed a distributor agreement with GTI Technologies of Shelton, CT. GTI will handle the sales, installation and maintenance of IEM's MOCVD gas abatement and toxic effluent treatment systems throughout the US, Canada and Mexico.

With the environmental impact of wafer fabrication an important issue, the new agreement enables GTI to promote the Excalibur and Gemini systems to the US market. The Excalibur removes arsenic and phosphorus liquid effluent, while the Gemini range treats the hazardous, toxic and pyrophoric gases used in compound semiconductor manufacture. GTI will also handle sales of IEM's Centurion trap-cleaning workstation.

Accent expands product lines

Accent Optical Technologies, a manufacturer of semiconductor process control and measurement tools headquartered in Bend, OR, has bought Philips Analytical's operations in Waterloo, Canada. The operations include two product lines, the DCD Pro X-ray diffraction tool and two photoluminescence (PL) mapping systems, that are primarily for the characterization of compound semiconductors. The deal also includes intellectual property and 53 employees worldwide.

According to Steve Blight, VP and general manager of Accent's optoelectronics division, Accent bought the operation from Spectris, a UK-based developer of precision instrumentation and control systems. The deal coincides with Spectris's €150 m (\$148 m) acquisition of Philips's entire X-ray analytical business.

"Waterloo is a good resource for our developments and also a good resource to help satisfy our customers' demands," said Blight. "Our focus is on the compound semiconductor sector and by merging with the strongest competition we can put the best features [from each] into the same product line." The Philips products, which comprise the DCD Pro, PLM-100 and PLM-150, characterize epitaxially grown wafers and will expand Accent's existing PL product lines.

While some of the final details, including new employee status, have yet to be decided, Blight says that Accent should start work at the Waterloo plant in the near future. "We are currently working through a strategy with sales and services and [the start of operations] is contingent on the closure of the deal with Spectris," he said. "Hopefully we will begin [operations] in a couple of months."

Philips Analytical also recently announced its intention to cease semiconductor ellipsometry equipment-manufacturing activities in the Netherlands, claiming that it could no longer justify making investments in the product line (*Compound Semiconductor* August 2002 p25). Since this news, the company has changed its position and "is currently investigating the possibility of transferring the product line to a third party".

While a spokesperson for Philips Analytical was unwilling to reveal extra information concerning the interested companies, he said: "The initial announcement triggered three parties to approach us. These parties are interested in buying the ellipsometry activities and continuing to develop new technologies and products."

Negotiations with these parties are ongoing and further announcements are expected over the next few months.

The new plant is situated at the company's electronic specialty gases manufacturing complex, which is located in Hometown, PA, and Air Products expects the plant to be in full operation by fall this year. White Ammonia features a minimum purity of 99.99996% (6.6 nines), and the company is also targeting 99.99999+% (7.0+ nines).

Air Products to open new ammonia plant

Air Products and Chemicals has invested in a new distillation plant to produce ultra-high-purity ammonia (White Ammonia) for compound semiconductor manufacturing.

IntelliEPI receives Vitesse award

Intelligent Epitaxy Technology (IntelliEPI), a manufacturer of InP and GaAs epitaxial wafers located in Richardson, TX, has received the 2001 Supplier of the Year Award from Vitesse Semiconductor.

IntelliEPI has been supplying Vitesse with 4 inch InP HBT wafers grown by MBE for high-performance communication applications over the past two years.

Vitesse grants its award to suppliers who achieve the highest marks in five areas during Vitesse's qualification process. These areas are quality, flexibility, pricing, customer service and strategic advantage.

Tegal agrees to buy Sputtered Films

Tegal has signed an agreement to acquire Sputtered Films of Santa Barbara, CA, a privately held manufacturer of sputtering equipment for thin-film deposition. The payment for the acquisition comprises 1.5 million Tegal shares and a performance-based future cash payment. As Wall Street closed for business on the day that the agreement was announced, the stock element of the agreement was worth \$1,170,000.

Sputtered Films designs and manufactures sputtering equipment for semiconductor, photomask, advanced packaging (including flip chip) and compound semiconductor applications. The company recorded revenues of approximately \$5 m over the past 12 months, and has 18 employees who will continue to be based in Santa Barbara.

People news

● **TriQuint** has named **Ralph Quinsey** as its new president and CEO. Quinsey replaces Steven Sharp who joined the company in 1991 as president, CEO and director, and led it through its successful IPO in 1993. Sharp will remain as TriQuint's chairman of the board. Quinsey most recently served as VP and

general manager of ON Semiconductor's Analog division, in addition to spending 20 years with Motorola.

● **RF Micro Devices** has named an outside director as its new chairman. **Albert Paladino** has been involved with the company since 1992, and succeeds CTO Bill Pratt, who remains on

the board. Paladino has previously held positions with Raytheon, GTE Laboratories, NIST and the Congressional Office of Technology Assessment.

● **Keith Evans**, former VP of business development for IQE, has been hired by **Applied EPI** as the company's new VP of Advanced Technology.

Praxair forms single electronics unit

Praxair of Danbury, CT, a supplier of process gases and delivery systems, has formed a new business unit called Praxair Electronics. The new unit combines Praxair's electronics and semiconductor groups, which had done business separately. "This is one of Praxair's key growth markets and our customers operate in a fiercely competitive, fast-moving industry," said executive VP, Thomas von Krannichfeldt. "Praxair Electronics will have a single team focusing intensely on our customers' needs and providing competitive products and services."

Epichem Ltd. (UK)
Tel: 44-151-334-2774
www.epichem.com
Epichem, Inc. (USA)
Tel: (1) 610-706-0606



EPICHEM

**Discover the
Epichem Difference!**

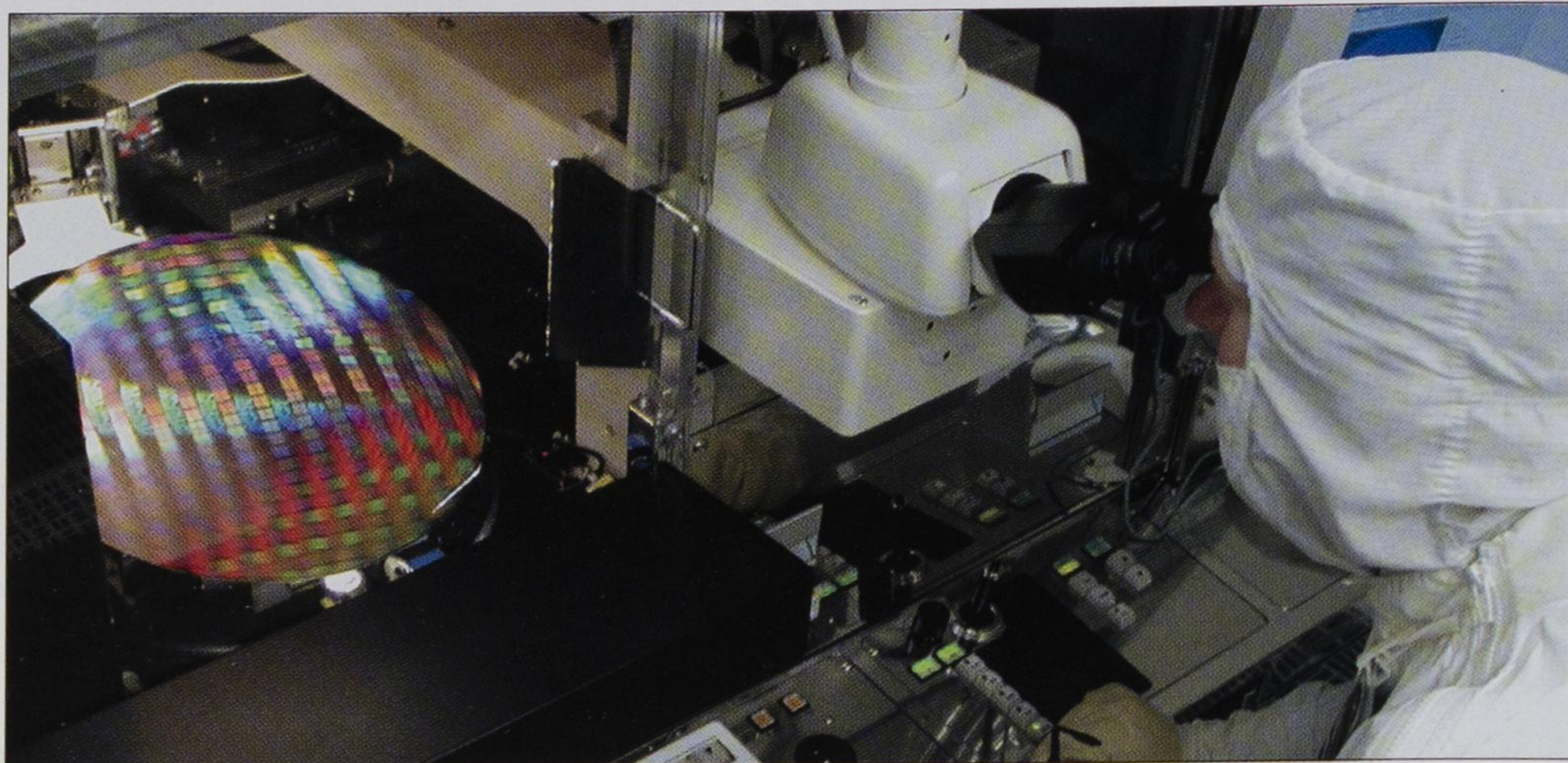
**Global Supplier of Specialty Chemicals
for the Semiconductor Industry**

Intel unveils next-generation process

Intel has revealed details of its new 90 nm CMOS process, which it plans to implement on 300 mm wafers next year. The company claims that its process will be the first in production to implement strained silicon; other technologies such as high-speed copper interconnects and a new low-k dielectric material will also be used.

Strained silicon structures consist of a thin silicon layer deposited on top of a thicker, graded SiGe buffer, which provides a higher mobility in the silicon channel than in a bulk silicon structure. IBM recently announced that it would implement strained silicon, silicon-on-insulator and high-k dielectric materials in its 65 nm process within five years (see *Compound Semiconductor* August 2002 p29).

The 90 nm technology node is the next generation after the 0.13 μm process, which Intel is currently using to make the bulk of its microprocessor ICs. Intel's 90 nm pro-



An Intel technician inspects a 300 mm silicon wafer at an Intel fab in Hillsboro, OR.

cess features transistors with gate lengths of 50 nm, and gate oxides that are only 1.2 nm thick. The company recently used this process to demonstrate SRAM chips

which had a record-breaking capacity of 52 Mbit. The chips packed 330 million transistors into an area of only 109 mm^2 – roughly the size of a fingernail.

Soitec reveals 300 mm SOI plant

Silicon-on-insulator (SOI) wafer manufacturer Soitec is gearing up to manufacture 300 mm SOI wafers at its new plant in Bernin, France, following orders that total several millions of dollars. The company will use Bernin II as well as its existing plant, Bernin I, to meet the demand.

The new fab, which Soitec says is the industry's largest dedicated 300 mm SOI plant, contains 12 production lines and has a total production capacity of 1.2 million wafers a year. The first line is scheduled for qualification in November of this year and production is expected to start before the end of the year.

"Industry analysts anticipate that by 2009, 300 mm SOI will account for up to 50% of the 300 mm substrates consumed within the indus-

try," said Soitec's president Andre Auberton-Herve. "We have been shipping 300 mm SOI wafers since January of this year and have the high-volume production capacity in place."

The Bernin II plant is also set up to manufacture 200 mm wafers. This brings Soitec's total production capacity of 200 mm wafers to 2 million a year.

- Soitec has failed in its attempt to have a recent court ruling overturned in its patent battle with rival SOI wafer manufacturer SiGen. The litigation relates to Soitec's US patent number 5,374,564, which describes the company's "Smart-Cut" layer transfer process (see *Compound Semiconductor* June 2002 p32). As a result of the upheld verdict, several of the key claims of the patent have now been invalidated.

Memscap acquires Cronos from JDSU

French MEMS manufacturer Memscap is to buy JDS Uniphase's Cronos MEMS business unit in a stock deal that is worth around \$8.5 m. Memscap will pay an additional 6.5 million shares, or \$5.2 m, if the unit reaches unspecified revenue targets over a

2.5 year period. As part of the agreement, Memscap will become the exclusive supplier of MEMS-based products to JDS Uniphase. Cronos, which is based in Research Triangle Park, NC, was bought by JDS Uniphase in April 2000 for about \$565 m. Even so, analysts believe that JDS Uniphase has got a good deal; laying off the 100 staff at Cronos and closing its two plants could have cost the company \$7–8 m.

TI process speeds SiGe manufacturing

Texas Instruments (TI) has developed a new SiGe complementary bipolar-CMOS manufacturing process, and the company claims that it is three times faster than other complementary bipolar processes. The process, which is called BioCom-III, integrates npn-type and pnp-type transistors and achieves a 50% noise reduction for operational amplifiers and other high-performance mixed-signal products.

"BioCom-III gives our engineers the ability to create an awesome array of high-performance products, which customers want but can't currently get," explained Gregg Lowe, senior VP of TI's high-performance analog business. "This technology and the ensuing products will strengthen our position in the high-performance analog market."

Using BioCom-III, TI plans to develop analog components that operate at 100 MHz with a distortion level of -100 dB , and will first make voltage-feedback and variable-gain operational amplifiers that outstrip the performance of today's amplifiers by two times. Final qualification is scheduled for the third quarter of this year and volume manufacturing on 200 mm wafers is expected by the end of 2002.

Atmel shuts down 8 inch wafer facility

Atmel has closed its manufacturing facility in Irving, TX, with the loss of 300 staff. Purchased in 2000 from Hitachi, the 8 inch wafer facility was due to manufacture CMOS flash memory ICs and RF circuits using an 0.18 μm SiGe BiCMOS process.

According to marketing manager Jeff Katz, the site was on pre-production status and had not made revenue shipments. Atmel says the move will allow the company to consolidate its manufacturing activity and reduce costs significantly.

"Given the current business environment, combined with today's advanced 0.18 μm and 0.13 μm processes, we simply do not need as many wafers to manufacture the same number of semiconductor chips," said Atmel's CEO, George Perlegos. "Even with the recovering demand that we expect, our remaining facilities will serve us well, and we will be well positioned to support the upturn when it arrives."

Agere to deliver SiGe ICs for hard disks

Agere plans to deliver the first SiGe-based preamplifier IC, a key component of hard-disk drives for computer data storage. The device is made using a 0.25 μm SiGe process, and is designed to operate at speeds four times faster than those of existing preamplifiers. Agere says that compared to current designs, the SiGe process provides a 50% reduction in preamplifier power consumption, a critical parameter for disk drives used in mobile applications and consumer products.

Equipment news

- EV Group, a manufacturer of MEMS and semiconductor wafer-processing equipment, has completed the installation and qualification of an automated SOI production wafer-bonding system at Analog Devices' SOI fab in Belfast, Northern Ireland.

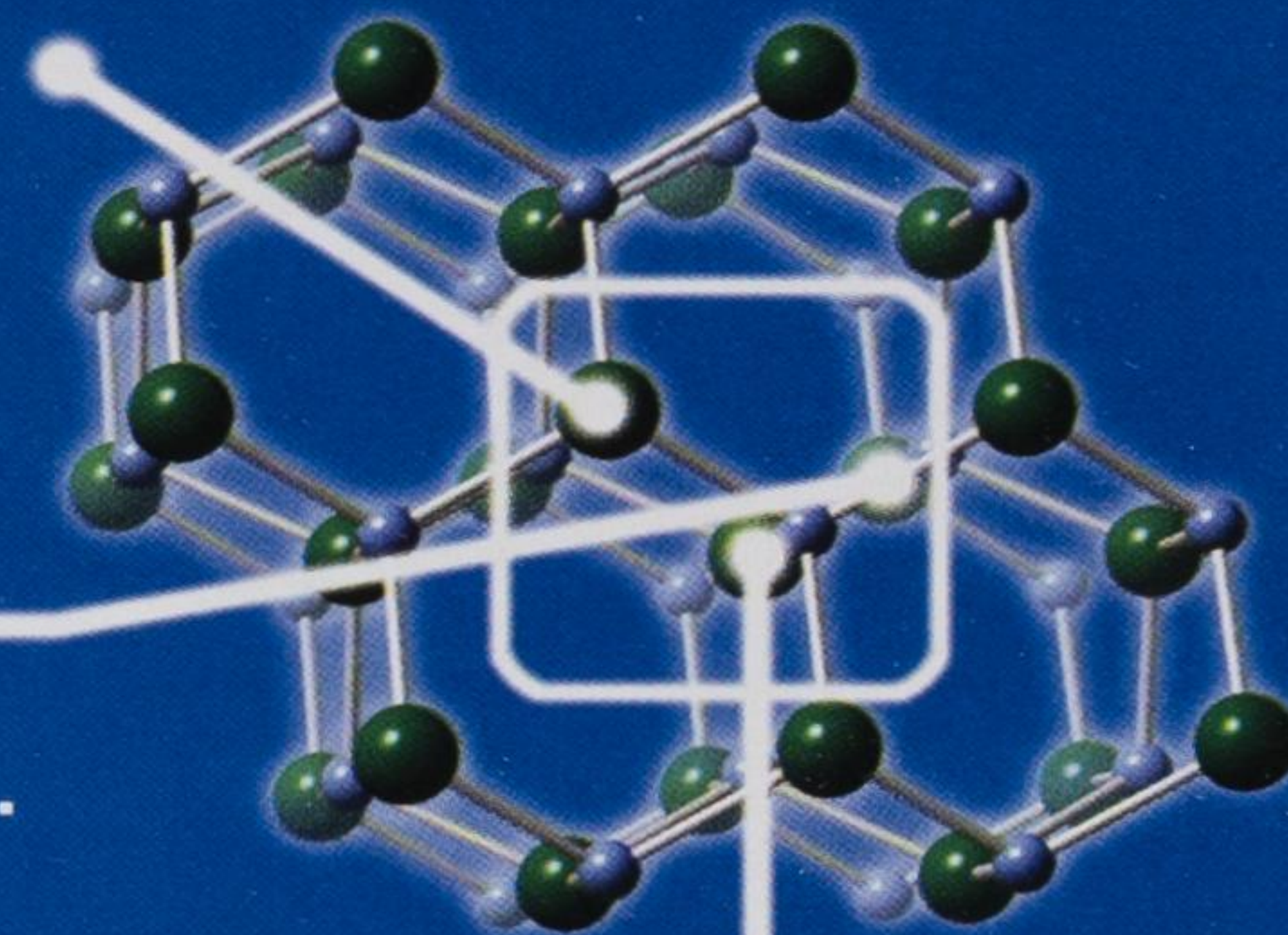
- MBE system manufacturer Thermo VG Semicon has introduced the EpiStar CV200, a new ultra-high-vacuum low-pressure CVD cluster tool designed to grow silicon and SiGe epitaxial structures.

Consortium to assess CVD tool

A new European Union project will assess the performance of a low-energy plasma-enhanced CVD (LEPECVD) tool from Unaxis Semiconductors. The evaluation of the tool will take place in Grenoble, France, at ST Microelectronics/LETI. Other participants in the LEPECVD 300 Semiconductor

Equipment Assessment (SEA) project are Motorola, Picogiga and Wacker. The new tool is intended for the high-throughput, low-temperature deposition of both silicon and SiGe layers. The system is fully automatic and can accept either 200 mm open cassettes or 300 mm wafers.

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.

7 Commerce Drive
Danbury, CT 06810

Tel: 203.794.1100
Fax: 203.830.2123

www.atmi.com
GaN@atmi.com





GEO, the world's largest supplier of Gallium...

is also your most reliable source for Gallium.

GEO Gallium is responsive, flexible and reliable... and we're geographically positioned to expeditiously serve all your needs no matter where you are. We hope that expands your perception of what GEO Gallium can do for you.



GEO Gallium

NORTH AMERICA

GARY EVANS

EMAIL: GARY.EVANS@GEOSC.COM

TEL: (514) 769.0300

FAX: (514) 769.8928

EUROPE (AND REST OF WORLD)

GERARD MARTIN

EMAIL: GERARD.MARTIN@GEOSC.COM

TEL: (33) 1.56.62.76.00

FAX: (33) 1.56.62.76.01

JAPAN

YOSHI NAKAGAWA

EMAIL: YOSHIMITSU.NAKAGAWA@AP.RHODIA.COM

TEL: (81) 3.35.83.6998

FAX: (81) 3.35.82.6255

GEO GALLIUM S.A.
17, RUE MARBEUF
75008 PARIS, FRANCE
(33) 1.56.62.76.00
FAX (33) 1.56.62.76.01
WWW.GEOSC.COM

GEO Gallium is a subsidiary of GEO Specialty Chemicals, Inc.

CMOS gets ready for high-speed wireless LANs

While GaAs and SiGe are the obvious choices for manufacturing devices for 5–6 GHz WLANs, lower noise figures achieved through the control of parasitics are keeping CMOS in the frame.



The Toshiba researchers believe that a CMOS approach is technically superior to Si BJT technology.

In recent quarters most areas of RF device production (both Si and III-V) have seen little to no growth, which is a reflection of flat cell-phone sales and push-back in the widespread implementation of 3G networks. However, there has been one RF market segment that has been experiencing explosive growth over this time – devices used for wireless local-area networks (WLANs). These devices are currently using the IEEE 802.11b standard (2.4 GHz) and are soon to migrate up to the IEEE 802.11a standard (5–6 GHz). Examples of rapid growth have been noted in the recent quarterly statements of many III-V device manufacturers, including RFMD which experienced quarterly sequential growth of 90%, to \$5.9 m, in sales of WLAN components. TriQuint also saw its WLAN product shipments double over the previous quarter and GCS has reported the production ramp-up of InGaP HBTs for WLAN applications.

Raising the standard

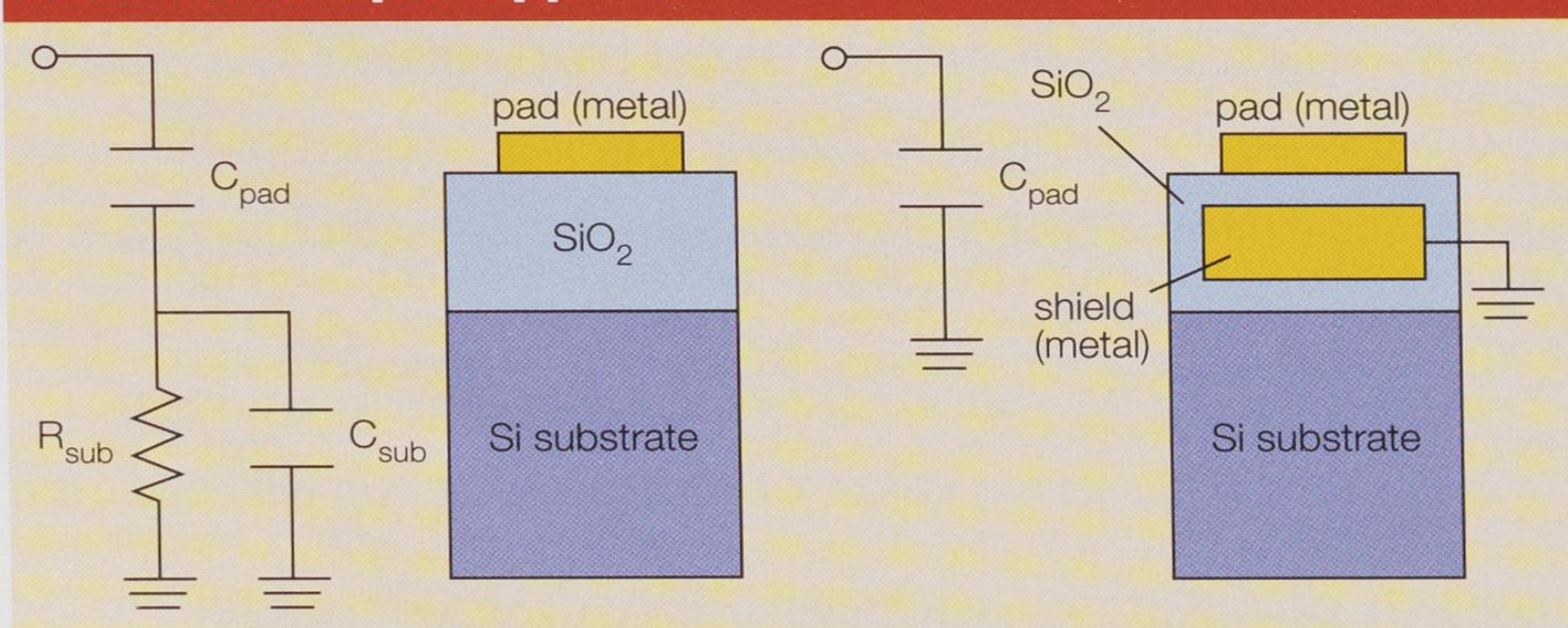
While the current standard (2.4 GHz) is ideally suited for wireless interconnections in small businesses and homes, the newer standard (5–6 GHz) targets larger environments, including entire office buildings and corporate and university campuses. One might not be surprised that there is stiff competition between Si and III-V devices in the 2.4 GHz market, but while it is often

assumed that at the 5.8 GHz regime the superior RF capabilities of III-V (and possibly SiGe) will dominate, this may not be the case.

An example of this is clearly demonstrated by researchers at Toshiba (Fujimoto *et al.*) who have developed a 7.0 GHz CMOS LNA exhibiting an NF of only 1.8 dB. Even in the Si world many still feel that a BJT offers superior performance to that of a MOSFET device, though most would concede that a CMOS device will be more cost-effective than a BJT. However, for LNAs, specifically when they are used in the front end of a WLAN receiver, minimizing noise is critical to the overall performance of the device. The main noise sources in MOSFETs are due to the thermal noise of the channel and the gate resistance. Advanced MOSFET processing, using low-resistance salicided gates, eliminates the gate-resistance issue, leaving thermal noise in the channel as the primary noise source.

In the case of the BJT, the noise sources are the thermal noise due to base resistance and the shot noise of the collector current. Unfortunately for the BJT, these noise sources are not independently controllable. Base resistance can be decreased by using larger geometries, but this requires more collector current to maintain a high f_t , which in turn causes more shot noise in the collector. Therefore, one source of noise is typically traded off for another, making it very difficult to reduce the overall noise characteristic. Because of this limitation in BJTs, the Toshiba researchers believe that a CMOS approach is technically superior to that of a Si BJT, and so have focused on this device for 802.11a WLAN applications.

The shielded pad approach



The conventional pad, shown on the left, has a resistive component due to the Si substrate. The resistance in the equivalent circuit causes signal power loss and increases noise. Using shielded pads, as shown on the right, removes the resistive component which leads to a lowering of the signal loss and noise.

Noise reduction

The parasitic resistance exhibited by the lossy Si substrate at high frequencies not only consumes signal power, but also generates thermal noise. The methods used to minimize this effect include the use of SOI substrates, as well as high-resistivity Si substrates. While both methods improve RF performance, they also increase the manufacturing costs, reducing one of the major advantages of using CMOS in the first place.

Rather than utilizing substrate modifications to reduce noise, the Toshiba researchers have combined

The shielded pad approach improved gain by 4 dB and reduced noise by another 0.8 dB.

a standard 0.25 μm CMOS approach with two noise-reducing design modifications. The first uses a cascode configuration implemented with a dual-gate MOSFET. In a MOSFET structure, a parasitic diode exists at both the source and drain, causing signal loss into the Si substrate as well as a volume in which thermal noise can be generated. Using the dual-gate approach, where the area represented by the drain of the first MOSFET is shared by the area represented by the source of the second MOSFET, the effect is to reduce the overall area of the parasitic diodes (when compared with using two single-gate MOSFETs), and therefore the overall noise. Circuit simulations comparing the dual-gate to the single-gate approach indicate that the dual-gate-based LNA attains 1.2 dB higher gain and a significant 0.7 dB lower NF.

Pad shielding

The second modification made to reduce noise and to improve output power is to shield the pads of the device. It was observed that under 7 GHz operation the Q of the inductors, which were fabricated in low-resistivity thick metal above relatively thick insulating layers, had a value of 10. The pads, which are almost directly on the Si substrate (with a thin isolating layer beneath them), had a Q value of 5, indicating much

greater coupling to the substrate.

In order to eliminate this effect a shielded pad approach was implemented, in which an isolated metal layer encapsulated with CVD SiO_2 is placed beneath the pad and grounded (see figure). This shield completely isolates the pad above it from the Si substrate. The shielded pad approach improved gain by 4 dB and reduced noise by another 0.8 dB.

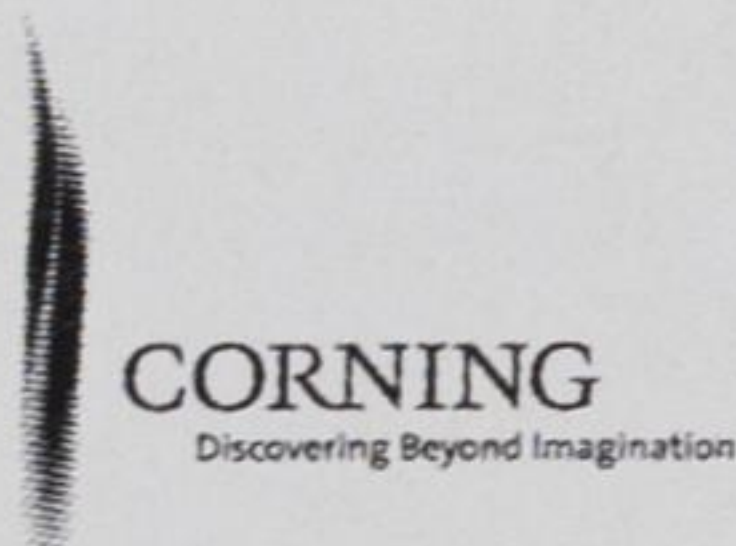
When both of these design modifications were implemented, the resulting 7 GHz LNA, operating with a 2.0 V power supply and consuming 6.9 mA of power, showed an increased output power of 5.2 dB and a reduction in NF of 1.5 dB. This resulted in a device with an overall gain of 8.9 dB and a NF of 1.8 dB. Such characteristics make this device more than suitable for WLAN applications at 5–6 GHz, and because it is fabricated in a basic CMOS process, with the only real processing change being the shielded pads, it will be able to maintain low processing costs. This combination of low cost and high performance represents very strong competition to any III-V solution in the rapidly growing WLAN market, and clearly demonstrates that CMOS can be a real player in the 5–6 GHz regime. ●

Further reading

Fujimoto *et al.* 2002 *J. Solid State Circuits* 37(7) 852.

AUCTION

www.henrybutcher.com



By Order of Corning O.T.I. S.p.A.

ONLINE AUCTION SALE

Wednesday 25th September 2002



OPTO-ELECTRONIC MANUFACTURING & TEST EQUIPMENT

(Most items 2001, As New, Still Crated) - Location: Milan, Italy

Crystal Growth: RIBER Molecular Beam Epitaxy System of III-V Compound (Unused, 2000/2001)

Wafer Fab: UNAXIS 'BAK 640C' Deposition of SiO on Gas (As New Crated); Custom Hi-Vac System with Two Turbo Pumps and Getter; (2 off) SSEC '2300E' Parallel Seam Sealers (As New Crated); LOGITEC 'LP50' Auto Polisher (As New Crated); (3 off) ATV 'SRO702' Programmable Inert Gas Reflow System (As New Crated); FRONTIER 'FSM 128' Film Stress Measurement System (As New); (2 off) Acid / Solvent Wet Benches; (3 off) TERRA UNIVERSAL Dry Storage Boxes; (2 off) NEWPORT Antivibration Workstations (As New Crated); (4 off) VARIAN L947 Leak Checkers (As New)

Bonders: CAMMAX 'DB600' Pick and Place bonder (As New Crated); WESTBOND '7372B' Die Bonder (As New Crated); WESTBOND '7200-AT12' Bonder + UNITEK Phasemaster IV DC Welder

Lasers & Welders: (3 off) LUMONICS 'IPEX-848' lasers (2000); COHERENT Innova Sabre Fred laser; UNITEK Linear DC Resistance Welding Power Unit (As New Crated)

980nm Laser Diode Test Systems & Burn in Racks: (15 off) NEWPORT Laser Diode Burn-In Racks, 128 Channels (As New Crated); (5 off) NEWPORT Laser Diode Burn-In Racks, 64 Channels (As New Crated); 980nm pump laser test station; Rework Station

Optical Test & Measurement: (5 off) GRAFTEK Thermal characterisation benches; (6 off) PHOTON Inc. 'LD8900' Goniometers (As New Crated); (4 off) AGILENT 'HP4242B' Modular DC source monitors with plug-ins (As New Crated); (25 off) KEITHLEY '2510' TEC Controllers (As New Crated)

Microscopes: (As New, Crated) (1 off) LEICA 'INM100' Microscope; (1 off) LEICA 'DH RME HC Motor'; (4 off) LEICA 'DM RM HC' Microscopes; (8 off) LEICA 'MZ6'; (1 off) LEICA 'MS5'

For further information please contact: corning@henrybutcher.com



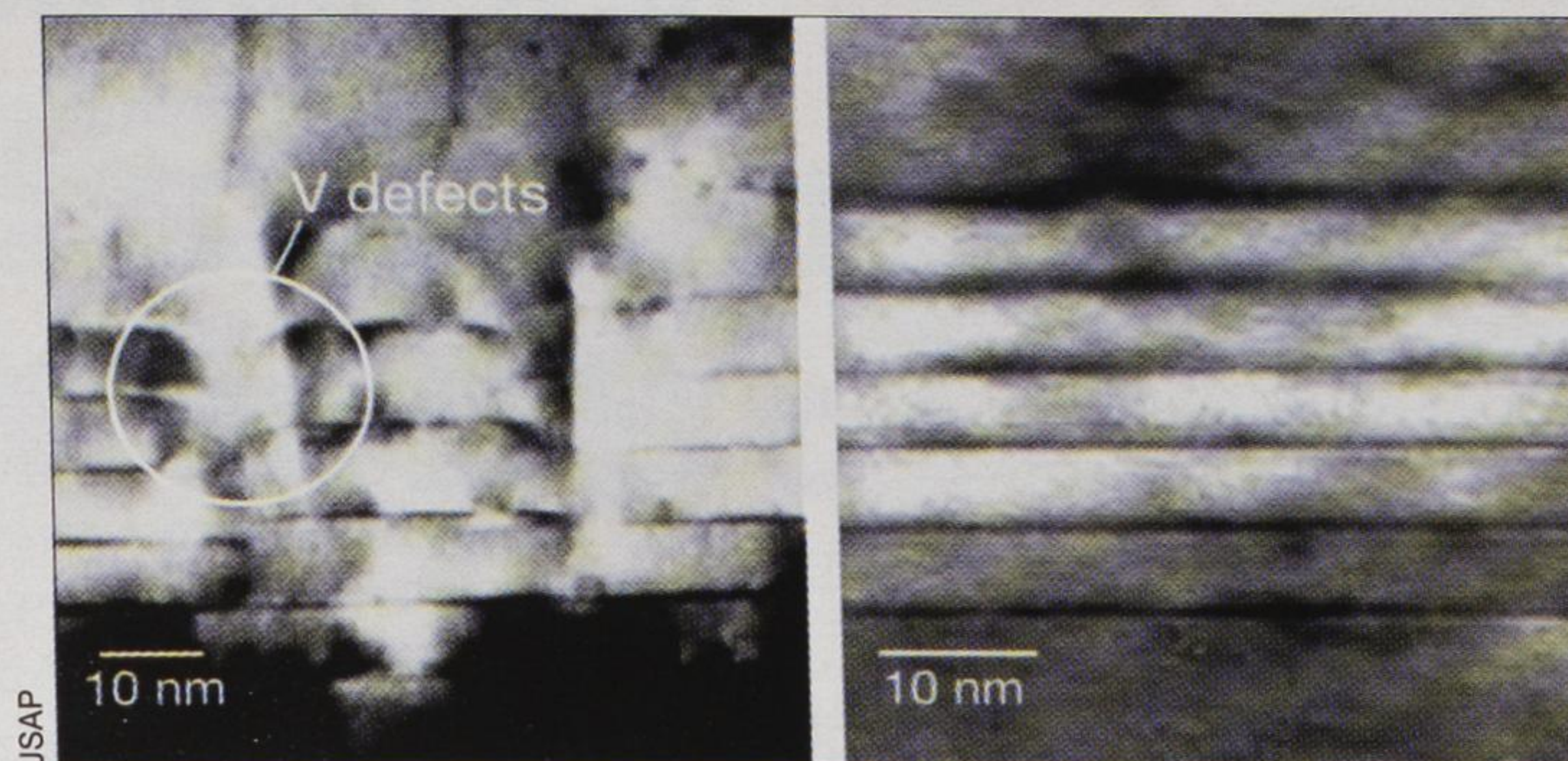
HENRY BUTCHER

Tel: + 44 (0) 20 7405 8411 Fax: + 44 (0) 20 7405 9772

Email: corning@henrybutcher.com

Delta doping lowers operating voltage

A high Si doping concentration in thick n-type GaN contact layers is essential for providing low-resistance layers that ensure lateral current spreading and low-voltage operation in GaN-based LEDs. However, it is well known that cracks occur when a thick GaN:Si layer is doped to concentrations greater than 5×10^{18} atoms/cm³. The high series resistance of a GaN:Si layer doped below 5×10^{18} atoms/cm³ can be a significant contributor to the LED operating voltage. Although there are reports of Si delta doping of GaN layers to



Cross-section TEM images showing the six-period MQW active region for the LED grown with a uniformly doped contact layer (left) and the Si delta-doped contact layer (right).

increase doping concentration, delta doping to improve lateral current spreading in GaN-based LEDs has been reported for the first time by researchers at Chonbuk National University in Korea (*Jap. J. Appl. Phys.* 2002 **41**(Pt. 2, 7A) L761).

The researchers grew devices with three types of contact layer: a contact layer with a Si delta-doping concentration of 9×10^{18} atoms/cm³, an undoped layer, and a uniformly Si-doped layer with a

concentration of 3×10^{18} atoms/cm³. TEM was used to study the effects of these doping schemes on the crystal quality of the device layers. The densities of threading dislocations were about 4.4×10^8 , 8×10^8 and 1×10^8 /cm² for undoped, uniformly Si doped, and Si delta-doped GaN layers, respectively. In the devices with uniformly doped contact layers, the InGaIn/GaN MQW regions had V-shaped defects and stacking faults, as shown in the figure.

The operation voltages and the dynamic resistances of the Si delta-doped LEDs and uniformly doped LEDs were 3.65 V and 27.0 Ω , and 3.94 V and 32.3 Ω at 20 mA, respectively. The leakage current at a reverse bias of -10 V was 2.8 mA for the delta-doped LEDs and 29.0 mA for uniformly doped LEDs. The researchers think that the operation voltage reduction is related to the high Si concentration and the improvement in crystalline quality due to the Si delta-doping in the contact layer.

QD laser designs tested by UK research team

A group of researchers from the universities of Sheffield and Cardiff in the UK has made a comparative study of the characteristics of two very different quantum-dot (QD) laser designs (*Appl. Phys. Lett.* 2002 **81**(1) 1). The two device designs consisted of multiple InGaAs QD layers grown closely within a single, wide GaAs QW (design A), and multiple QD layers confined within individual, narrow GaAs/AlGaAs QWs (design B). A significant degree of QD vertical alignment was seen in design A, with the possibility of electronic coupling between QD layers. These coupling effects are believed to be negligible in design B.

Both designs demonstrated extremely low threshold current density (J_{th}) at room temperature, with design B exhibiting superior performance (lowest J_{th} of 47 A/cm²) as a result of the increased carrier confinement provided by the AlGaAs barriers surrounding each QD

layer. However, at low temperatures ($T < 150$ K) the situation was very different and design A yielded a significantly lower J_{th} , indicating more efficient inter-dot carrier transport than design B.

Gain spectra for the two designs were determined at a range of injection currents. For design A, a narrow distribution of dominant lasing modes was observed at all currents above the threshold. This behavior is consistent with that seen in conventional QW and bulk lasers, where the gain of non-lasing wavelengths remains fixed as injection current increases above the threshold, giving a homogeneously broadened gain spectrum. For design B, lasing was observed over an increasingly broad range of wavelengths as the injection current was increased above the threshold. This is believed to be the first direct observation of an inhomogeneously broadened gain spectrum.

The researchers suggest that low-temperature carrier transport between dots in different layers is enhanced by the close proximity of dot layers in the first design, giving rise to a narrow distribution of lasing modes in design A. In design B carrier transport is hindered by the incorporation of quantum barriers between dot layers.

AlN/AlGaIn superlattices generate efficient UV LEDs

Thick, high-quality AlGaIn layers are essential to the development of efficient UV LEDs. Typically, GaN buffer layers are used for the growth of AlGaIn onto sapphire. However, using GaN buffers in UV LED structures reduces the light extraction efficiency. A research team at the University of South Carolina has reported the successful growth of high-quality AlGaIn layers using AlN/AlGaIn superlattice buffer layers (*Appl. Phys. Lett.* 2002 **80**(19) 3542). The AlGaIn layers had Al-mole fractions of 20%, thicknesses exceeding 2 μ m and were crack-free. Systematic high-resolution X-ray diffraction, TEM and AFM studies showed that the AlN/AlGaIn superlattices not only eliminate cracking through strain management, but also significantly

decrease the threading dislocation density by acting as effective dislocation filters (*Appl. Phys. Lett.* 2002 **81**(4) 604).

With the insertion of a 10 period superlattice, the threading dislocation density was reduced from 4.9×10^{10} /cm² to 6.8×10^8 /cm². The resulting high-conductivity thick AlGaIn layers are ideal n⁺-buffers for deep-UV LEDs because they significantly improve current spreading and light emission efficiency due to reduced defects. The group successfully fabricated $200 \times 200 \mu$ m² LEDs with emission at 325 and 285 nm, and output powers as high as 7 and 0.25 mW, respectively. According to the group, the LEDs emit with the highest powers reported to date at these emission wavelengths.

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

AlN interlayers expand heterostructure design

High-mobility 2D electron gases (2DEGs) can be realized in the AlGaN/GaN material system without any doping because of the piezoelectric and spontaneous polarization effects inherent to the III-nitrides grown in the (0001) direction. Stacia Keller and colleagues from the University of California, Santa Barbara, have explored the heterostructure design opportunities related to these effects when using AlN interlayers in GaN heterostructures (*Appl. Phys. Lett.* 2002 **80**(23) 4387).

GaN/AlN/GaN structures were investigated, where the AlN layer thickness was kept to 0.5–1.5 nm so that no 2DEG was observed for undoped structures. 2DEGs were then created through Si modulation doping in a 30 nm thick GaN cap layer. This allowed the effect of the AlN layer thickness and the Si doping concentration on the properties of the 2DEG to be studied.

When the AlN interlayer thickness was increased from 0.5 to 1 nm, the electron mobility increased from 720 to 1250 cm²/Vs at 300 K and 6400 to 12000 cm²/Vs at 77 K. The highest electron mobility value of 13800 cm²/Vs at 77 K was measured for samples with 1.25 nm thick AlN interlayers and a Si delta doping of 5×10^{12} cm⁻². The formation of the 2DEG was caused by the large polarization fields that exist in the pseudomorphically strained AlN interlayers. The polarization fields resulted in an upward shift of the energy bands in the GaN cap relative to the GaN layer beneath the AlN interlayer. As the thin AlN interlayers are transparent to electrons, the structures can also be thought of as GaN-GaN pseudo-heterojunctions with polarization-induced discontinuity.

Novel AlGaN/GaN HFET sets new standards

A collaborative effort between groups led by Russell Dupuis at the University of Texas and Milton Feng at the University of Illinois has led to an innovative high-performance delta-doped AlGaN/AlN/GaN HFET (*Elec. Lett.* 2002 **38**(9) 428). The epitaxial heterostructures were grown by low-pressure MOCVD, with the best performance from devices grown on semi-insulating 4H SiC substrates. The structure consisted of a 100 nm AlN buffer layer, 3 µm undoped GaN, 1 nm AlN barrier layer, followed by a 30 nm Al_{0.2}Ga_{0.8}N donor layer with delta doping after 5 nm of growth. Hall measurements taken at room temperature showed an electron mobility of 1058 cm²/Vs and a sheet carrier density of 2.35×10^{13} cm⁻². Delta doping combined with a binary barrier was used to improve the current carrying capabilities of the HFET. Devices with 0.25 µm gate lengths exhibited excellent output and transfer characteristics, yielding a maximum current density of 1.5 A/mm (at $V_g = +1$ V) and a peak transconductance (g_m) of 240 mS/mm. Excellent high-frequency characteristics were also seen with f_t and f_{max} values of 50 and 130 GHz, respectively.

Since publication of this data, further improvements to the device performance have been made. Devices fabricated with gate lengths of 0.15 µm have exhibited the highest drain current and transconductance values to date for nitride HFETs. A maximum current density of 1.82 A/mm (at $V_g = +1$ V) and a peak transconductance of 331 mS/mm have been recorded, and f_t and f_{max} have increased to 70 and 115 GHz, respectively. All reported data has been on unpassivated devices and surface passivation is expected to lead to higher performance levels.

CONTENTS

Strained silicon keeps CMOS on course

39

The future of SiGe beyond HBTs

45

Chip manufacturers look to wafer bonding

49

Strained silicon joins the drive to keep CMOS chips on course

The huge costs of scaling CMOS devices according to Moore's Law have left the silicon industry at a crossroads. **Mayank Bulsara** of AmberWave Systems describes how strained silicon technology will be able to push performance further without the need for big investment.

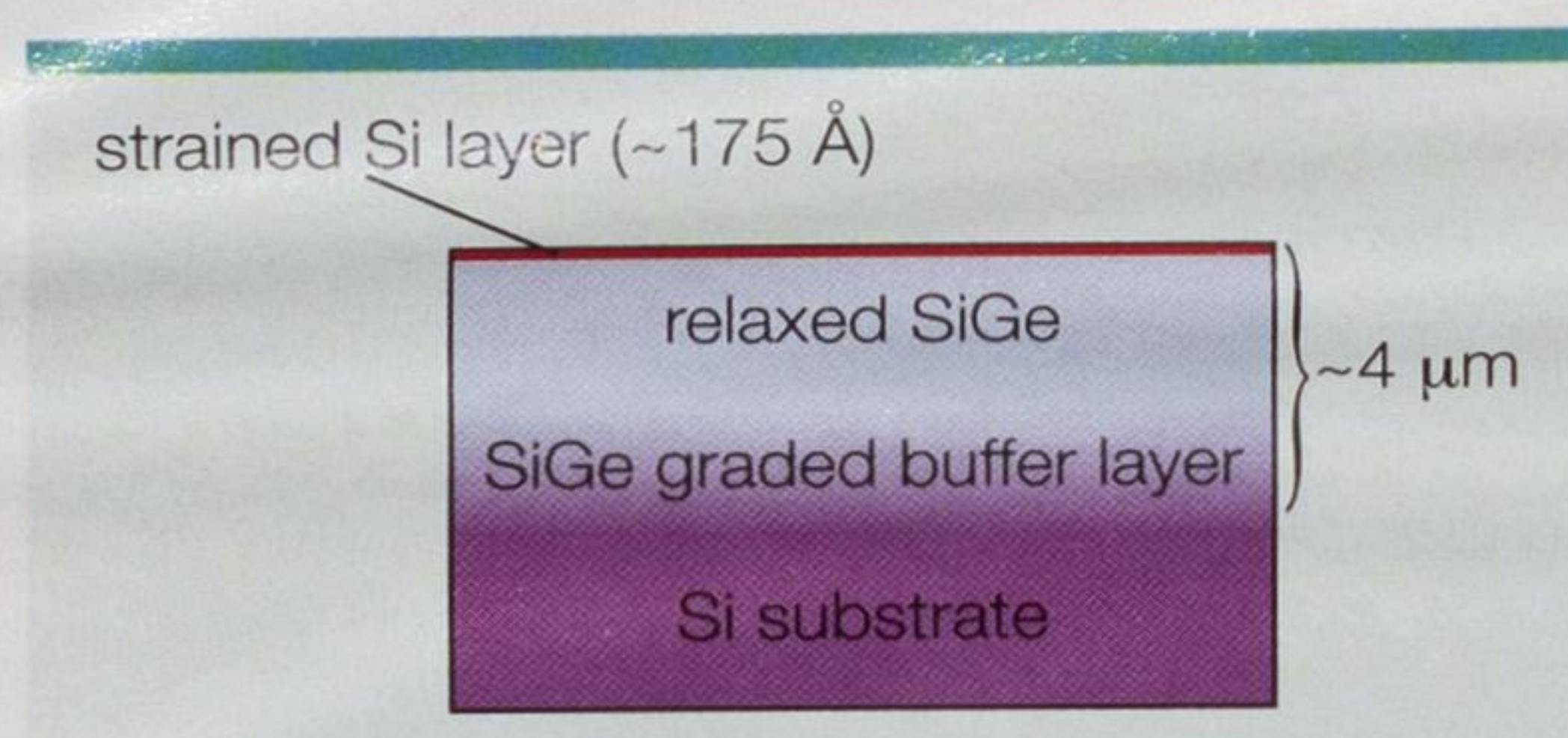


Fig. 1. A schematic of a basic strained Si heterostructure. The three basic elements are the bulk Si substrate, the epitaxial SiGe buffer layer, which creates a larger lattice constant, and the epitaxial tensile strained Si film, which provides for greater transistor performance.

The 30 year run of the semiconductor industry has been driven by the tremendous scientific and manufacturing work that has centered on Si CMOS technology. The technological improvements of CMOS chips are best exemplified by Moore's Law, which essentially predicts that transistor size scales down every 18 months, allowing for greater performance per transistor and increased transistor packing density. Both of these factors provide greater functionality in CMOS chips, which is beneficial to the consumer.

An implicit foundation of Moore's Law is that the performance benefits and technological innovations do not cost more than consumers are willing to pay (i.e. the economics of CMOS scaling must make sense). For 30 years the use of transistor scaling as the provider of greater system performance, without other significant perturbations in CMOS manufacturing, has made a variety of companies in the Si industry incredibly successful. However, the economics of CMOS scaling

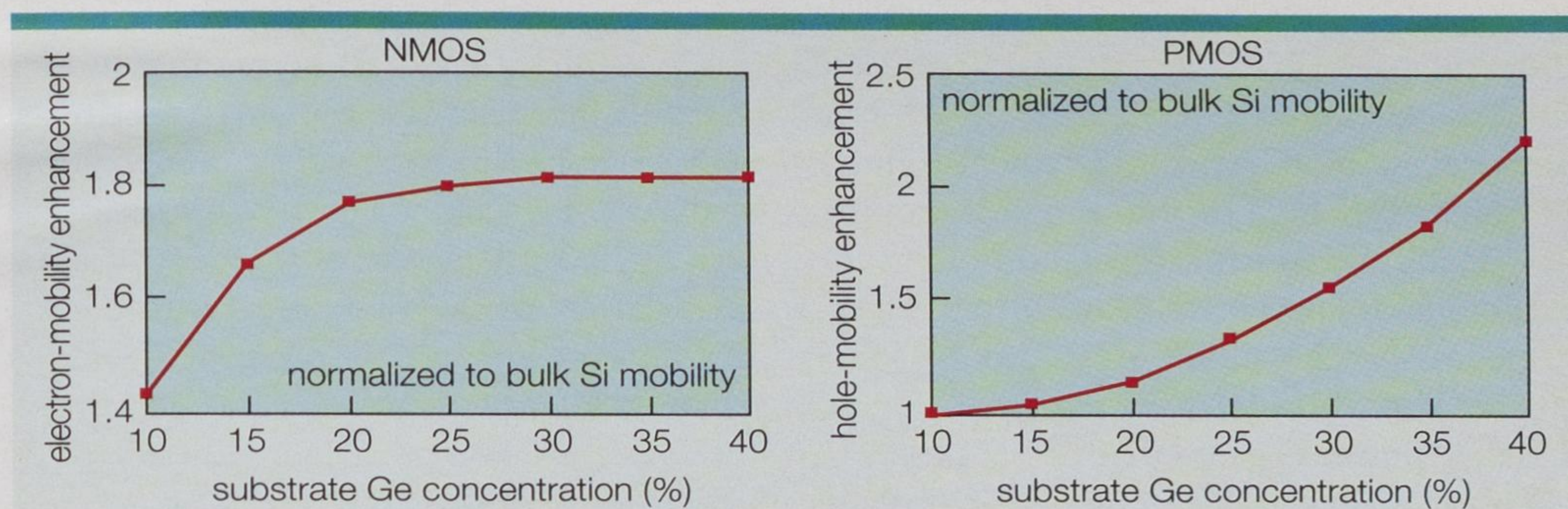


Fig. 2. Charts showing the relative mobility improvements of electrons (left) and holes (right) in strained Si compared with bulk Si as a function of Ge content in the underlying SiGe buffer. Improvements in mobility ranging from 1.8–2.2 times are available for both electrons and holes depending on how the strained Si heterostructure is engineered.

are no longer valid for many industry leaders. This is evidenced by the narrowing of gross margins, limited growth in such mainstay semiconductor industries as the PC microprocessor industry, and the increasing number of new joint ventures – with their associated cost-sharing models – for the construction of next-generation fabs.

New materials, higher performance

Perhaps the most telltale sign of the changing Si industry is that new materials are being taken seriously as replacements for SiO₂ as a gate dielectric and isolation layer, for Al as a metallization layer, and for Si as a base substrate. These materials are required to continue the steady progression of CMOS technology. The most interesting and long reaching of these material changes involves the Si substrate itself. Si has been the workhorse of the semiconductor industry for some time, but its fundamental properties in terms of carrier mobility and associated intrinsic performance are limited. These limitations are

now being exposed for various applications and the base Si substrate material is being replaced for some devices.

Silicon-on-insulator (SOI), which improves chip performance via capacitance reduction, has been introduced in products and is on the roadmap of most major Si chip companies. Single-isotope Si substrates with improved thermal conductivity are becoming relevant for highly integrated CMOS chips where heat dissipation is a concern. Going to the greatest extreme, integrated III-V devices on Si substrates have created tremendous interest, even though the direct application of such technologies may not take place for many years.

On the immediate horizon, one of the most promising alternatives for the replacement of bulk Si substrates in the CMOS industry is strained Si technology.

Strained Si technology enables improvements in CMOS performance and functionality via replacement of the bulk, cubic-crystal Si substrate with a Si substrate that contains a tetragonally distorted, biaxially strained Si

HETEROSTRUCTURES

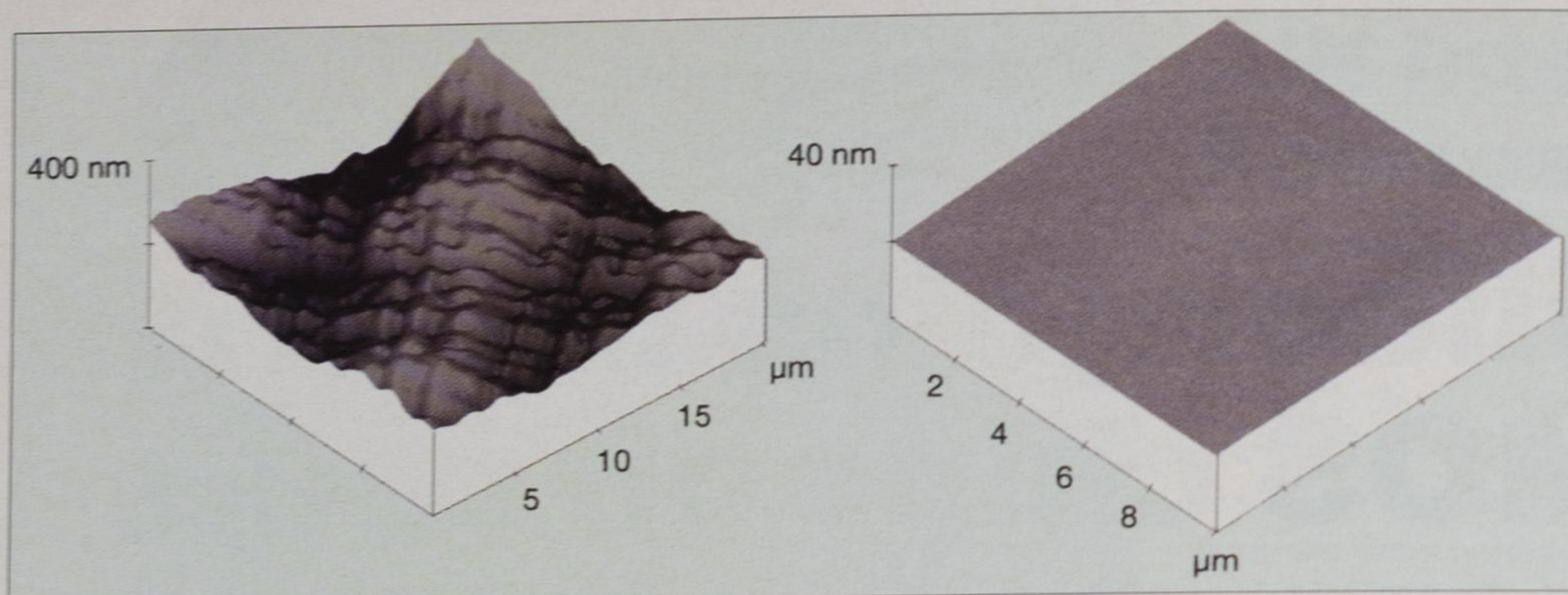


Fig. 3. AFM plots showing the difference between a standard SiGe graded-layer process with pronounced crosshatching (left), versus that of a multi-step epitaxial process that includes a CMP step (right). Note that without a CMP process the structure exhibits greater than 5 nm roughness, which is much too severe for state of the art lithographic techniques.

thin film at the surface. Due to changes in its crystalline structure (i.e. its symmetry is different due to its strain state), the strained Si film has electronic properties that are superior to those of bulk Si. Specifically, the strained Si film has greater electron and hole mobilities, which translate into greater drive current capabilities for NMOS and PMOS transistors, respectively. This increased transistor drive current can be traded off for a reduction of dynamic power consumption.

The ability to tailor the performance of strained Si technology for each specific application will have a far-reaching impact, from high-speed products like microprocessors and field-programmable gate arrays, to the low-power products used in wireless communications and other mobile devices.

Strained Si fabrication

The key to enabling high-performance devices is the fabrication of a low-defect-density strained Si film. Growing a Si layer on a SiGe film, which has a larger lattice constant than Si, generates the strained Si heterostructure. The challenge faced when forming this heterostructure is the engineering of the lattice constant of the SiGe film. Done improperly, the SiGe film can be very defective and the subsequent strained Si film will inherit the defect morphology of the underlying SiGe. The development of SiGe relaxed graded-layer technology by Eugene Fitzgerald of MIT provided an effective method for engineering the lattice constant of the SiGe film, and produced the first demonstration of high electron mobility in strained Si heterostructures (Fitzgerald *et al.*).

The sequence for fabrication of a strained Si heterostructure involves three steps. First a SiGe relaxed graded layer is formed to engi-

neer the lattice constant of the SiGe alloy. The relaxed SiGe graded layer is an epitaxial thin film with a sequence of layers that have a gradually increasing Ge content (typically the profile is linear) up to a final Ge composition. Next a constant composition Ge film is grown to spatially separate the subsequent strained Si film from the misfit dislocations that are intentionally introduced in the SiGe relaxed graded layer. The final step is the deposition of the Si film, which is placed in a state of biaxial tension as it conforms to the lattice of the constant-composition SiGe layer. Figure 1 shows a schematic of the basic elements of a strained Si heterostructure.

Once a low-defect-density SiGe film can be fabricated, the strained Si heterostructures can be tailored to enable various properties. One of the key determining factors for the performance enhancement available with strained Si technology is the amount of strain imparted to the strained Si thin film, which is determined by the Ge content in the underlying SiGe film.

Figure 2 shows that the electron- and hole-mobility enhancements increase with increasing strain (Currie *et al.*, Leitz *et al.*). Using a higher Ge fraction in the underlying SiGe layer increases the degree of strain in the Si. It should be noted that various reports have erroneously implied that strained Si does not provide hole-mobility/PMOS device enhancements. In fact, hole-mobility enhancement in strained Si has a more complicated behavior, but can extend beyond the electron-mobility enhancement achievable in strained Si if enough strain is imparted to the film.

Although working with higher Ge content in the SiGe layer increases the performance characteristics of the NMOS and PMOS transistors, the tradeoff is that the strained

Si film needs to be thinner due to critical thickness constraints. Thus, the engineering of strained Si heterostructures with higher Ge content provides less latitude for substrate manufacturing and, as will be discussed later, device processing.

Substrate supply

Strained Si technology provides great performance benefits for CMOS, but as with any new technology that is introduced to a manufacturing infrastructure, the ease with which it is adopted is very dependent on the number and severity of changes the new technology requires. In tandem, the manufacturing cost of the technology determines its rate of acceptance in the industry.

For strained Si technology, the key question for many manufacturers is whether the substrate technology can be taken from research laboratories, which typically use UHV epitaxy techniques, to large-scale production, which requires high throughput, low-cost techniques. Strained Si processes have now been demonstrated and devices have been produced using industry-standard low-pressure Si epitaxy systems, such as the ASM Epsilon and Applied Materials' Epi Centura platforms, and unique systems still under development such as the Aixtron G3 platform.

Although epitaxy and SiGe graded-layer processes are at the core of strained Si technology, the manufacturability of devices is largely dependent on a proprietary chemical-mechanical polishing (CMP) process introduced between the epitaxy of the relaxed SiGe buffer layer and the strained Si.

The ideal SiGe graded-layer epitaxial sequence typically results in a rough, cross-hatched surface morphology with a lateral periodicity of the order of 1 μm , and an RMS roughness greater than 4 nm. This rough wafer surface severely impacts the manufacturing of integrated circuits with state of the art ($<0.5 \mu\text{m}$) lithography requirements, in terms of yield, in-line metrology and photolithographic reliability. An intermediate CMP step is therefore paramount to enable the manufacturability of strained Si circuits in modern manufacturing facilities.

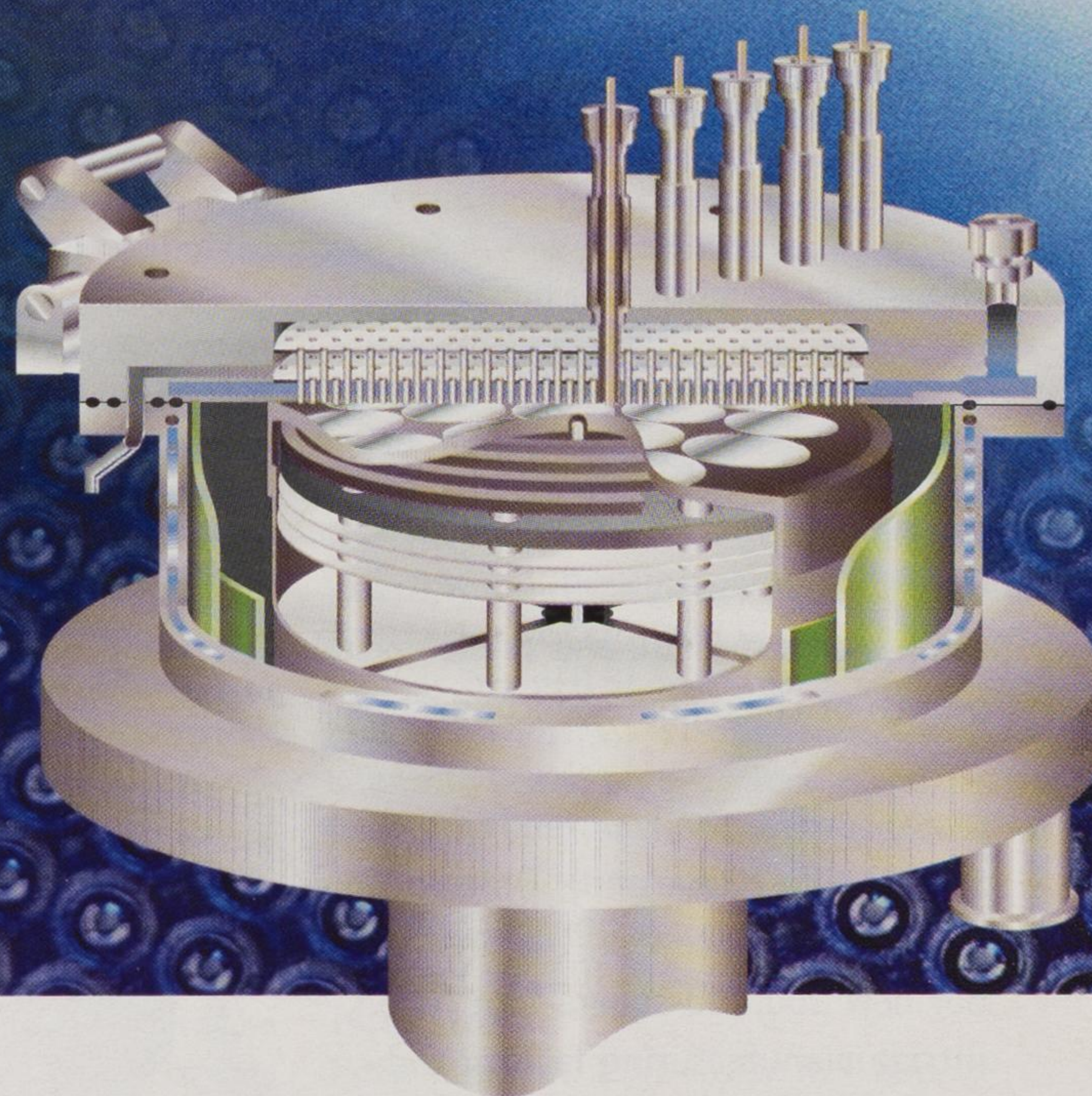
The CMP step eliminates the crosshatched SiGe surface roughness, producing strained Si wafers that largely appear like bulk Si to fabrication toolsets. Figure 3 shows AFM images of strained Si wafers with and without an intermediate CMP step.

An important point to mention is that the equipment and processes used in standard

CCS MOCVD Systems

Your future...
is our business

- World leading supplier of MOCVD solutions
- Unique Close Coupled Showerhead (CCS) Technology
- Truly scalable reactor concept
- A range of Production and R&D systems available
- Low cost of ownership
- High yield
- Proven for a wide range of compound semiconductor materials
- Global service and support network



Thomas Swan Scientific Equipment Ltd

Anderson Road, Buckingway Business Park, Cambridge, CB4 5FQ. UK. Web: www.thomasswan.co.uk

Tel: +44 (0) 1223 519444 Fax: +44 (0) 1223 519888 email: sales@thomasswan.co.uk

A member of the AIXTRON group of companies



We've gone to great lengths to serve you better.



Cleveland

Wales

Japan

Thousands of miles and hundreds of thousands of square feet to be exact.

That's so Advanced Ceramics Corporation can provide you with a worldwide capability for Boralloy® Pyrolytic Boron Nitride components for MBE and single crystal growth of compound semiconductors.

Distancewise, the trail leads from Strongsville (Cleveland), Ohio to Wales and Japan. Spacewise, the area includes our new 300,000-square-foot boron nitride manufacturing facility and a new world headquarters building in Strongsville, Ohio.

Why? So you won't have to go to great lengths to order products from Advanced Ceramics Corporation.



ISO 9002 Certified

Advanced Ceramics
CORPORATION™

Advanced Ceramics Corporation

Learn more at www.advceramics.com

U.S.: Tel: 440-878-5700 • Fax: 440-878-5928

United Kingdom: Tel: (44) 01446 773826

Fax: (44) 01446 773932

Japan: Tel: 03-5379-8261 • Fax: 03-5379-8404

Vapor Deposited Products:

Boralloy® Pyrolytic Boron Nitride crucibles, boats, tubes and plates for MBE and compound semiconductor crystal growth. Also available Boralectric® heating elements/electrostatic chucks, PyroShield Aluminum Nitride coatings and Metal Carbide coatings for graphite and Pyrolytic Graphite.



epitaxial Si wafer processing can be readily implemented for the manufacture of strained Si substrates – no new manufacturing infrastructure is required. This allows for a cost basis that can provide 200 mm strained Si substrates in high volume (> 1,000,000 wafers per year), with costs in the vicinity of \$200 per wafer. In comparison, standard p– on p+ 200 mm epitaxial Si wafers cost approximately \$80 each, and 200 mm SOI wafers currently cost more than \$200 each. Epiwafer manufacturer IQE Silicon Compounds has announced the commercial availability of strained Si substrates, based on technology licensed from AmberWave Systems, that incorporate the intermediate CMP step described above (*Compound Semiconductor* May 2002 p15).

CMOS production and circuit design

Strained Si technology offers its greatest rewards to the CMOS manufacturers who can enable greater performance and flexibility without increasing costs, and to the circuit designers of products that demand the latest CMOS capabilities at reasonable cost. However, just as Moore's Law for transistor scaling is only as good as its economic foundations, strained Si technology must fit within, and at times enhance, the cost framework of standard CMOS product cycles.

Once wafer costs are addressed, the next consideration for this technology is the ease of fabrication of strained Si devices and circuits. The typical sequence of steps for the fabrication of CMOS circuits upon strained Si substrates is unchanged, which means that no equipment changes or specialty processes are required. However, there are specific modules that need to be updated, as the material properties of the strained Si substrate are somewhat different. For example, dopant activation and dopant diffusion characteristics are altered due to the presence of Ge in the substrate. This results in different thermal budgets for strained Si technology. Overall, the process changes that are necessary can be simpler than those required for moving from one node of standard CMOS technology to the next (e.g. moving from a 0.18 μm technology node to a 0.13 μm node). An additional benefit is the fact that no new equipment is required with strained Si technology.

Perhaps the one feature of strained Si technology that distinguishes it most from bulk Si technology is the fact that the thin film of strained Si, which is limited in thickness due to critical thickness constraints, cannot be stripped indiscriminately. This limits the use

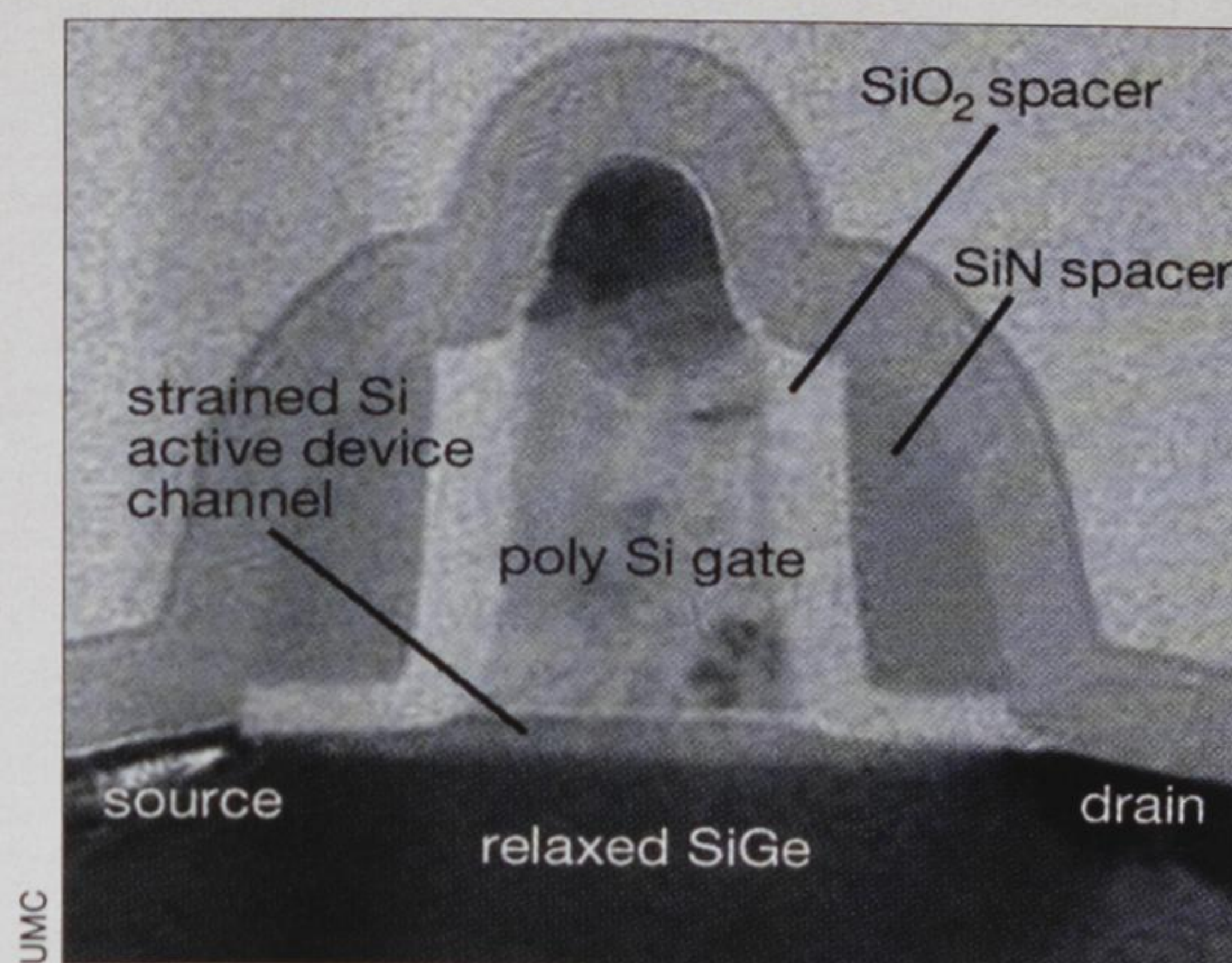


Fig. 4. A cross-sectional electron micrograph of a strained Si transistor fabricated by UMC. The fabrication sequence used 130 nm node Si technology, and the physical gate length for the transistor shown is 90 nm.

The equipment and processes used in standard epitaxial Si wafer processing can be readily implemented for the manufacture of strained Si substrates.

of aggressive cleaning strips and other legacy processes that are commonplace in the Si industry. In practice, as long as approximately 5 nm of strained Si remains at the end of the processing sequence, the transistors will exhibit optimal performance (Currie *et al.*).

With these constraints in mind, strained Si transistors have been fabricated at aggressive manufacturing nodes. Figure 4 shows a cross-sectional image from an electron microscope of a strained Si transistor fabricated with 130 nm Si CMOS technology by United Microelectronics Corporation (UMC) in Taiwan. UMC is the second largest Si foundry service provider in the world, and is developing strained Si devices through a technology partnership with AmberWave Systems. UMC presented the results of the jointly developed strained Si technology at its June technology symposium in Santa Clara, CA. Here, the company showed drive current enhancements of 43% over bulk Si NMOS.

Performance expectations

Depending on the extent of transistor engineering, it is anticipated that the first generation of strained Si technology in products will exhibit approximately 30% drive current

enhancement for NMOS transistors, and 5–10% drive current enhancement for PMOS transistors. The stated enhancements can be readily incorporated into existing mask sets and designs, prolonging the lifecycle of circuit designs, which cost tens of millions of dollars to create and validate. Also, with limited redesign to take full advantage of the transistor enhancements, product roadmaps can be extended even further.

The infrastructure for design does not change with strained Si technology, so circuit designers can expect SPICE models and design libraries similar to those they receive today from their fabrication partners. It is anticipated that product verification for strained Si-based circuits based on 130 nm node technologies will begin this year, and the first products will be on the market in 2003.

The future for strained Si

Manufacturing practices in the CMOS industry are currently experiencing a discontinuity, where new approaches are necessary in order to maintain improved product capability within reasonable economic constraints. New materials in CMOS manufacturing are key to this disruption, and strained Si technology is a very promising technology for CMOS manufacturers and circuit designers. Strained Si has the potential to provide great performance benefits with minimal disruption to standard CMOS manufacturing infrastructure.

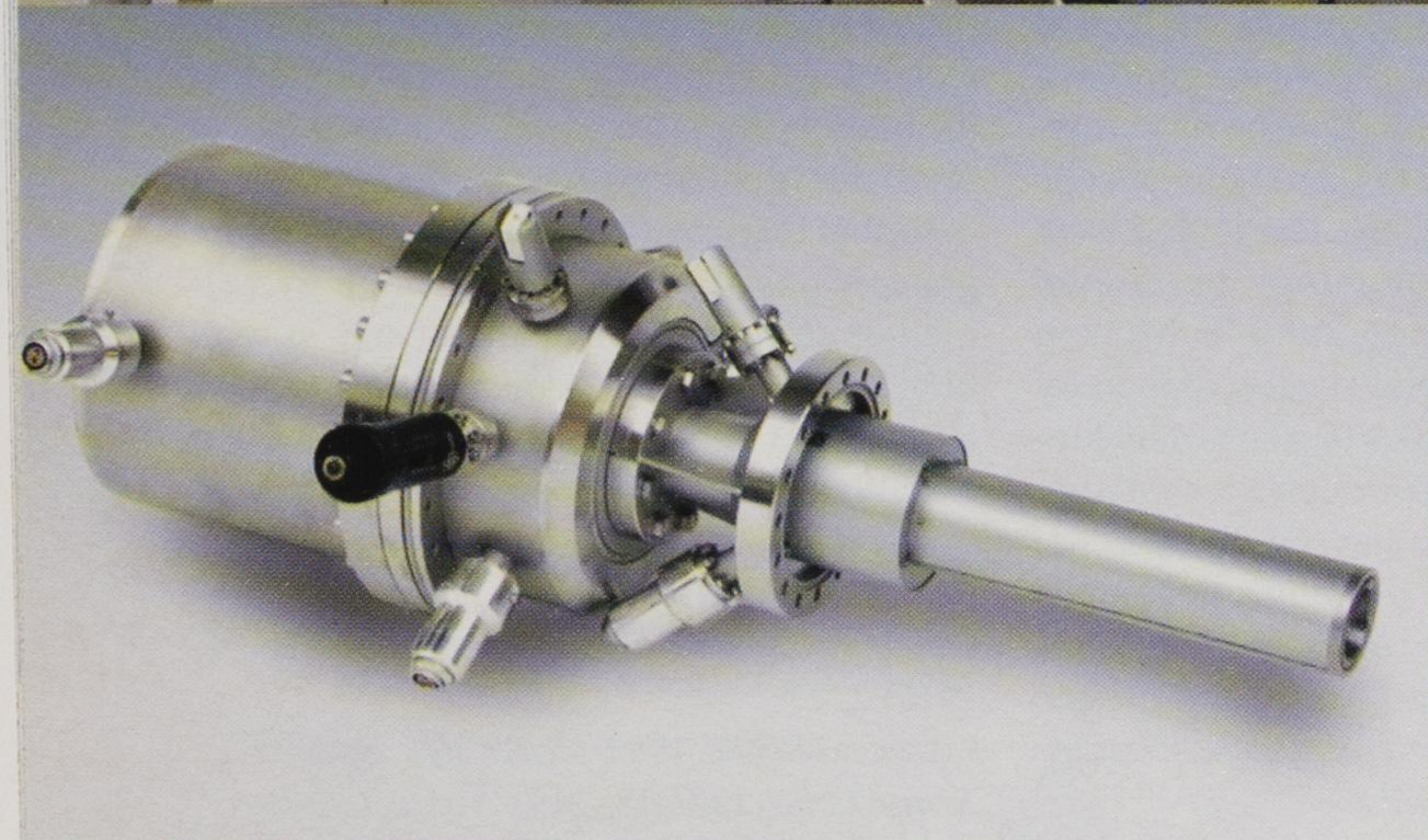
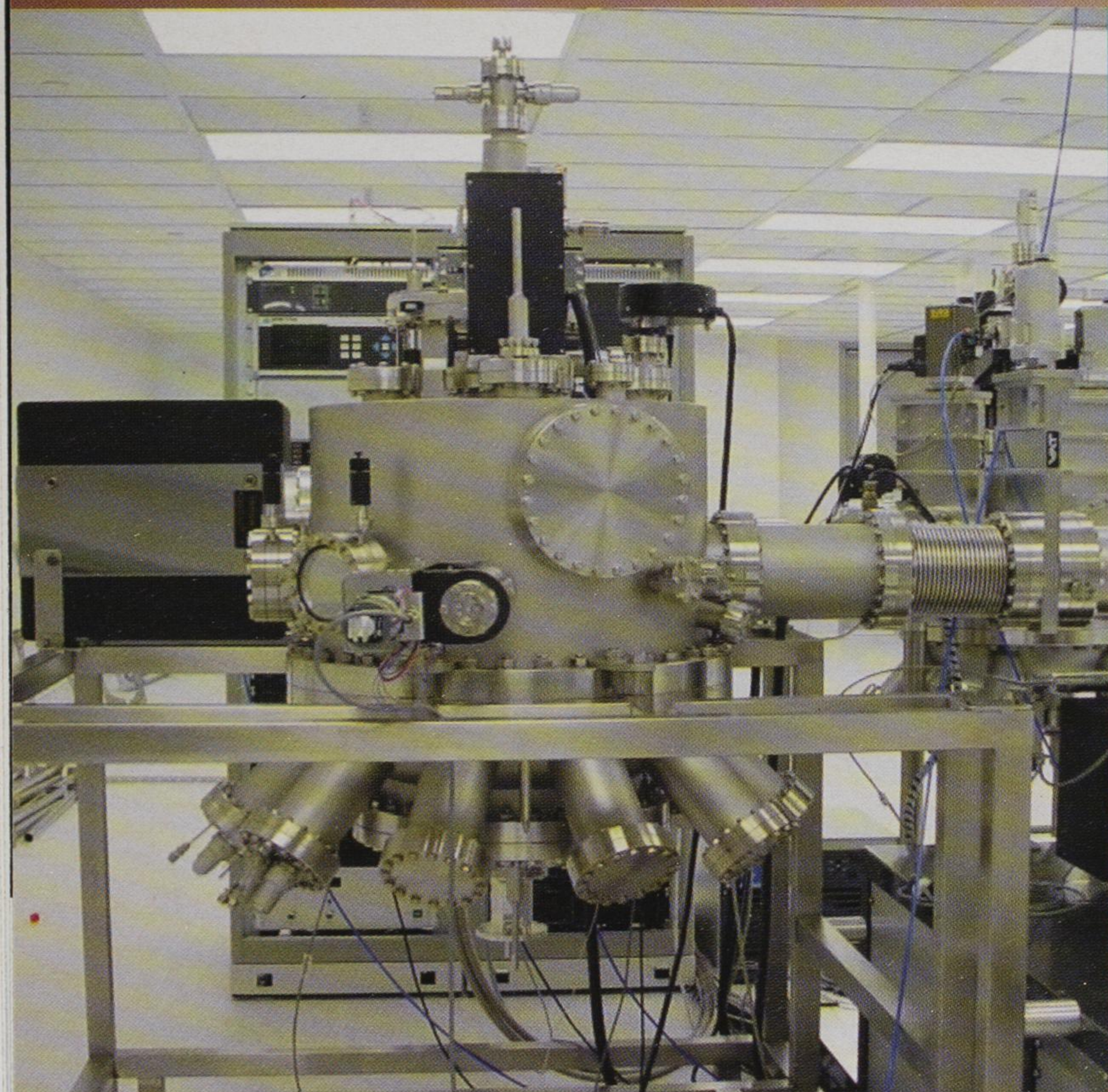
Strained Si is the cornerstone of a series of lattice-engineered structures that enable continued improvements to be made in CMOS technology. Depending on the Ge content in the underlying SiGe buffer, a series of novel transistor structures can be fabricated in order to further improve CMOS technology. Future generations of strained Si technology will include strained Si on insulator and, as with bulk Si, all other CMOS improvements (low-k interlayer and high-k gate dielectrics, Cu metallization etc) will be complementary. ●

Further reading

- Currie *et al.* 2001 *J. Vac. Sci. Technol. B* **19**(6) 2268.
- Fitzgerald *et al.* 1991 *Mater. Res. Soc. Symp. Proc.* **220** 211–215.
- Leitz *et al.* 2002 *J. Appl. Phys.* **92**(6) (in press).

Mayank Bulsara is a co-founder and CTO of AmberWave Systems Corporation, www.amberwave.com.

Proven Technology for Production MBE



DCA production MBE systems now cover run capacities of 3x2", 4x4" and 7x6". The P600 and P900 systems, with 3x2" and 4x4" capacities, are designed for the precise production of high-quality complex compound semiconductors.

The P7X6 system provides the highest throughput with the possibility to process seven 6" wafers simultaneously.

These production MBE systems complement DCA's wide range of R&D systems for III-V, Ga-N and Si/Ge epitaxy.

DCA High Capacity Effusion Cells and Crackers are known for their rugged design and long lifetime. The cells and crackers are now available as a retrofit for most production MBE systems on the market.

For your nearest representative please visit our web site at: www.dca.co.uk
or email us at: dcausa@worldnet.att.net

DCA
INSTRUMENTS

The future of SiGe devices beyond HBT applications

Since 1998 the SiGe HBT has been an “off-the-shelf” device, closing the gap between high-volume silicon and high-performance III-V RF electronics. Looking to the future, the HFET is expected to be the next SiGe device to reach commercial markets. **Thomas Hackbarth, Marco Zeuner** and **Ulf König** discuss why they think the HFET will lead the race towards higher speed devices.

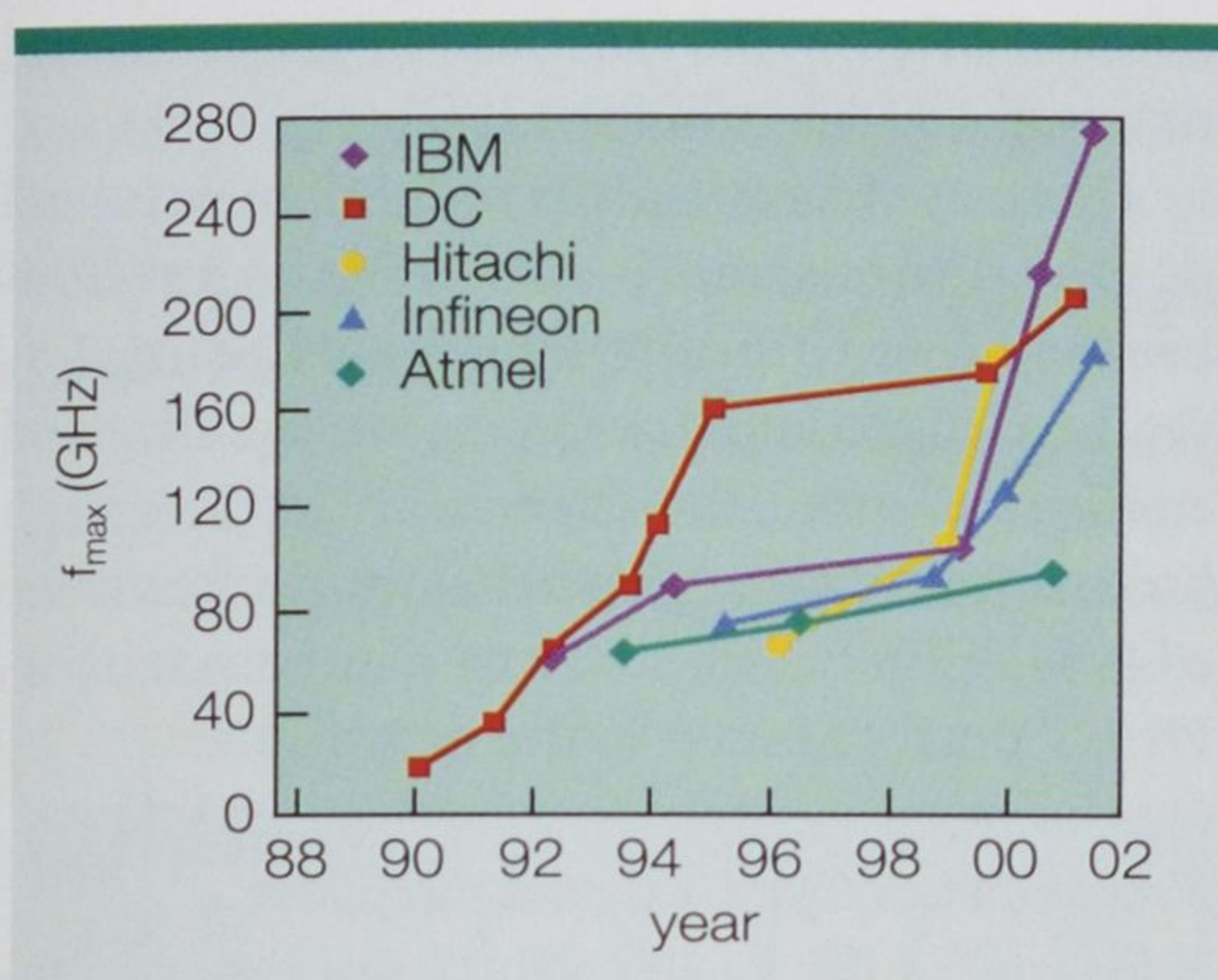


Fig. 1. Advances in device processing have led to the $f_{\max}$ values of SiGe HBTs increasing almost tenfold in the last decade.

In the early 1980s several groups started to add Ge to Si-based devices to ensure that their performances could track the SIA roadmap. By the 1990s the SiGe HBT was the first device to have frequencies greater than several tens of GHz, and a decade later the technology was transferred to production.

In 1998 Temic (now Atmel) and IBM were the only companies to sell commercial HBT devices and circuits for the communications market. Today almost all BJT and BiCMOS IC suppliers worldwide, and even some competing GaAs companies, are working on SiGe. The $f_{\max}$ values first reported from the labs have since increased by nearly a factor of ten (figure 1), which indicates tremendous progress in device processing. Although production has lagged behind performance, because of a need to develop relaxed and robust structures, the SiGe HBT will continue to move into the semiconductor industry.

In parallel to the developments of HBTs, a second generation of SiGe devices has been investigated: the SiGe HFET. Using Ge to manipulate the device's band alignment and

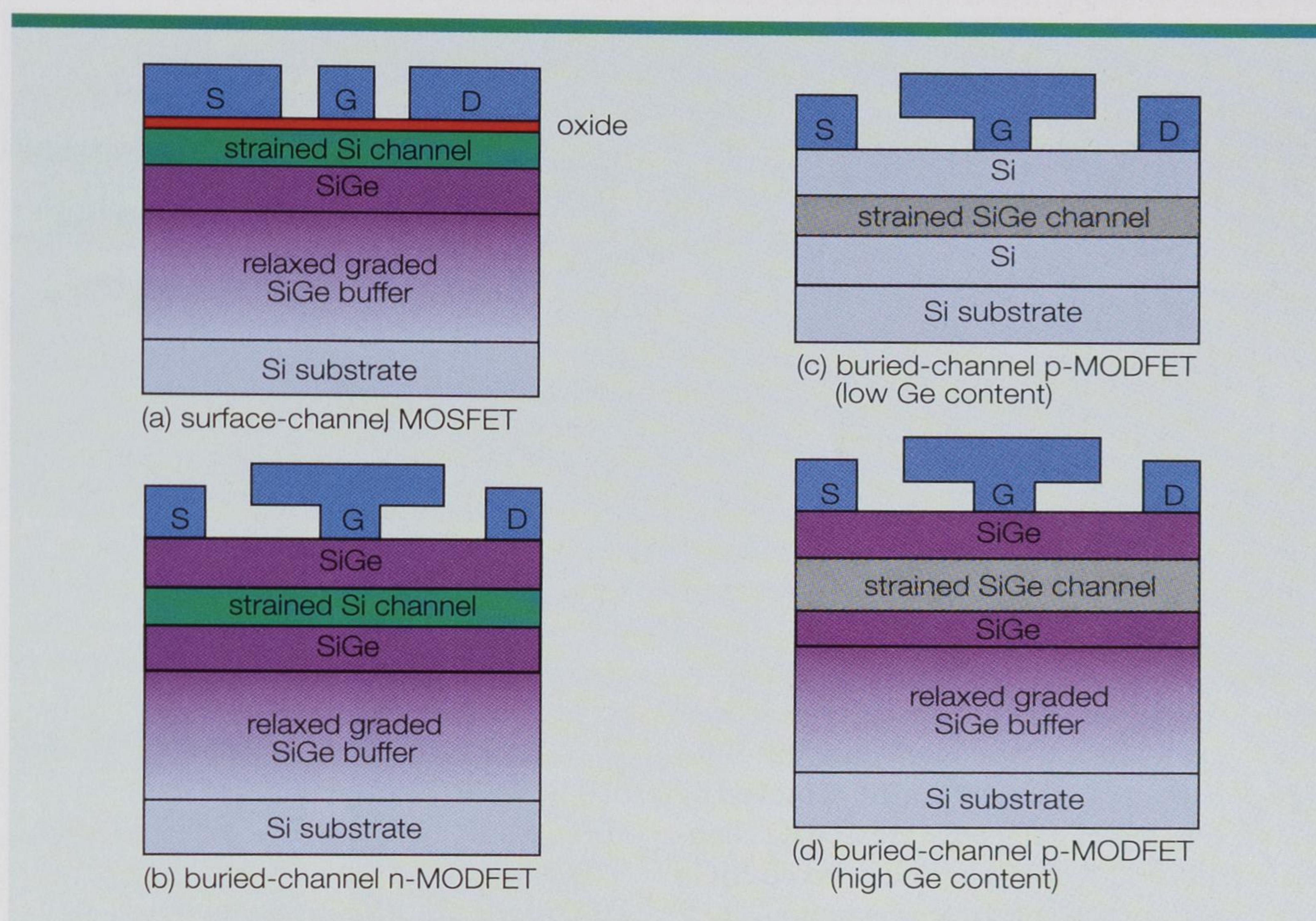


Fig. 2. Different types of SiGe HFETs, based on a variety of vertical layer stack structures.

lattice parameters, strained-channel FETs with a Si two-dimensional electron gas (2DEG) or a SiGe two-dimensional hole gas (2DHG) have been developed with carrier mobilities far exceeding those of Si.

Four different types of FET can be distinguished by the layer stack structure shown in figure 2. A surface-channel MOSFET (figure 2a) typically comprises a tensile-strained Si channel on top of a strain-relieved SiGe buffer. The SiGe buffer acts as a virtual substrate and has an adjustable lattice constant. This device can be treated like a conventional CMOS transistor, with only a few restrictions on the thermal budget during processing. With appropriate p- and n-type doping below the channel, the threshold voltage is easily ad-

justable. In 2001 IBM, as well as ST Microelectronics, Hitachi, Motorola and others, predicted that this device would be the next one on the market after the SiGe HBT.

A buried-channel n-type modulation-doped FET (n-MODFET) (figure 2b) is an upgrade of the surface-channel MOSFET and contains a buried channel that allows modulation doping. Until now, Schottky and junction gates have been predominantly developed on this structure, but variations with gate dielectrics are also feasible. By altering the modulation doping and gate/channel distance, the sub-threshold slope, threshold voltage and break-through behavior can be tuned.

Simple buried-channel p-MODFETs (see figure 2c) can be fabricated by depositing a

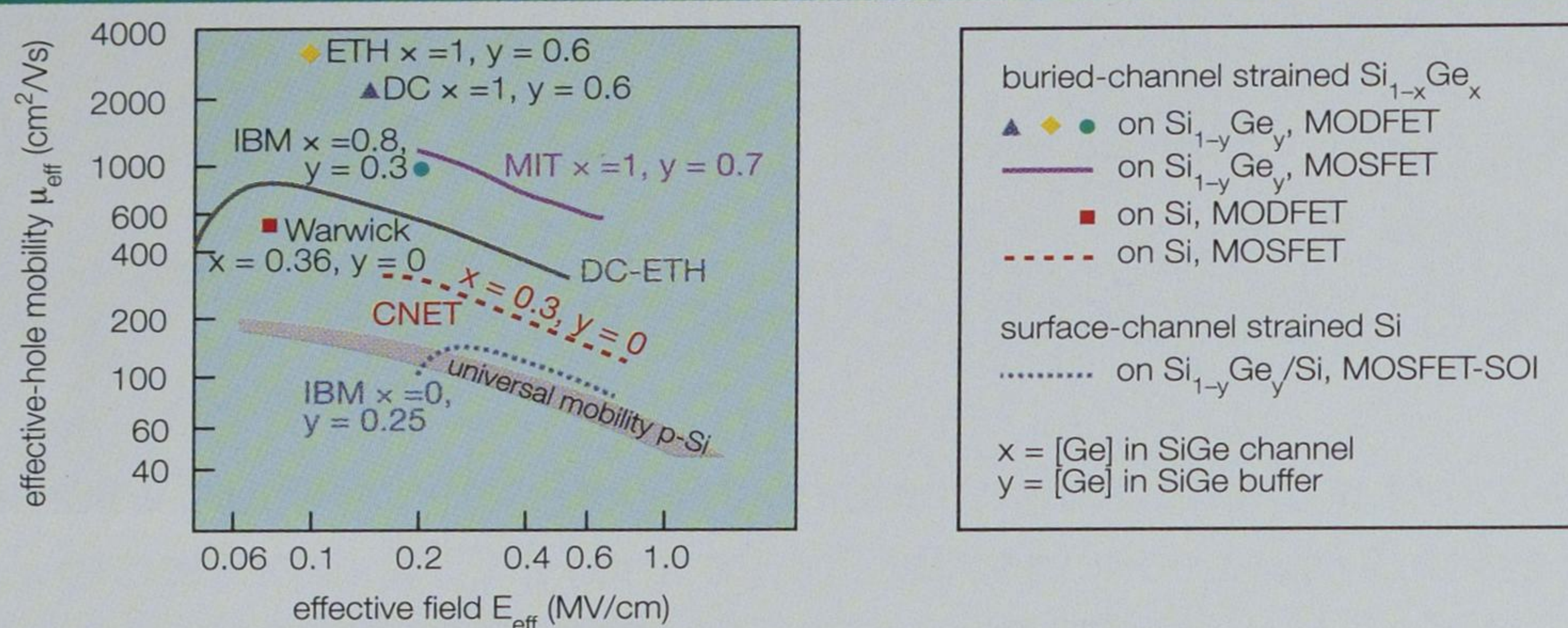


Fig. 3. Effective-hole mobilities achieved with various SiGe p-HFETs. The performance of these devices is nearing that of Si n-MOS devices, which is key to their use in CMOS circuits.

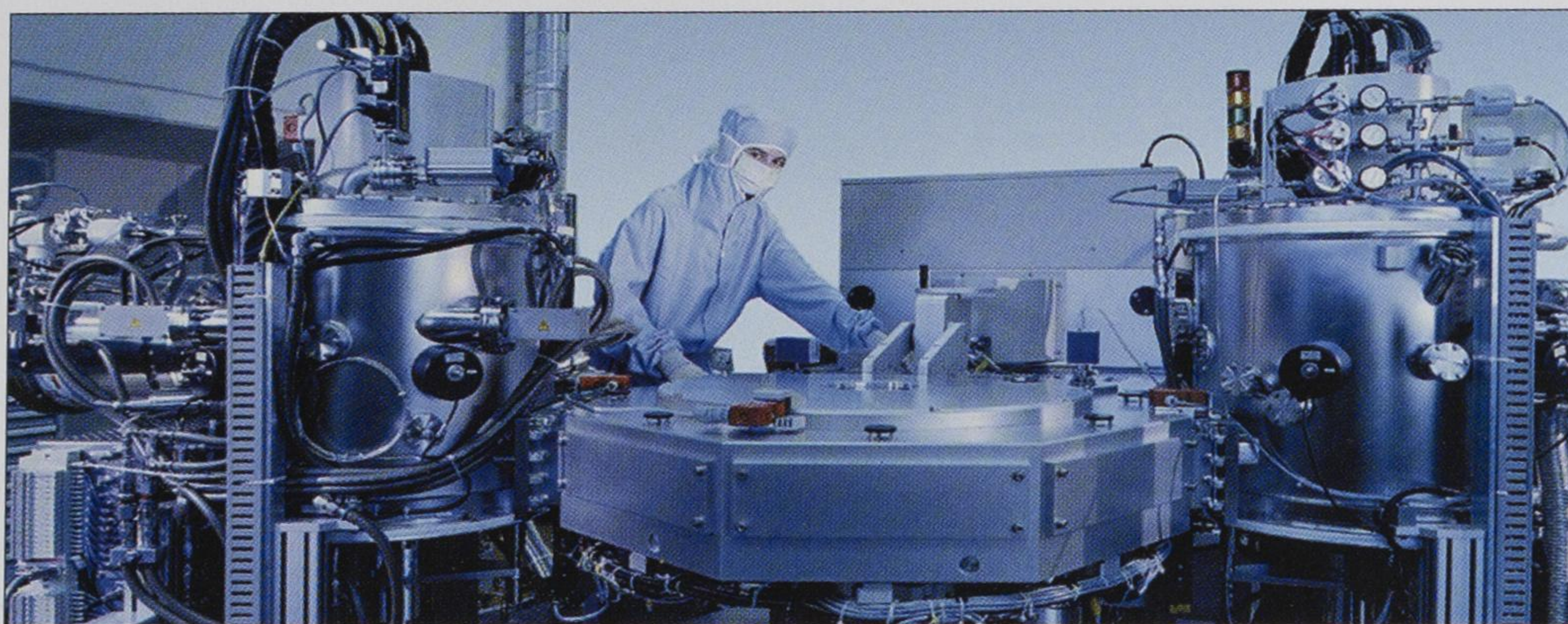


Fig. 5. A low-energy plasma-enhanced CVD system, which was jointly developed by Unaxis Semiconductors and ETH-Zürich, enables buffer growth rates of up to 5 nm/s.

compressively strained SiGe channel directly onto the Si substrate, although the critical layer thickness limits the Ge content to about 30%. Much better performance can be achieved by using Ge-rich or even pure Ge 2DHG channels (figure 2d), but again a relaxed SiGe buffer as a virtual substrate is essential.

The need for speed

An important figure of merit for these high-speed devices is their carrier mobility. Surface-channel MOSFETs on relaxed $\text{Si}_{1-y}\text{Ge}_y$ buffers (with $y = 10\text{--}30\%$), exhibit up to an 80% improvement in universal mobility compared with Si n-MOS devices. This can be translated into a performance enhancement of about 30–40% for transconductance, saturation current and f_t .

Much higher mobilities can be achieved with the buried-channel n-MODFETs. Unlike gate-oxide surface-channel devices, these devices do not suffer from surface scattering. As a result, electron mobilities of up to $2800\text{ cm}^2/\text{Vs}$, which is five times greater than standard Si, have been achieved.

On the downside however, quite high

amounts of Ge close to the surface can cause problems in devices that utilize gate oxides. To counter this, investigations into low thermal budget oxides or alternative dielectrics are currently underway.

Taking p-FET devices, improvements in effective-hole mobilities have been even more pronounced (figure 3). Pseudomorphic $\text{Si}_{1-x}\text{Ge}_x$ channels (with x between 0.15 and 0.36) give mobility improvements of approximately a factor of two, again mainly because of reduced surface scattering.

These simple structures can achieve a p-FET performance close to that of standard Si n-MOS devices, which is an important requirement for future CMOS circuits. High Ge content or pure Ge channels on relaxed buffers benefit from Ge's extremely high hole mobility. For example, room-temperature mobilities of up to $3000\text{ cm}^2/\text{Vs}$ have been reported for pure Ge 2DHGs, which is a factor of 15 above the mobility in standard Si p-MOS devices.

Over the last decade, researchers have been racing to develop both p-type and n-type MODFETs. Values for f_{max} have increased by

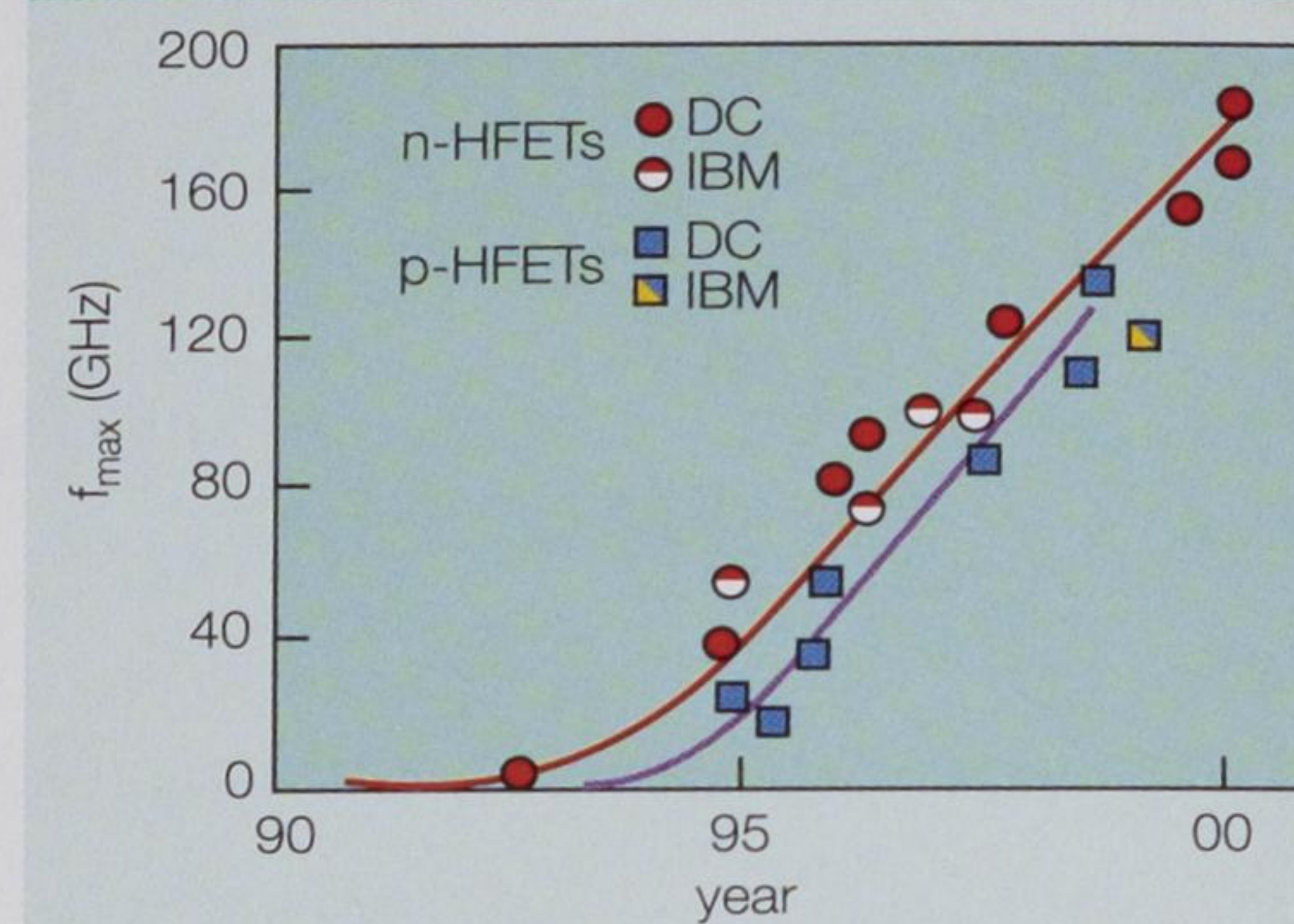


Fig. 4. Progress in f_{max} of n-type and p-type MODFETs. The f_{max} of n-type MODFETs peaked at 183 GHz in late 2001.

a factor of 10 within the last seven years, and reached 183 GHz in late 2001 (figure 4).

These advances follow reductions in lateral device dimensions – gate lengths have decreased from $1\text{ }\mu\text{m}$ to less than 100 nm – as well as improvements in crystal quality and optimization of the layer stacks. Ge's high hole mobility also means that the performance of p-HFETs is expected to catch up with n-HFET performance in the near future.

From prototype to production

To transfer the high mobilities and oscillation frequencies achieved in prototype devices into real products, a strain-relieved virtual substrate is crucial. Most devices contain a graded buffer that is several microns thick, grown using MBE or UHV-CVD at rates typically below 0.5 nm/s .

Less time consuming and cheaper approaches for buffer growth have led to MODFETs with f_{max} values greater than 100 GHz . The University of Stuttgart, Germany, has developed low-temperature epitaxy and the Forschungszentrum Jülich, Germany, has used ion-implantation-assisted relaxation to grow buffers that are only $200\text{--}300\text{ nm}$ thick.

Unaxis Semiconductors and ETH-Zürich have jointly developed a low-energy plasma-enhanced (LEPE) CVD system that rapidly grows layers of SiGe at 5 nm/s (figure 5). Record 183 GHz n-MODFETs have been grown on a buffer prepared by LEPECVD, and the p-MODFET structure with the hole mobility of $3000\text{ cm}^2/\text{Vs}$ has been produced entirely with LEPECVD (both at ETH-Zürich).

An alternative route towards low-cost processing, which was taken by Daimler-Chrysler, makes use of optical lithography rather than electron-beam methods to define the gate. A 500 nm fin-like polyimide dummy gate acts as a mask for contact

implantation and is laterally shrunk using dry etching. After planarization, the polyimide is etched away and the remaining trench is filled with the gate metal.

By adopting this technology, the source, gate and drain areas are more easily self-aligned, while a broader gate head can be independently defined. With a gate length of 100 nm and source/gate and gate/drain distances of 200 nm, transit frequencies have reached 90 GHz. This is approximately 50% higher than devices with e-beam-defined gates.

Lateral scaling versus performance

Comparing the maximum frequencies of today's HFETs and HBTs, the latter was in the lead in early 2002. However, it will be interesting to see what the future holds once the backlog in HFET development has caught up.

For example, lateral-dimension scaling effects on FETs and HBTs will bring improvements to performances (figure 6). The transit time in HBTs is mainly influenced by epitaxy-related properties such as thickness, Ge content and doping profile of the base. Reducing

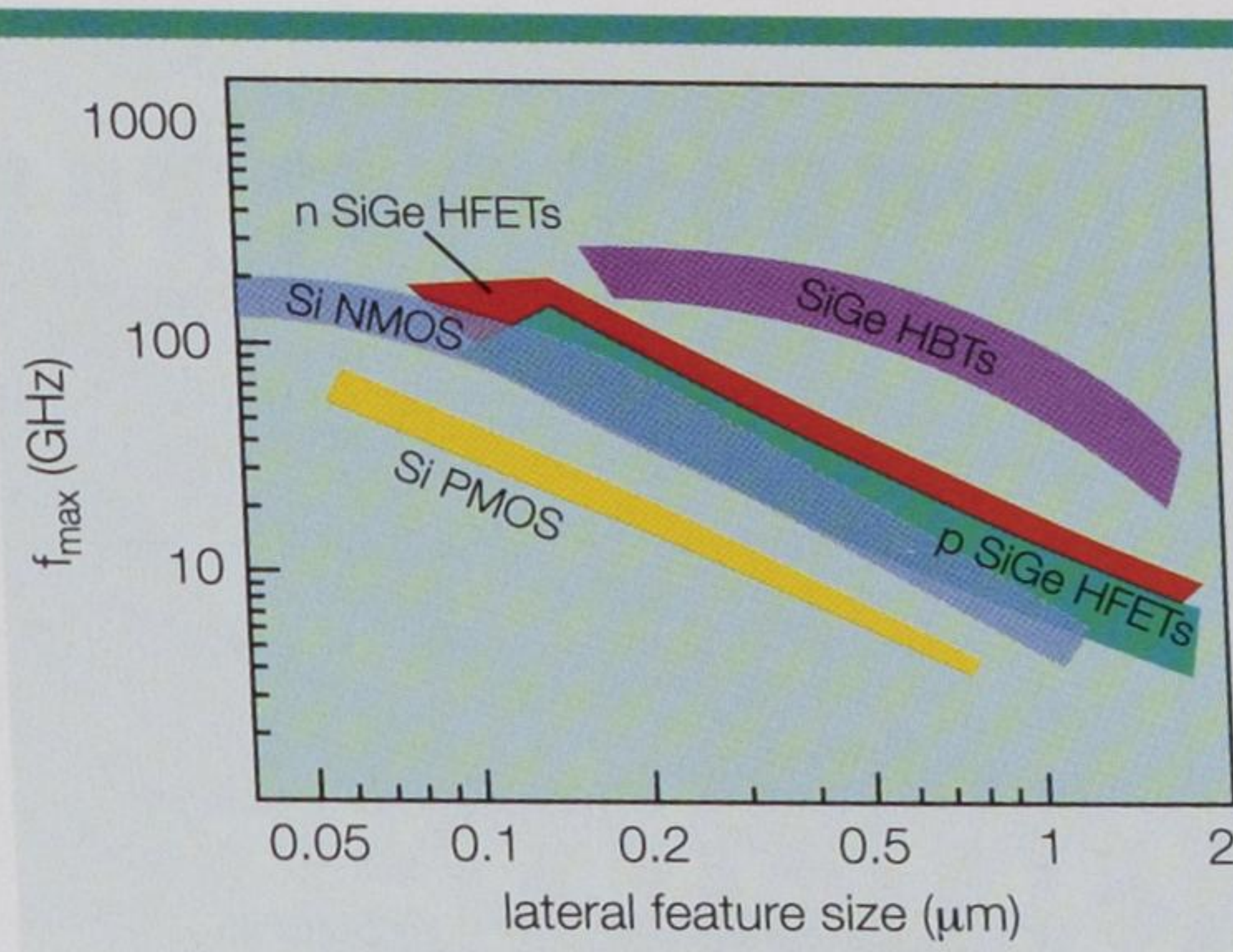


Fig. 6. Lateral-dimension scaling effects on FETs and HBTs. Reducing lateral dimension increases $f_{\max}$ and leads to a tradeoff between capacitance and resistance.

these device dimensions, however, brings a tradeoff between capacitance and resistance, which explains the saturation in speed at gate lengths below 0.5 μm in figure 6.

For FETs, smaller gate lengths and source/drain spacings yield lower transit times as well as reduced access resistances. This trend could be slowed by increasing the capacitance and

short-channel effects below gate lengths of 100 nm, but at these lengths velocity overshoot can help to improve performance.

For p-type devices, SiGe p-HFETs largely outperform the mainstream Si PMOS devices, while the performance enhancements of n-HFETs compared with standard Si NMOS devices has been less pronounced. However, in terms of development, the end of the road has not yet been reached.

Conservative simulations reveal that an $f_{\max}$ of 300 GHz can be achieved in a SiGe n-HFET with a 50 nm gate length, and this figure could be doubled when velocity overshoot is taken into account. Roughly the same performance is expected with SiGe p-HFETs. Potential performances such as this will be the driver for future Si-based high-speed electronics.

Thomas Hackbarth and Marco Zeuner are scientific members of the DaimlerChrysler Research Center in Ulm, Germany.

Ulf König is senior manager of SiGe growth, processes, devices and circuits at the center.

Tornado ICP®

Inductively Coupled Plasma Etching System

SAMCO's proprietary "Tornado Coil Electrode" efficiently generates a stable high-density plasma and enables the highly selective etching of quarter-micron patterns.

Low bias minimizes plasma-related damage to devices.

Applications

- AlGaAs LED
- GaN LED
- InP Taper Etching
- Surface Emitting Laser Matrix Pattern
- GaAs FET
- Laser Diode Array

Laser Diode Array (Material: InP)

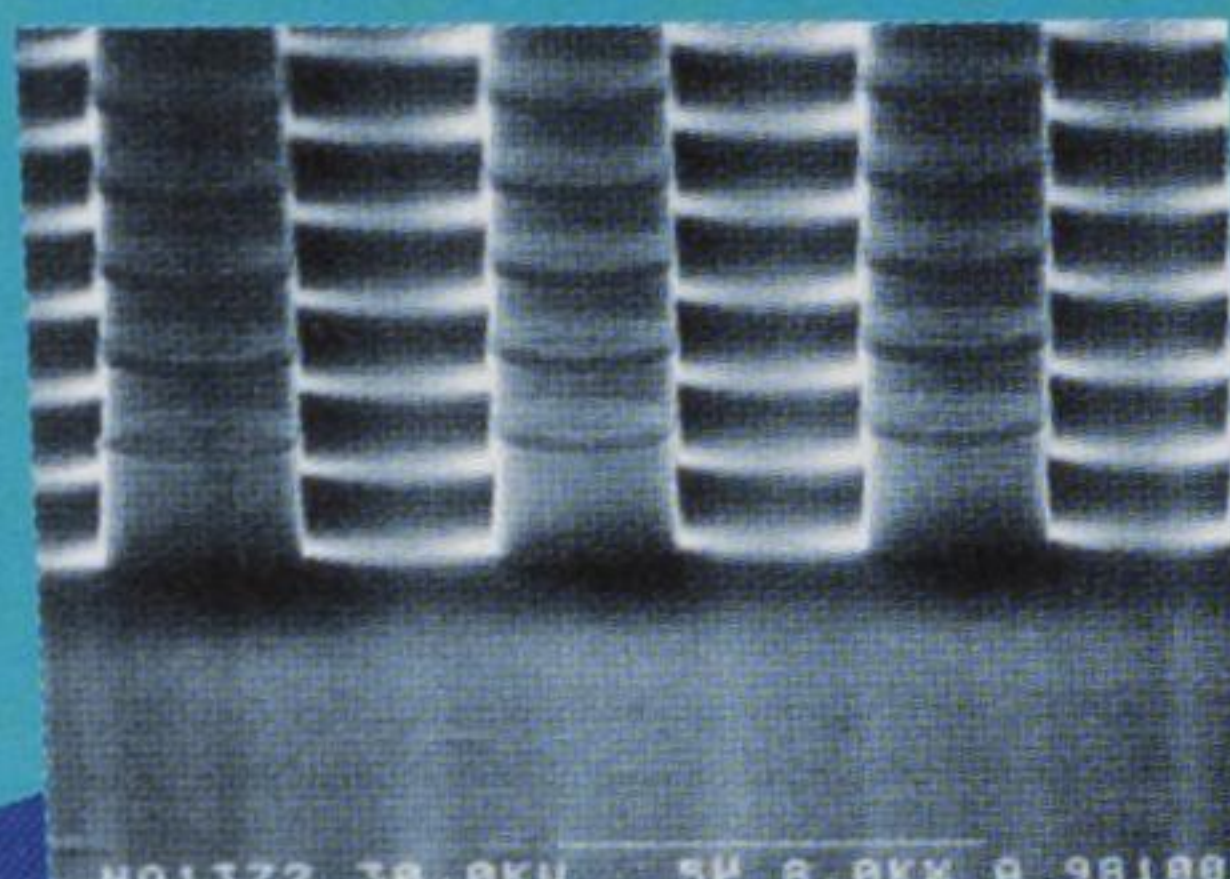


Photo Courtesy of Iga/Koyama Research Lab, Tokyo Institute of Technology



For Production
RIE-200iPC



For R&D
RIE-200iP

Thin Film & Surface Technology
samco
SAMCO INTERNATIONAL, Inc.
<http://www.samcointl.com>

Head Office
36 Waraya-cho, Takeda, Fushimi-ku, Kyoto 612-8443 JAPAN
Phone: +81(75)621-7841 FAX: +81(75)621-0936
E-mail: intl@samco.co.jp
United States Office
532 Weddell Drive, Suite 5, Sunnyvale, CA 94089 USA
Phone: +1(408)734-0459 FAX: +1(408)734-0961
E-mail: sales@samcointl.com

TEKCORE

FAST, FLEXIBLE AND COST EFFECTIVE

Looking for Quality, Reliable and Fast Service products of GaN based HB LED Wafer and Bare Chips

Contact Tekcore:

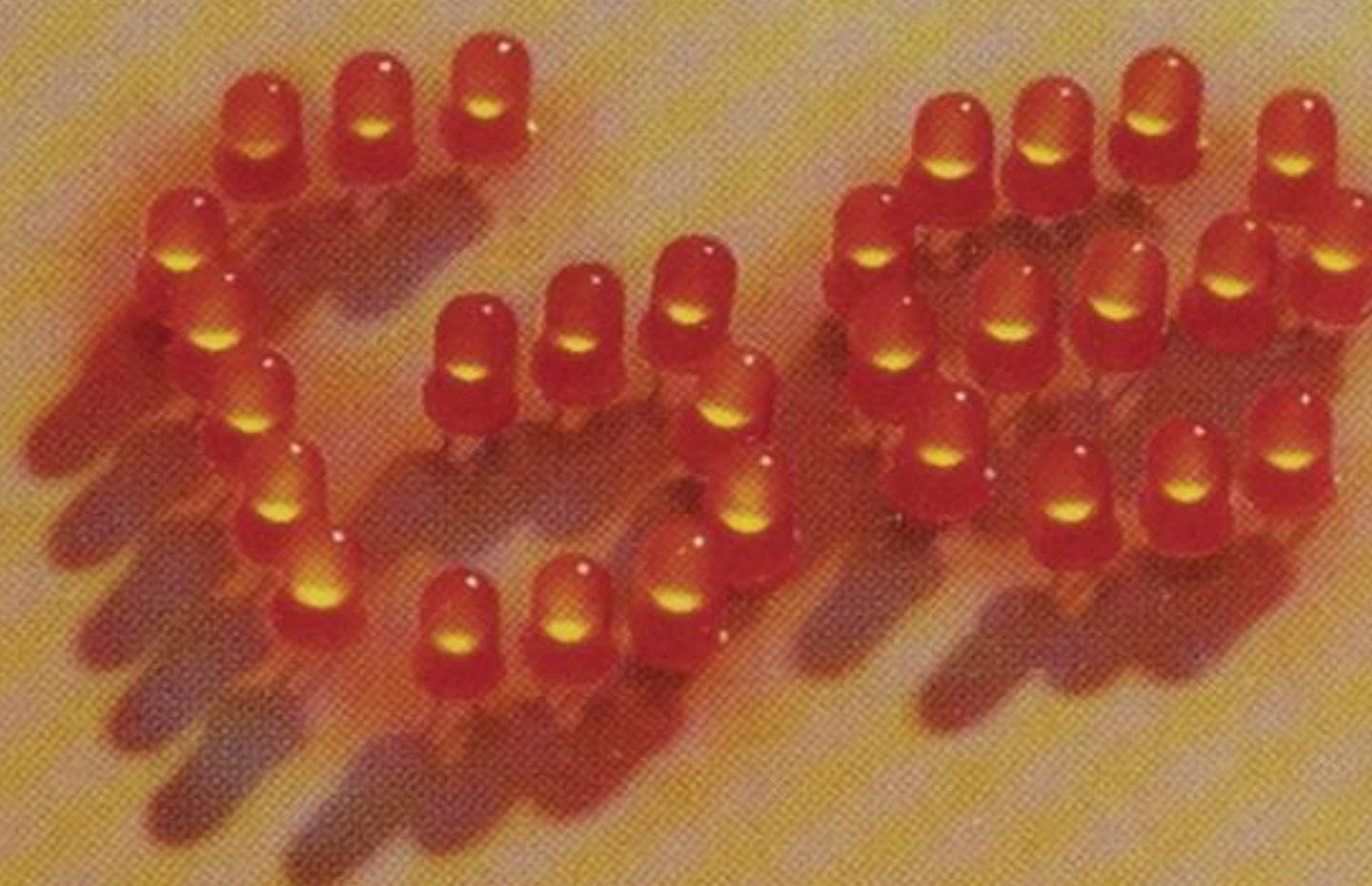
- 2" and 3" [late 2002] Epi wafers
- HB Blue and Green LED bare chips
- Products in the pipeline Large area LED, UVLED, PHEMT, Blue laser diodes,
- State-of-the-art facility, including High throughput Reactors
- Excellent Technical Capability
- Strong Management

Tekcore Co., Ltd.

#18, Tzu-Chung 3rd Road, Nan-Kung Industrial Zone, Nantou, Taiwan.
Tel: +886-49-2261626
Fax: +886-49-2261635

Sales @ tekcore.com.tw
www.tekcore.com.tw

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

Chip manufacturers look to wafer-bonding technology

As the demand for chip-level integration increases, the ability to successfully bond a range of materials onto a wafer is key. **Shari Farrens, Viorel Dragoi, Paul Lindner and Bernhard Wieder** report on the various wafer-bonding techniques that are available to chip manufacturers.

If the last century is remembered for the birth of the transistor and the development of MEMS and the Internet, then the integration of devices into low-cost, mass-produced, portable systems-on-chips will certainly leave its mark on this century. During the last 30 years researchers have made many advances in semiconductors, optics and related technologies, and we can already use a variety of bonding methods to create laminated starting materials and vertically integrated electronics, and combine multifunctional components onto a single die.

To realize full component integration, an understanding of materials compatibility is crucial. Si, with its low cost and good thermal, mechanical and electrical properties, still holds the lion's share of the semiconductor industry. Its oxide serves as an excellent dielectric layer in IC manufacturing, as well as an etch stop layer in micromachining applications for MEMS devices. However, Si's limited bandgap and its modest mobilities can limit device performance and restrict optical applications.

Scientists have therefore turned to GaAs and other compound semiconductors for use in various optoelectronic applications. More recently a paradigm shift has emerged; rather than choose between Si or compound semiconductors, why not combine the best of both worlds into integrated systems? This has now become possible through wafer-bonding technology.

Beyond Si

Wafer bonding, used to join two flat mirror-polished clean surfaces, is by no means restricted to Si wafers. Appropriate polishing methods and control of the surface chemistry enables a variety of solids with different structures (amorphous, polycrystalline, single crystals), crystallographic orientation and lattice constants to be bonded. Indeed,



Fig. 1. An automated wafer alignment and bonding system for high-volume manufacturing.

Rather than choose between Si or compound semiconductors, why not combine the best of both worlds into integrated systems?

wafer bonding allows for materials combinations that were simply not possible when using epitaxial growth.

Many variations of wafer bonding are applied in microelectronics, MEMS, micro-opto-electromechanical systems (MOEMS) and advanced wafer-level packaging. Some of the most widely used wafer-bonding techniques include anodic bonding, direct (fusion) bonding, eutectic and thermo-compression bonding, as well as temporary bonding for handling brittle compound

semiconductor wafers. The choice of bonding method depends on the initial substrate and the final application.

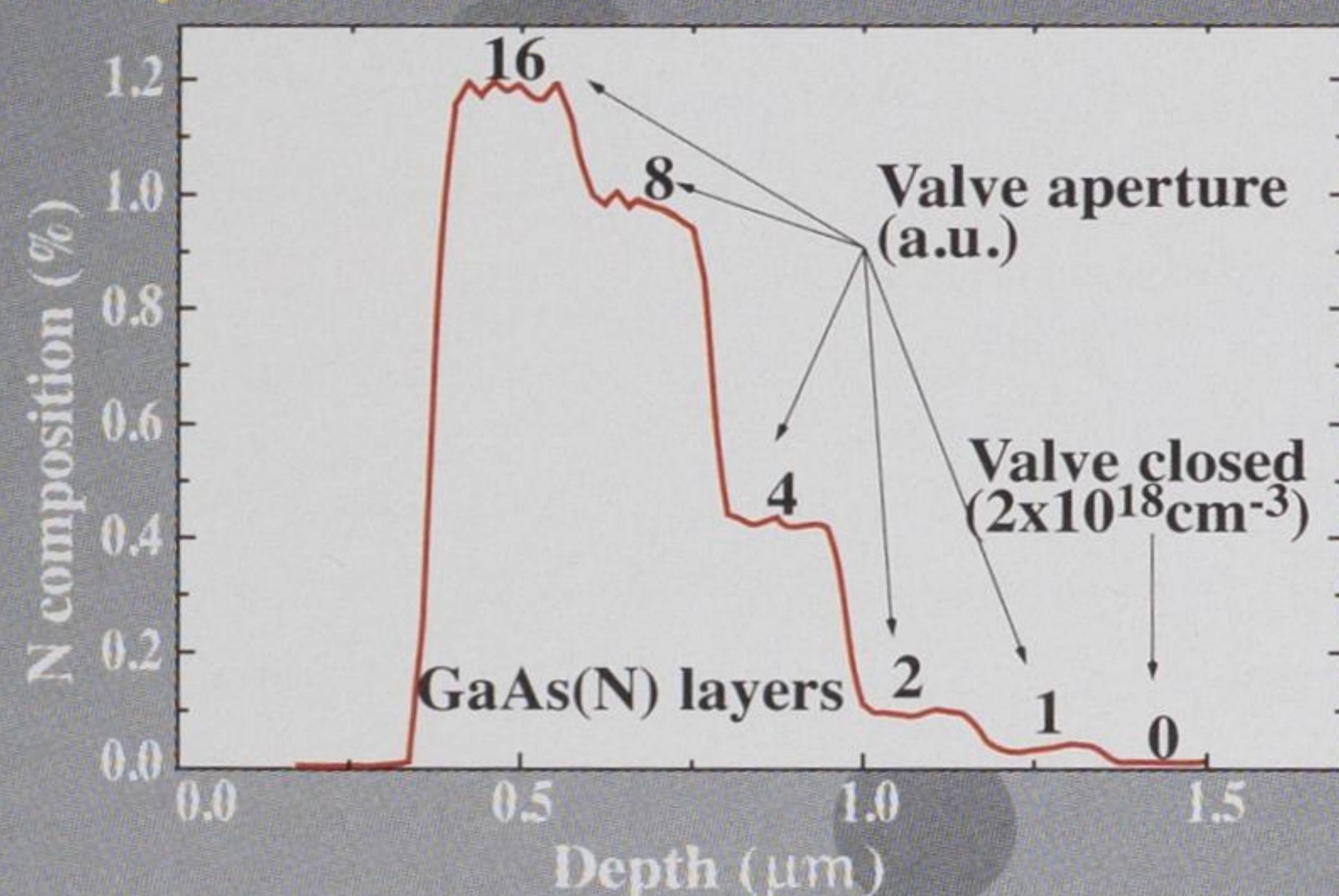
Anodic bonding

Anodic bonding is a mature technology that was first introduced at the end of the 1960s. Used to join a Si wafer with a glass wafer that contains a high amount of alkali metal oxides, the technique's key applications include sensor encapsulation and wafer-level packaging (figure 1 shows a typical production system).

Anodic bonding takes place with heating and in an applied electric field. At a certain temperature, which depends on the composition of the glass, the oxides dissociate and the mobile metal ions are driven into the glass by the electric field. This process creates an oxygen-rich layer at the Si-glass interface. The oxygen ions are forced to the Si surface by the electric field and oxidize the Si. The resulting bond strength is very high and the process is irreversible.

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@imaginet.fr

COVER STORY HETEROSTRUCTURES

www.compoundsemiconductor.net

Soda lime glasses were originally used in anodic bonding, but recent advances in the design of anodic glass substrates has led to significant improvements. Refining the glass chemistry has reduced contamination, while the thermal expansion coefficients of the glass now match those of semiconductor substrates.

Fusion bonding

Most materials, when properly polished, adhere to each other at room temperature and can be used for wafer bonding. Si-on-insulator (SOI) fabrication is one example of such bonding and was first reported in the middle of the 1980s.

SOI substrates consist of a thin Si "device layer" on an oxidized Si wafer. During SOI fabrication a thermally oxidized Si wafer, called the handle wafer, is bonded to a blank Si wafer, known as the donor wafer. The donor wafer is subsequently thinned or cleaved to achieve the required device layer thickness.

Two types of SOI material dominate. The first is thin SOI, which has a device layer thickness below 500 nm and is used for high-performance microelectronic applications. The second is thick SOI, which has a device layer thickness larger than 2 μm and is used in power devices as well as MEMS and MOEMS.

SOI makes a good starting material because of its lower operating voltages, which lead to lower power consumption and faster chip performance, and its radiation hardness. SOI is also useful in optical applications because of the large difference in refractive index between Si and its oxide. The material has great potential for the integration of optoelectronic and electronic components as it can be patterned and used to confine and transmit light.

Different material combinations obtained by fusion bonding include crystalline quartz on Si for high-frequency applications (Eda *et al.*), and GaAs or InP on Si for combining opto- and microelectronic devices (Kopperschmidt *et al.*). Also, different III-V materials can be combined to fabricate VCSELs (Ram *et al.*) and LEDs (Kish *et al.*). While a lot of fusion bonding can take place at room temperature, the bonding of III-V compound semiconductors requires elevated temperatures (300–600 °C), as well as flowing hydrogen or forming gas (Lo *et al.*).

Eutectic bonding

Eutectic bonding is frequently used for MEMS devices and advanced packaging, and meets the demand for hermetic as well as vacuum sealing for many microsystems. This

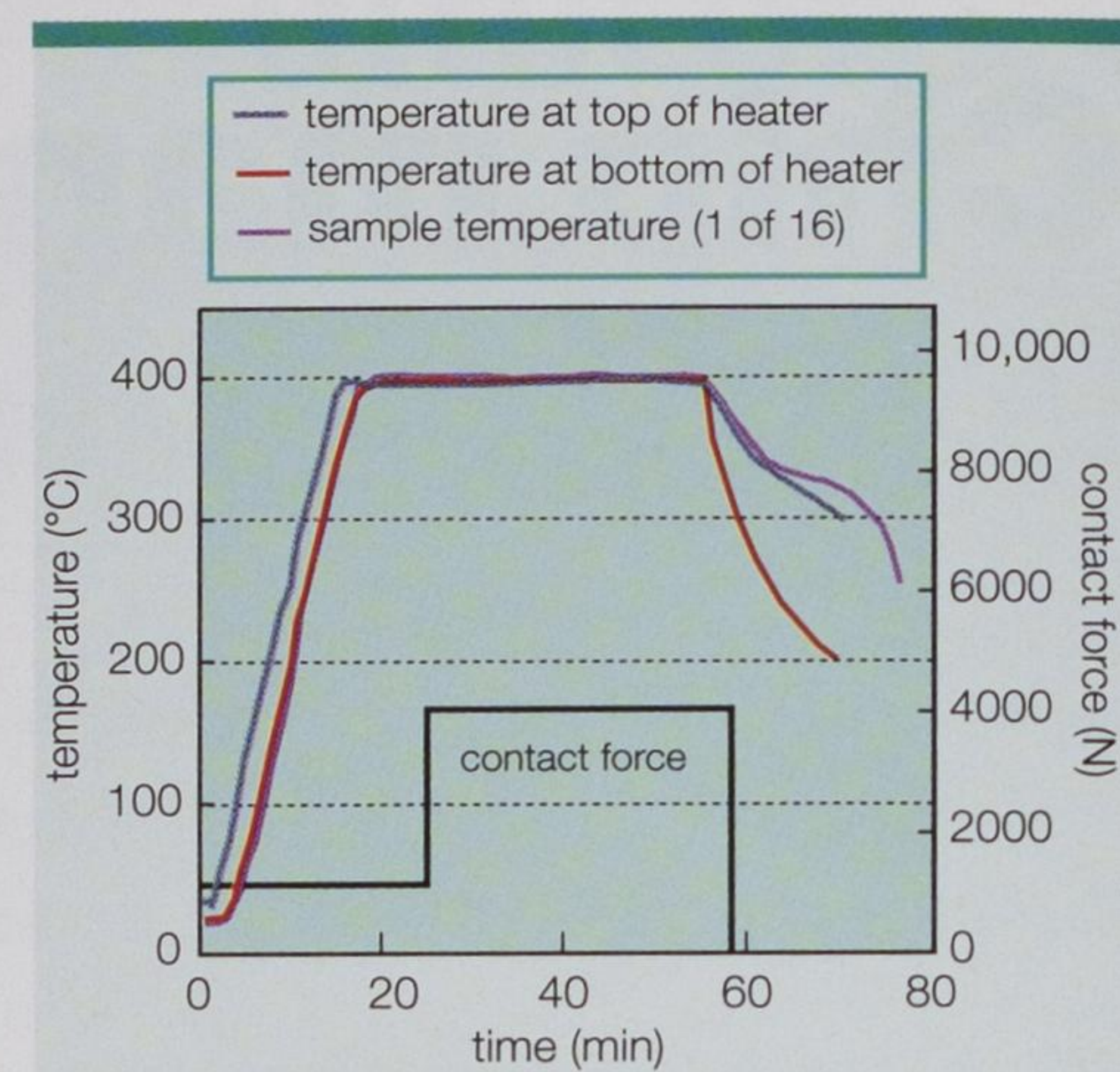


Fig. 2. A typical bonding profile for eutectic bonding. This method of bonding is typically used for MEMs and advanced packaging.

technique is based on the use of bonding materials that form a eutectic alloy in specific temperature conditions. A typical temperature profile of the bonding is shown in figure 2.

Systems such as Au-Si, Au-Sn or Pd-Si are widely used. For Au-Si eutectic bonding, a gold layer of the desired thickness is first deposited on one of the two wafers. The Si is provided either from the bulk of one of the wafers or from deposited thin films.

At the Au-Si eutectic point of 363 °C, a liquid Au-Si alloy that contains 3% Si and 97% Au is formed. The actual bonding temperature is some 10 °C higher than the eutectic point, which allows sufficient solid-liquid interdiffusion at the interface. The eutectic alloy then solidifies on cooling.

Thermocompression bonding

Glass frit was and often still is used in the process of thermocompression bonding. Small glass beads suspended in a carrier paste are deposited onto the substrate. Deposition takes either a blanket form or is patterned using screen printing or similar techniques. After deposition, degassing is used to dehydrate the paste and remove the solvents. Heat is used to soften the frit and pressure is then applied to hermetically seal the substrates together.

Large IC manufacturers, which are keen to construct hybrid circuits and 3D architectures, are exploring ways to build vertical transistors and stack individual devices. Thermocompression bonding, using metal-to-metal bonding, has become a favored fabrication step. For example, 3D interconnects fabricated using thermocompression bonding could help to reduce the data congestion caused by today's wire interconnects.

A key driver for the uptake of thermo-compression bonding is the transition from aluminum primary metallization layers to lower resistivity materials such as gold and copper. While in the past the IC industry has avoided using gold and copper because of unwanted effects from electromigration, diffusivities into Si and high fabrication costs, today's demanding IC performance requirements have forced manufacturers to switch to these elements.

Adhesive bonding

Unlike other techniques, adhesive bonding uses an intermediate layer. Suitable intermediate layer materials include evaporated glass, polymers, spin-on glasses, resists and polyimides. This bonding technique has several advantages over other techniques. For example, surfaces can be made planar prior to bonding and patterns are easily encapsulated on the wafer surface. Also, particles with a smaller diameter than the layer thickness can be incorporated into the intermediate layer, a feature known as particle compensation. A lower annealing temperature is an additional advantage. Low-temperature bonding also means that the thermal stresses, which build up during annealing, are reduced.

Today's most studied intermediate materials are resists, polymers, spin-on glasses, benzocyclobutene from Dow Chemicals, and SU-8 from MicroChem. A typical example of the integration of compound semiconductors and Si at wafer level is shown in figure 3. Here a spin-on glass is used as an adhesive. The glass absorbs the different expansion coefficients of GaAs and Si, which allows the fabrication of a flat final wafer sandwich.

Temporary bonding

The demand for temporary bonding is rising as the use of back thinning and backside lithography in GaAs and other III-V device fabricated processes increases. While production steps are made difficult due to the enormous fragility of thinned wafers, temporary bonding can be used to overcome these handling problems.

Adhesive materials, such as spin-on adhesives, spun-on wax or dry adhesives, are used to bond a III-V device wafer to a carrier substrate (either quartz, glass or even Si). The III-V device wafer is either coated uniformly with wax, or a dry film is laminated to its surface. By doing this, the wafer can then be bonded to a carrier substrate.

Using a carrier substrate improves the

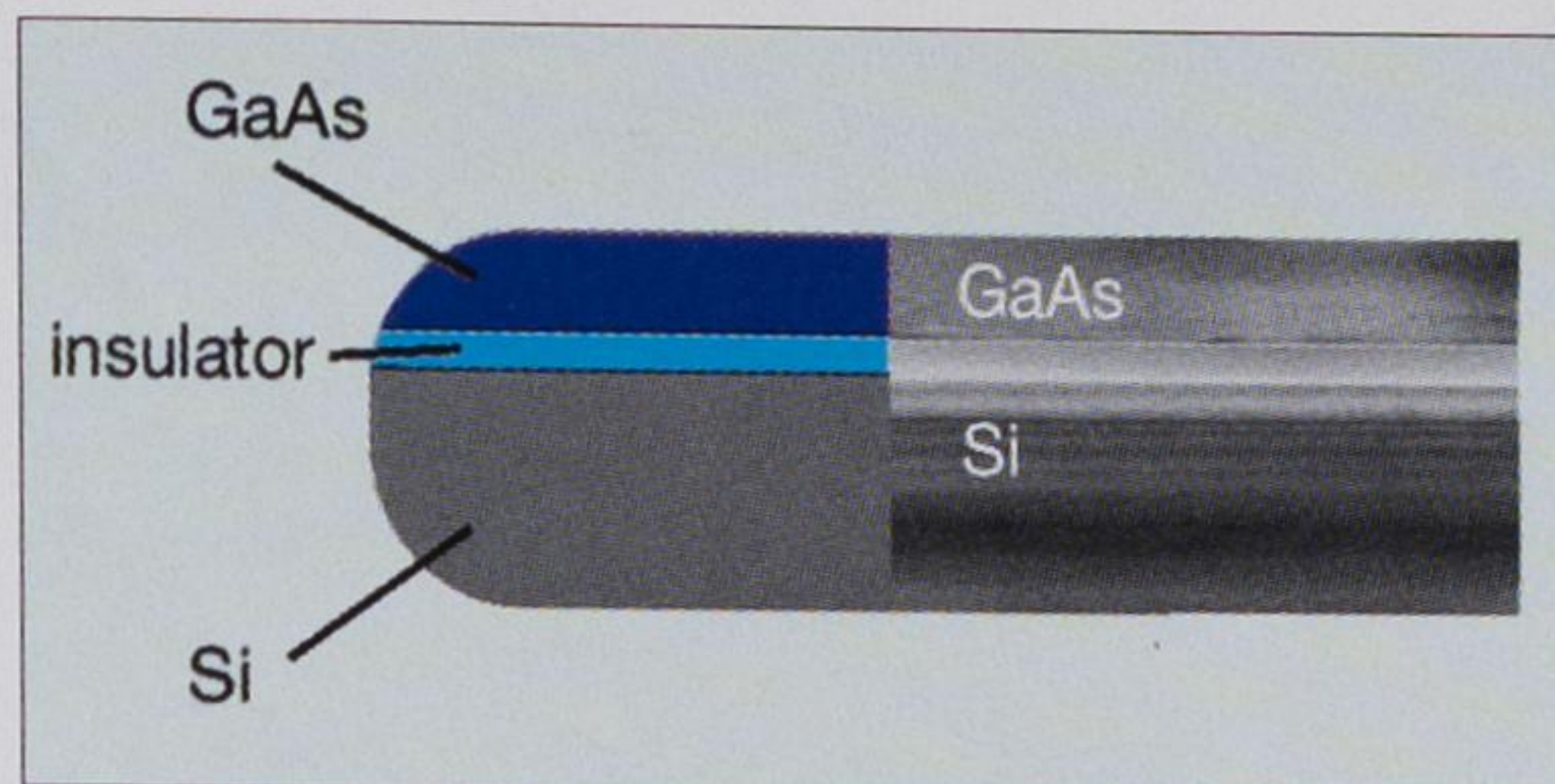


Fig. 3. The integration of GaAs and Si at wafer level using adhesive bonding. This type of bonding makes use of an intermediate layer, and in this instance a spin-on glass is used.

wafer's mechanical strength, while the wax or adhesive film reliably bonds and protects the wafer's active surface during grinding and polishing. After bonding, the typical total thickness variation for the wafer stack is required to be less than 5 μm .

Once backside processing is complete, the original substrate is quite easily debonded from the carrier substrate by either melting the wax, or by exposing the tape or polymer adhesive to UV or to solvent gases. The original substrate can then be placed on a permanent support structure.

Enabling technology

The range of wafer-bonding techniques has become a critical enabling industrial technology over the last 10 years. Various wafer-bonding approaches are successfully used in many fields of microelectronics, MEMS, MOEMS, optics and optoelectronics. Commercially available industrial equipment has led to processes being developed for both R&D and high-volume manufacturing. ●

Further reading

K Eda *et al.* 1993 *Electrochemical Society Proc.* **93**–29 373.

F A Kish *et al.* 1998 *Electrochemical Society Proc.* **97**–36 25.

P Kopperschmidt *et al.* 1998 *Appl. Phys. Lett.* **72** 3181.

Y H Lo *et al.* 1997 *SPIE Proc.* **3006** 26.

R J Ram *et al.* 1993 *Appl. Phys. Lett.* **62** 2474.

Shari Farrens and Viorel Dragoi are chief scientists, Paul Lindner is head of technology and Bernhard Wieder is the US technology manager at EV Group.

SAES gas purifiers give you the solution for defect-free epi growth. Our wide selection of MonoTorr heated getter and MicroTorr ambient metal supported technologies use the most advanced chemical processes to remove oxygen and carbon species from hydrogen and nitrogen carrier gases in any epi process.

Our specialty gas purifiers for ammonia, arsine, phosphine, HCl and others are proven and tested with analytical and process data to be sure our formula gives you the right answer.

Complete your formula for growth with SAES.



SAES Pure Gas, Inc.
(805) 541-9299

www.PureGasTechnologies.com

USA Head 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

United Kingdom & Scandinavia

West Associates (Europe) 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

Sofrasil S.A.
109 Rue de Javel
75015 Paris
France
Tel: (33) 01-4554-4000
Fax: (33) 01-4554-4004
E-mail: ralph_hananel@compuserve.com

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 Izumi
2-26-4 Myojin-cho
Hachioji, Tokyo
192-0046 Japan
Tel: (81) 0426-56-2032
Fax: (81) 0426-56-6885
E-mail: bmiskin@axt.co.jp

Call Us Today!

Up to 150mm GaAs Wafers
Up to 100mm InP Wafers
Up to 100mm Ge Wafers

- Epi-Ready
- Low EPD
- High Strength & Ultra-thin
- Large volume

The Technology of Choice for Compound Semiconductors

Compound semiconductors come to Silicon Valley

The industry's largest event moves to San Jose, emphasizing manufacturing solutions for all types of III-V and silicon heterostructure devices. **Marie Meyer** previews CS-MAX 2002.

The future of compound semiconductor manufacturing will be under discussion at the 2002 Compound Semiconductor Manufacturing Expo (CS-MAX), to be held November 11–13, 2002 at the McEnrey Convention Center in San Jose, CA. Visitors will be able to chart the progress the compound semiconductor industry is making in developing robust, economical high-volume manufacturing techniques.

CS-MAX is the industry's largest event, having drawn more than 900 attendees to the inaugural event in Boston last year. Its mission statement is to encourage productive interchanges among engineers and managers engaged in high-volume manufacturing of compound semiconductor devices, and to provide a showcase for new ideas from semiconductor equipment and materials companies that can increase the productivity of compound semiconductor fabs. CS-MAX is intended to fill the role for compound semiconductors that the Semicon shows play for silicon – namely, an annual forum for new ideas that will bring economic benefit to the industry.

Technical program highlights

Manufacturing compound semiconductors requires specialized knowledge at almost every process step. CS-MAX will explore production-related issues that are unique to the industry. It is the first conference that brings together all of the compound semiconductor device types and materials systems that are currently in production. Papers will be presented in several areas, including:

- GaAs and InP ICs;
- LEDs and other III-V optoelectronics;
- wide-bandgap semiconductors;
- silicon heterostructures;
- fab management;
- front- and back-end processing;
- epitaxy;
- characterization;
- environmental health and safety.



More than 100 papers from 80 different organizations will be presented on topics relating to the production of III-V devices.

More than 100 papers will be presented in 28 sessions over two and a half days. The speakers, who are drawn from 80 different organizations, will focus on manufacturing-related issues, with special emphasis on productivity and yield enhancements, and cost-saving techniques.

LEDs

Three full sessions will be dedicated to topics that are unique to LED manufacturing. Back-end issues will be addressed by AXT Optoelectronics in a paper entitled "Challenges in low cost flip chip LEDs for solid state lighting". GELcore will make a presentation discussing their die attach process for power LEDs. And there will be two presentations, from Emcore and JPSA, on the alternatives to scribe-and-break for separ-

ating InGaN-on-sapphire die, demonstrating higher die yield and throughput, but with lower operating costs.

The testing of LED die remains a challenging aspect of LED production. Eric Bretschneider of Uniroyal Optoelectronics will present a paper on the spectroradiometric measurements of LED die, comparing the overall performance of photodiode and CCD array approaches. Op-Test will discuss how angular variation in fiber-optic probes impacts the measurement accuracy of LED die in production environments. The results of measurements on GaN and AlInGaP devices, and the implications for the design of measurement systems, will be discussed. There will also be a presentation from Kelvin Shih of Lawrence Technological University on a new LED junction-temperature measurement technique. This technique uses the LED junction itself as a sensor, and shows how the relative brightness of the LED at different currents and ambient temperatures can be calculated and plotted. In addition, several LED-related papers will also feature in the epitaxy and characterization sessions.

Microelectronics

Presentations on the production of III-V ICs will include the following:

- Anadigics – automated inspection for monitoring InGaP HBT backside via processes;
- Agere Systems – high-speed and large output voltage swing InP-based DHBT driver ICs;
- Anadigics – the effects of gold concentration temperature and agitation on the cross-wafer resistance uniformity of electroplated backside vias in thinned GaAs wafers;
- Filtronic Compound Semiconductors – manufacturable microwave power FET technology;
- Skyworks Solutions – throughput optimization of HBT ion implant isolation using doubly charged helium;
- Sumitomo Electric Industries – InGaAs/InP single-HBT fabrication process with high

uniformity and high yield for multi-10 Gbit/s optical communication applications.

There will also be a number of presentations on InP processing, as well as the continuing evolution of the metamorphic approach as an alternative to the use of InP substrates. Raytheon RF Components will report on the qualification of a production MHEMT process for low-noise and high-frequency applications. IQE will present a comparison of metamorphic buffer layers for M-HBT applications. And United Monolithic Semiconductors will present a paper that is entitled "Selective double recess technology on metamorphic HEMTs: improving the on-state breakdown behavior".

Optoelectronic components

Presentations in the optoelectronics area will include those by:

- LuxNet Corporation – high-performance, high-yield and throughput VCSEL process technology;
- JDS Uniphase – cost-effective short design cycle approach to monolithically integrated photodiode lenses;
- Alfalight – the impact of GaAs substrate quality on laser diode lifetime.

In addition, there will be a presentation from the University of Ulm on the development of a new chemically assisted ion-beam etching process for the fabrication of high-quality dry-etched laser mirrors in the GaAs/AlGaAs material system. Results will be presented showing that the process produces lasers with a performance comparable to that of lasers with cleaved facets fabricated from the same epitaxial material.

Unaxis will present the results of a systematic study of GaAs/AlGaAs non-selective etch using BCl_3/Cl_2 chemistry, for the purpose of establishing an optimized non-selective dry etch for VCSELs.

RSoft Design Group will present an overview of simulation techniques for photonic semiconductors. There will also be presentations from Palomar Technologies on optimal eutectic bonding techniques for enhanced laser reliability, and a paper from Taiwan's PROWtech on estimating optical thickness errors in VCSEL structures from optical reflection spectra.

Fab management and safety

Fab management strategies will be discussed in two sessions. Highlights include a presentation on failure mode and effects analysis, and its use in reducing time to market



The McEnrey Convention Center in San Jose.

in the context of manufacturing photonic integrated circuits. Modulight of Finland will present an analysis of database-centered manufacturing, and other fab management presentations include:

- M+W Zander – operational cost reduction in compound semiconductor manufacturing;
- Eshinui – consumable and material tracking and tracing logistics management;
- Global Communications Technology Corporation – a case study of the KMTI model for GaAs fab management.

A new feature of CS-MAX this year is a session on safety issues, organized with the assistance of the CS Forum group of the Semiconductor Environmental Safety and Health Association. Topics will include waste gas abatement in MOCVD growth, and a presentation from Motorola on the removal of arsenic from wastewater.

Epitaxy and characterization

Several papers on epitaxy and characterization will be presented, addressing all of the compound semiconductor material systems used in production environments.

Two sessions will discuss the growing interest in applying analytical tools to process gases. Topics include ammonia purification and management for GaN growth, different approaches for hydrogen purification (nickel/titanium and palladium), control of sulfur impurities in arsine, and trace water detection in phosphine.

In the characterization sessions the National Institute of Standards and Technology will present a paper on a new program to establish standard reference materials for the calibration of characterization equipment for epitaxial III-Vs. The aim of the program is to allow greater accuracy in the correlation of optical transitions (from photoluminescence) and film strain (from X-ray rocking curves) with film composition. Candela

Instruments will present a paper on a new system for detecting and classifying defects on compound semiconductor epiwafers, using reflected laser light that is evaluated by four detection techniques. Other topics to be discussed include the photoluminescence characterization and FTIR reflectance metrology of wide-bandgap materials; Raman imaging of local structure in compound semiconductors; the topographic and electrical characterization of semi-insulating GaAs, InP and SiC substrates; the extraction of low-mobility, low-conductivity carriers from field-dependent Hall data; and the *ex situ* characterization of InGaAsP.

Sessions on epitaxy and starting materials will be discussing several of the fundamental issues that can have a major impact on the cost and performance of compound semiconductor devices. The future of InP will be touched upon in two presentations: Showa Denko will discuss their results so far with LEC-grown 6 inch InP; and IQE will discuss the commercial production of large-diameter InP HBT epiwafers by MBE. There will also be several presentations about high-volume production using MBE and MOCVD, and some presentations will be covering metalorganic source material.

Exhibition

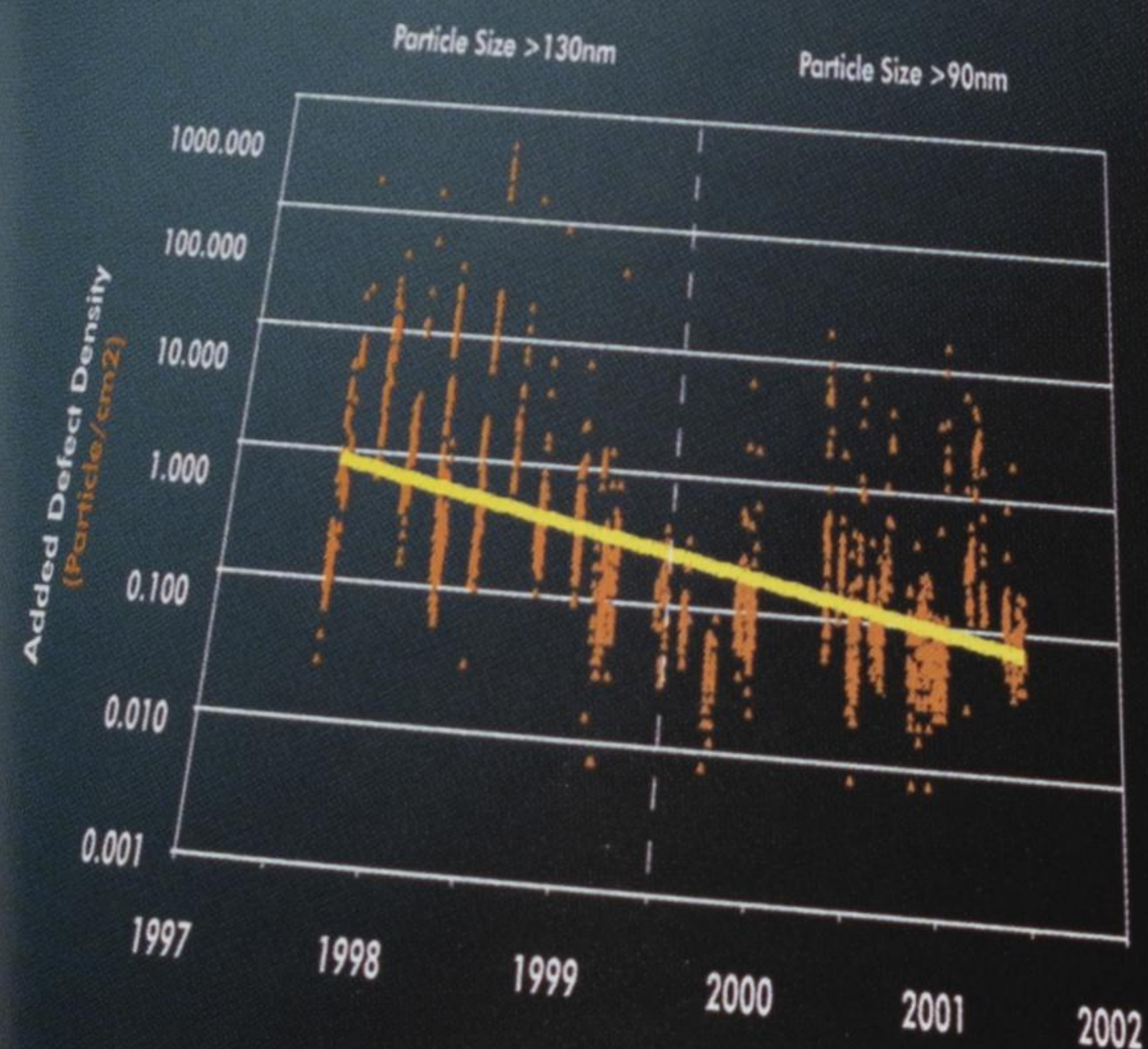
Once again CS-MAX will feature a major exhibition of compound semiconductor-related equipment and materials. Given the economic slowdown of the last 18 months, achieving cost-cutting advantages takes on new significance, and CS-MAX presents a unique, efficient opportunity to survey the current state of the art in off-the-shelf and customized solutions.

The growing exhibitor list includes more than 70 companies, a complete list of which is available on the CS-MAX website. The exhibit will be open from 9 a.m. to 5 p.m. on Tuesday the 12th, and from 9 a.m. to 4 p.m. on Wednesday the 13th. Exhibit-only registrations are available.

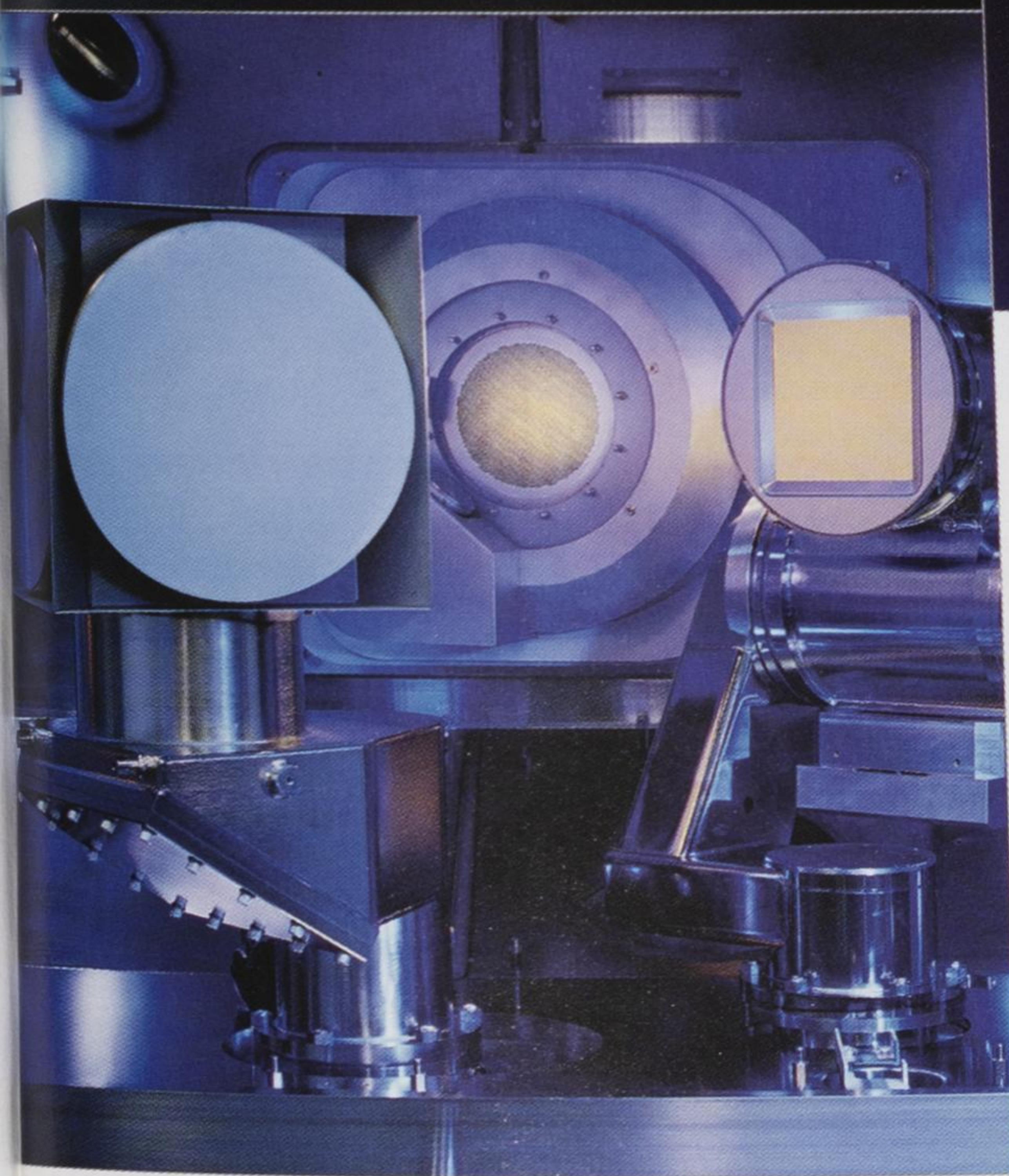
For compound semiconductor manufacturers, just like their silicon counterparts, success depends upon the constant drive to increase performance while at the same time reducing costs. CS-MAX 2002 is an ideal venue for exploring what the industry infrastructure has to offer.

If you would like more information about CS-MAX 2002, please visit the conference website at www.cs-max.com.

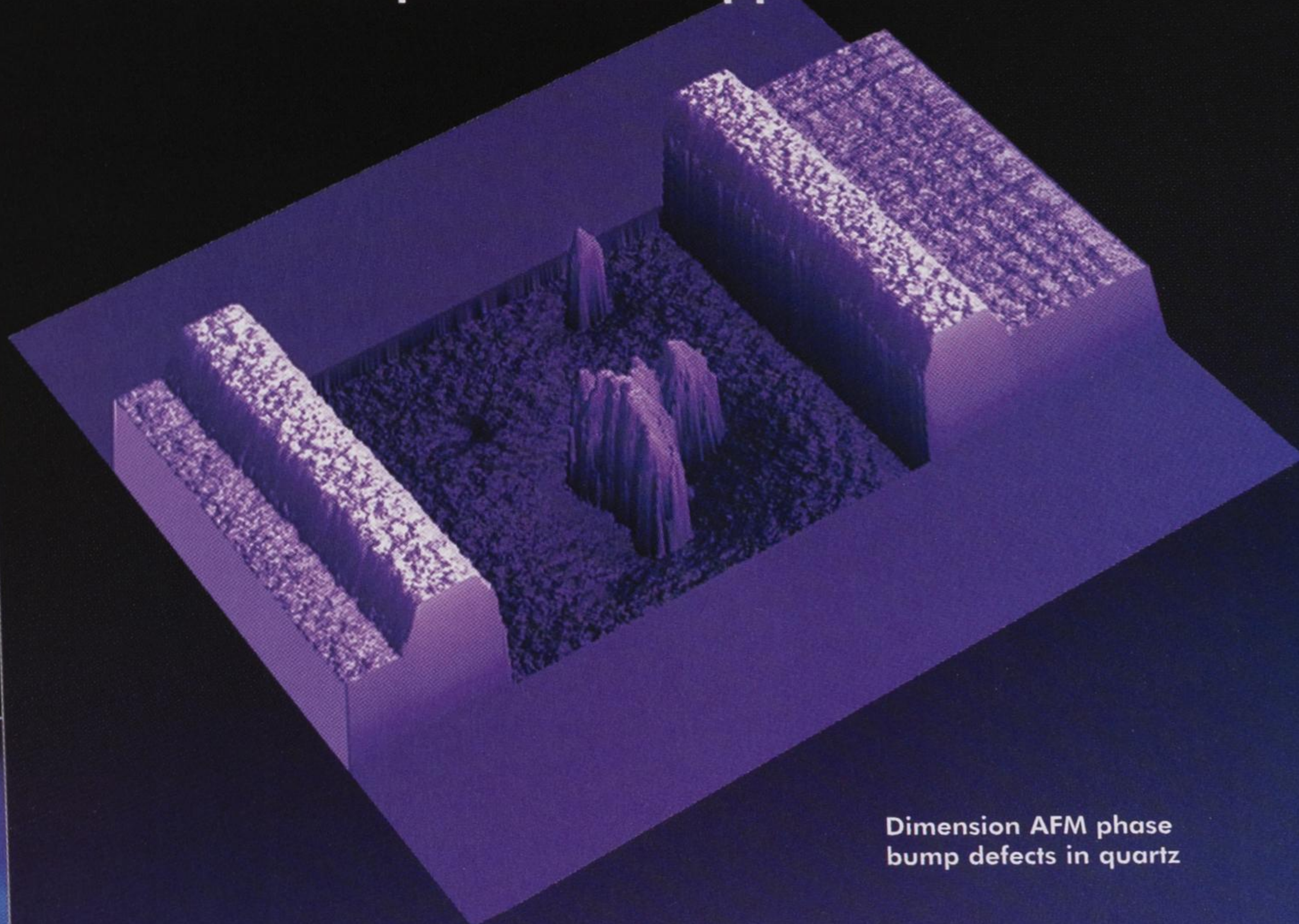
**Advanced photomasks require
low defect density deposition
and sub-nanometer metrology.**



Tool geometry (below) provides low particulate deposition and high yield for advanced photomasks



**Veeco's process equipment and metrology
for advanced photomask applications.**



Dimension AFM phase
bump defects in quartz

**Veeco NEXUS LDD-IBD and Dimension X3D AFM
for unsurpassed results.**

For sub-100nm linewidths, producing photomasks becomes more difficult and complex. Only Veeco has the combination of low defect density ion beam deposition (NEXUS™ LDD-IBD) for single- and multi-layer EAPSM and EUV mask production, and the sub-nanometer resolution of the Dimension X3D™ Atomic Force Microscope (AFM) for measurement and defect review. Together, these technologies create an unbeatable team for producing advanced photomasks—for generations to come.

www.veeco.com/mask
1.888.24.VEECO

Veeco

To advertise your product in this section, contact Joanna Hook on tel. +44 117 930 1033, or email joanna.hook@iop.org.

TechCut 4

Allied High Tech Products Inc

The TechCut 4 is a precision low speed saw excellent for cutting smaller, delicate samples that cannot tolerate excessive friction and heat caused by high speed sectioning. The gravity-fed cutting system uses adjustable weights to apply or counterbalance downward force to the sample during sectioning. With a 3–6 inch blade range, samples up to 2 inches can be sectioned. Features include: Touch pad switches control all functions; Variable speed with LED: 10–500 rpm (10 rpm increments);

Micrometer sample indexing, 1 μ m resolution; Corrosion-resistant aluminum & stainless steel construction.

Contact Gary Liechty, Allied High Tech Products Inc, 2376 East Pacifica Place, Rancho Dominguez, CA 90220, USA
Tel. +1 310 635 2466
Fax +1 310 762 6808
Email gdliechty@alliedhightech.com
Web www.alliedhightech.com



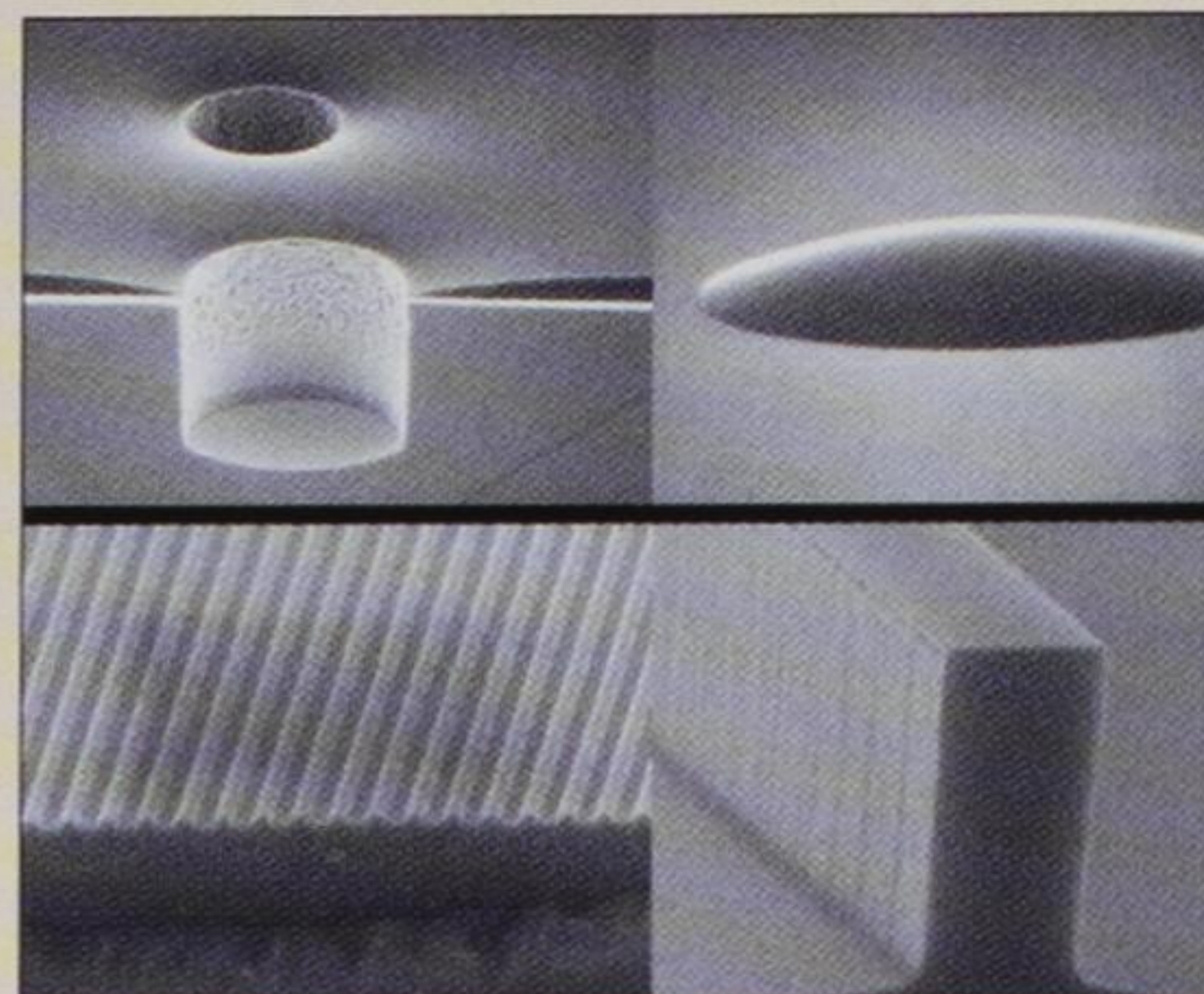
InP Etching Solutions

Unaxis Semiconductors

Unaxis introduces InP dry etching solutions spanning R&D projects from prototype fabrication to volume production. Systems can be configured with either RIE or ICP process technology on manual or automated wafer handling platforms. Reproducible, uniform thermal coupling between the substrate and a heated recirculating fluid electrode is accomplished with mechanical or electrostatic clamping and flow backside helium. Processes developed on entry level Unaxis systems are easily transferred to production platforms with features

that increase maintenance intervals and improve cost-of-ownership. Whether shallow or deep etching, frontside features or backside vias, Unaxis has a hardware and process solution to meet your application needs.

Contact Notker Kling, Unaxis Semiconductors, 10050 16th St N., St. Petersburg, FL 33716, USA
Tel. +1 727 577 4999
Email notker.kling@unaxis.com
Web www.semiconductors.unaxis.com



Double Doping Cluster Source

MBE Components

The use of the Double Doping Cluster Source on one 4.5 inch flange increases the capacity of your MBE system (e.g. GEN II) by only needing a single port for Be and Si doping. Each cell has a conical 5 ccm PBN crucible. After melting the source material in an upwards position, the doping source can even be used in downward ports. A water-cooled shielding between the single cells reduces their thermal

interaction. Cross contamination is minimized by the use of individual shutters separated by a Ta shielding.

Contact Dr. Eberl MBE-Komponenten GmbH, Gutenbergstr. 8, D-71263 Weil der Stadt, Germany
Tel. +49 7033 6937 0
Fax +49 7033 6937 20
Email sales@mbe-components.com
Web www.mbe-components.com



MicroLine 500

Micro-Metric Inc

The MicroLine 500 automatically performs critical dimension measurements on cassettes of wafers. The system employs an auto-loading robot, pre-aligner and motorized positioning stage along with pattern-recognition software to load, align, and measure wafers without operator intervention. It provides measurement accuracy of 0.01 micron with 4 nm (one Sigma) repeatability. The system includes

an extremely flexible, proprietary programming language (MCL) that offers the user full control of the system's functionality.

Contact Micro-Metric Inc, Suite 102, 1050 Commercial St, San Jose, CA 95112-1419, USA
Tel. +1 408 452 8505
Fax +1 408 452 8412
Email info@micro-metric.com
Web www.micro-metric.com



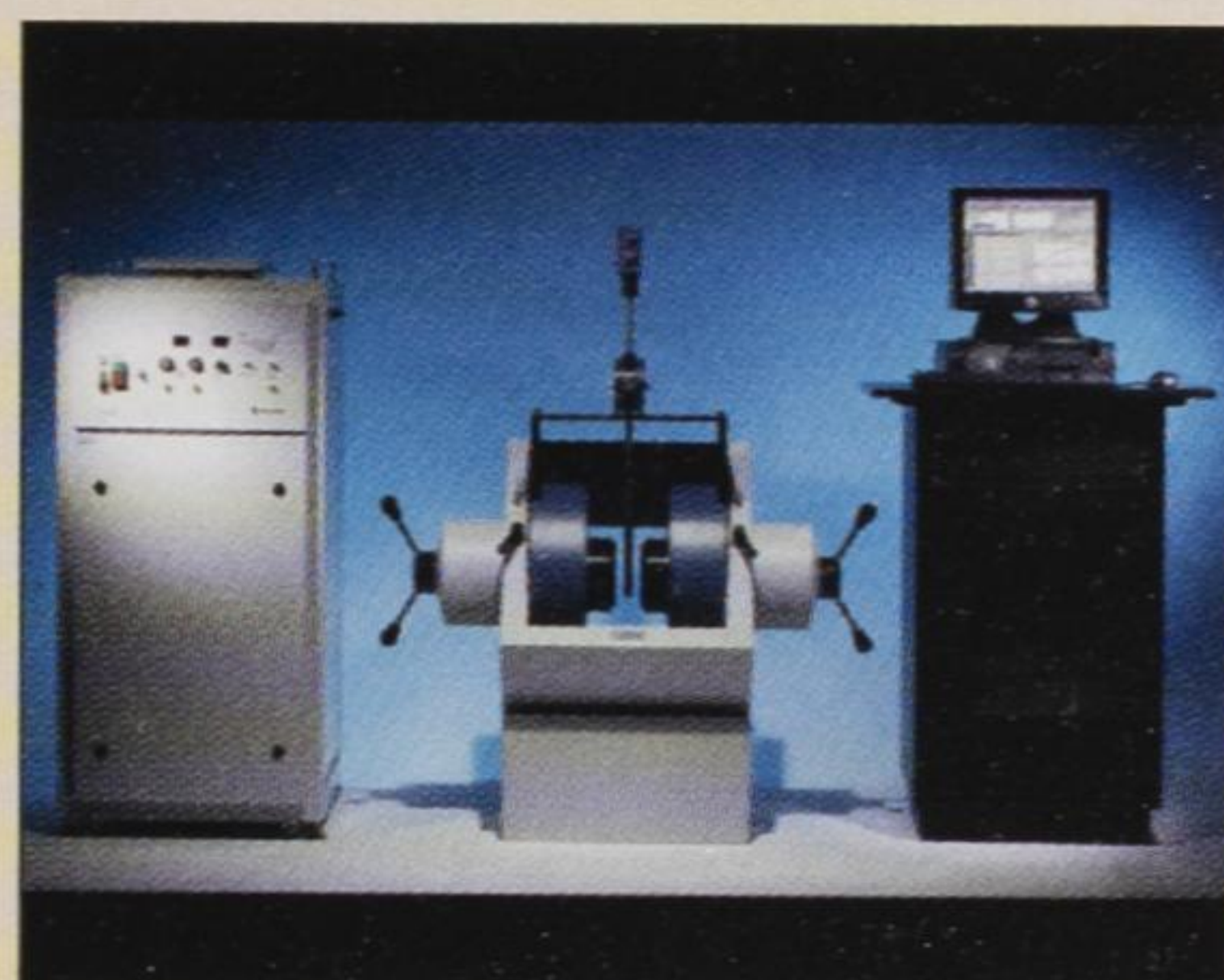
Hall Effect Measurement Systems

Lake Shore Cryotronics Inc

The new 7600/7700 series are the most sophisticated electronic transport measurement systems available. Hall coefficient, voltage, carrier density etc, measurements can be made on samples with resistances from 0.1 m Ω to 80 G Ω , in fields to 2 tesla and temperatures from 15K to 800K. Options including multiple contact I-V measurements, 4-sample or 6 inch wafer capability, and QMSA software

(extracts the mobility and concentration of each carrier species in multi-layer materials) are available.

Contact Lake Shore Cryotronics Inc, 575 McCorkle Boulevard, Westerville, OH 43082, USA
Tel. +1 614 891 2244
Fax +1 614 818 1600
Email sales@lakeshore.com
Web www.lakeshore.com



C2 Optical Surface Analyzer

Candela Instruments

Candela Instruments C2 Optical Surface Analyzer offers fully automated surface inspection for 2 inch to 8 inch optoelectronic or semiconductor wafers. C2 combines scatterometry, reflectometry, ellipsometry and optical profilometry to measure reflectivity and topographic variations across the entire wafer surface.

Applications include: Defect Detection and Classification (particles, stains, pits, bumps, and scratches); Film Thickness Uniformity; and Surface Roughness measurements.

Contact Gale Lane, Candela Instruments, 48890 Milmont Drive, Suite 103D, Fremont, CA 94538-7362, USA
Tel. +1 510 413 0900
Email query@candela-inst.com
Web www.candela-inst.com



Wireless market brings respite for GaAs IC makers

Financial results for the June quarter indicate that the contraction has stopped, at least for now, in the RFIC market, but the fiber market is still floundering.



For the first time in six quarters revenue rose at the majority of GaAs IC companies.

Last month in this column the differing fortunes of RF Micro Devices and Vitesse were used to illustrate the difference in demand patterns between RFICs and optical networking ICs. RFMD had just turned in its best quarterly report in two years, whereas Vitesse produced one of its worst ever. Subsequent reports from the other GaAs companies in our Portfolio confirmed the pattern. For the first time in six quarters the number of GaAs IC companies showing growth in their revenues outnumbered those showing declines. In fact only two companies showed a decline, and they were the two that were most exposed to the fiber market – Vitesse and Multilink.

Anadigics

Boosted by sales of power amplifiers for CDMA, Anadigics posted a significant increase in revenue for the June quarter. Total sales were \$23 m, compared with \$19.5 m for the first quarter. Revenue from the wireless product line was up 45% over the previous quarter (and up more than 100% compared with last year), totalling \$13.1 m, or 62% of total sales.

Anadigics' top customer is Kyocera, but the company is also shipping CDMA power amplifiers to LG Electronics, among others. LG handsets containing Anadigics' InGaP power amplifier modules will go on sale in the US later this year.

However, Anadigics still posted a loss of \$8.8 m for the quarter. Company management is predicting that revenue for the third quarter will be consistent with the second quarter, with wireless-driven revenue growth resuming in the fourth quarter.

Celeritek

Celeritek reported revenues of \$15.3 m, a 16% increase compared with the prior quarter and a 9% increase over the year-ago period. The company reported a net loss of \$1.3 m, compared with a net loss of \$5.1 m for the comparable quarter in 2001.

Commenting on the results, president and CEO Tamer Hussein said that Celeritek shipped a record number of PA modules, and that further increases are expected in the current quarter. Like Anadigics, Celeritek is thriving on business from Korean manufacturers of mobile handsets, especially those with CDMA models. The company expects to report revenues of \$15 m to \$16 m in the September quarter.

Skyworks

In its first quarter as a merged company, Skyworks Solutions reported revenues of \$113 m and a net loss of \$182 m. Company management says that the revenue reflects an increase of approximately 7% from the combined sales of Alpha Industries and Conexant's wireless business in the previous quarter. The loss figure includes several one-time charges associated with the merger.

Skyworks' management says that the company continues to increase its penetration into Motorola handsets, and is now supplying parts to "virtually every" Motorola CDMA and GSM phone. In the June quarter Skyworks also began volume shipments to Samsung, the first major customer won by the merged company.

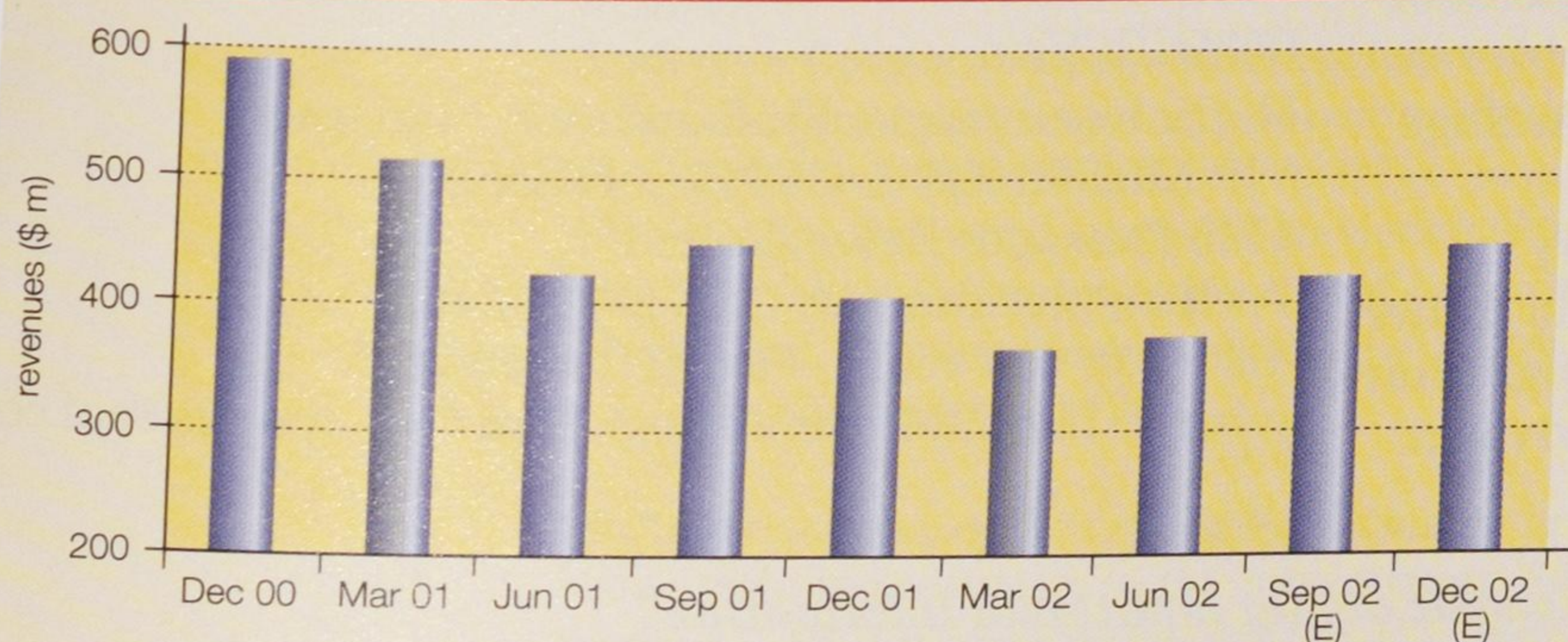
Skyworks president and CEO David Aldrich predicts that revenue will grow by 10% in the September quarter, reaching \$150 m. He said that the company will also "approach operating break-even" in the quarter, with more revenue growth and a return to profitability in the December quarter.

TriQuint

TriQuint reported revenues of \$61.2 m with a net income of \$2.4 m in the June quarter. These results do not include those of the Infineon GaAs operation that TriQuint recently purchased; they will appear for the first time in the results for the September quarter. TriQuint also recently purchased a portion of IBM's RFIC business, which will also impact the third-quarter figures.

For the first time in six quarters TriQuint exited the period with a book-to-bill ratio of greater than 1 (1.07).

Combined quarterly revenues of nine GaAs companies



Semiconductor Wafers MBE Charges
Evaporation Sources Sputter Targets
Semi Insulating Wafers Silicon Wafers
Semiconductor Wafers MBE Charges
Evaporation Sources Sputter Targets
Semi Insulating Wafers Silicon Wafers
Semiconductor Wafers MBE Charges
Evaporation Sources Sputter Targets
Semi Insulating Wafers Silicon Wafers
Semiconductor Wafers MBE Charges
Evaporation Sources Sputter Targets
Semi Insulating Wafers Silicon Wafers
Evaporation Sources Sputter Targets

GaAs GaSb

Beryllium

For MBE

InP GaP

Atomergic Chemetals Corporation
Farmingdale, New York (USA)

Producers of Fine Chemicals, Semiconductor Wafers
and MBE/Sputtering Materials

Tel# 631-694-9000 Fax# 631-694-9177

e-mail: info@atomergic.com

Web Site: <http://www.atomergic.com>



Intelli EPI

The Right Choice
The Intelligent Choice

Intelligent Epitaxy Technology, Inc.



- ◆ Pure-Play Epi Foundry
- ◆ Industry's First "Productions Ready" 4 x 4 inch InP Epi Capabilities
- ◆ Real-time in situ growth sensor technology

We supply the following best-valued epi wafers

- GaAs-based
 - PHEMT
 - HBT (C-doped, Be-doped)
 - MHEMT
- InP-based
 - HBT (4 x 4", DHBT, SHBT)
 - HEMT
 - RTT, RTD
- Opto-electronics
 - 980 Pump lasers
 - VCSEL
 - PIN
 - QWIP
 - Lasers

201 E. Arapaho Road, Suite 200, Richardson, TX 75081
Tel: 972-234-0068 • Fax: 972-234-0069 • E-mail: info@intelliepi.com • www.intelliepi.com

ANNOUNCING

THE 17th ANNUAL

2002 GaAs IC TECH EXHIBITION

(in conjunction with the 24th Annual IEEE GaAs IC Symposium)

PLACE: MONTEREY CONFERENCE CENTER,
MONTEREY, CALIFORNIA

DATES: October 20-22, 2002

- ◆ The largest forum of its kind showcasing all aspects of the GaAs IC industry.
- ◆ One complimentary Symposium Registration Package per booth.
- ◆ Be a Symposium Benefactor by partially or fully sponsoring a coffee break, lunch or reception for either the Symposium or Exhibition. Appropriate recognition will be given to corporate benefactors in the Advance Program and at the Event.

CONTACT:

Harry Kuemmerle, III, Exhibition Manager
VIP MEETINGS & CONVENTIONS
1515 Palisades Drive, Suite I
Pacific Palisades, CA USA 90272-2167
Tel: (310) 459-4691 Fax: (310) 459-0605
e-mail: harry.k@vipmeetings.com OR vipmtgs@aol.com

visit our website: www.gaasic.org for additional information
on current or previous exhibitors and Symposium program

**TriQuint's
book-to-bill
ratio is now
above 1 for
the first time
in 18 months.**

Market overview

Company	Symbol	Closing price on August 15	52-week low-high	Market cap*	P/E ratio†
GaAs IC companies					
Anadigics	ANAD	2.81	2.31-21.05	85.9m	N/A
Celeritek	CLTK	8.65	6.36-16.91	105.8m	N/A
Endwave	ENWV	1.62	1.13-6.28	14.4m	N/A
Multilink	MLTC	0.35	0.30-16.60	26.1m	N/A
RF Micro Devices	RFMD	8.15	5.16-29.53	1.346bn	121.5
Sirenza Microdevices	SMDI	1.80	1.13-8.49	53.7m	N/A
Skyworks Solutions	SWKS	4.04	2.89-36.43	558.9m	0.63
TriQuint	TQNT	4.87	4.85-24.48	640.3m	N/A
Vitesse	VTSS	1.26	1.11-20.17	253.0m	N/A
Opto companies					
Agilent	A	16.03	15.06-37.99	7.442bn	N/A
Agere	AGRa	1.73	1.38-6.30	2.836bn	N/A
Alcatel Optronics	ALAO	2.21	1.50-9.63	36.5m	N/A
Coherent	COHR	20.92	19.70-39.50	604.1m	N/A
Cree	CREE	15.31	10.35-33.32	1.114bn	N/A
JDS Uniphase	JDSU	2.37	2.06-12.44	3.591bn	N/A
Stratos Lightwave	STLW	0.67	0.65-7.40	48.8m	N/A
Uniroyal Technology	UTCI	0.12	0.07-6.47	3.4m	N/A
Semiconductor materials and equipment companies					
ATMI	ATMI	17.28	14.50-37.10	527.9m	N/A
AXT	AXTI	7.35	5.77-21.64	164.9m	N/A
Emcore	EMKR	3.16	2.68-20.15	115.9m	N/A
Kopin	KOPN	6.33	5.30-19.05	438.9m	N/A
Tegal	TGAL	0.83	0.13-2.81	11.9m	N/A
Trikon	TRKN	4.80	4.01-15.90	67.1m	N/A
Veeco	VECO	14.22	12.30-40.12	413.0m	N/A
European companies (currency data in €)					
Aixtron	AIXG.F	7.75	5.25-30.00	501m	N/A
Bede	BED.L	2.58	1.60-3.33	74.7m	N/A
Bookham	BHM.L	1.62	0.93-3.03	229.4m	N/A
Filtron	FTC.L	2.28	1.32-7.03	168m	N/A
IQE	IQE.L	0.69	0.31-3.06	113m	N/A
Picogiga	PGIG.LN	1.50	1.04-5.62	9.69m	N/A
Riber	RIBE.LN	0.99	0.84-5.66	18.5m	5.65
STS	SRTS.L	0.54	0.47-2.69	16.9m	3.13

*Market capitalization = # shares × current share price; †Price/earnings ratio = current share price/(income for the last four quarters/# shares).

Company management expects a revenue increase of \$69 m to \$74 m in the September quarter, with break-even results or a small loss.

In brief

Endwave Corporation reported both improved revenues and gross margins in the June quarter. Revenue rose 41% sequentially to \$6.2 m. Actual net loss was \$6.1 m, compared with a loss in the previous quarter of \$11.4 m. And while gross margins are still in the negative territory, they are at least moving in the right direction, rising from -49% to -20%.

Multilink was one of the two GaAs IC companies to show declining revenues in the June quarter. Sales dropped to \$5.0 m compared with \$10.1 m in the pre-

vious quarter and \$35.1 m in the year-ago period. "The markets for our legacy products have undergone further deterioration during the past three months, and our customers continue to order and forecast very cautiously," said CEO Richard Nottenburg. "In response, we are downsizing aggressively and working on developing a product portfolio outside the optical core."

Sirenza Microdevices reported sequentially level net revenues of \$4.9 m, compared with \$5.4 m in the year-ago quarter. Losses widened to \$973,000, from \$752,000 in the previous quarter. "Although sequential comparisons were level following a strong first quarter, we continued to see signs of market stabilization and improving consistency in our business through the second quarter," said president and CEO Robert Van Buskirk. ●



new challenge?

AOI is exploring the boundaries of laser technology and inventing ways to build better semiconductor lasers. We are currently expanding our Houston area manufacturing and R&D groups.

A sample of our current openings:

Vice-President of Manufacturing
MBE Growth Engineer
Quality Control Manager
RF Packaging Engineer
Semiconductor Processing Engineers
Semiconductor Processing Manufacturing Mgr.

AOI is an E.O.E.

for further information or to submit a resume:

jobs@ao-inc.com • 13111 Jess Pirtle Blvd. • Sugar Land • TX • 77478

www.ao-inc.com/careers

Opportunities for Employment Advertisements

Compound Semiconductor is the number one publication in the compound semiconductor field, with readers at virtually every fab and lab in the industry. If you are looking for managers, engineers and technicians with III-V experience, advertising in *Compound Semiconductor* is your most cost-effective option.

Specifications

Please submit your advertisement as a 300 dpi, CMYK, Acrobat 3.0 compatible PDF file with all fonts embedded. If you do not have an advertisement, we can prepare one for you – simply email us your text and a copy of your logo.

Deadlines

October issue – September 6; November issue – October 4

Rates and sizes

Please contact Dan Huckle or Joanna Hook, or download our media pack in PDF format from our website.

Contact

Dan Huckle, Joanna Hook
Compound Semiconductor
Institute of Physics Publishing
Dirac House
Temple Back
Bristol BS1 6BE, UK
Tel. +44 117 930 1033
Fax +44 117 930 1178
Email dan.huckle@iop.org, joanna.hook@iop.org

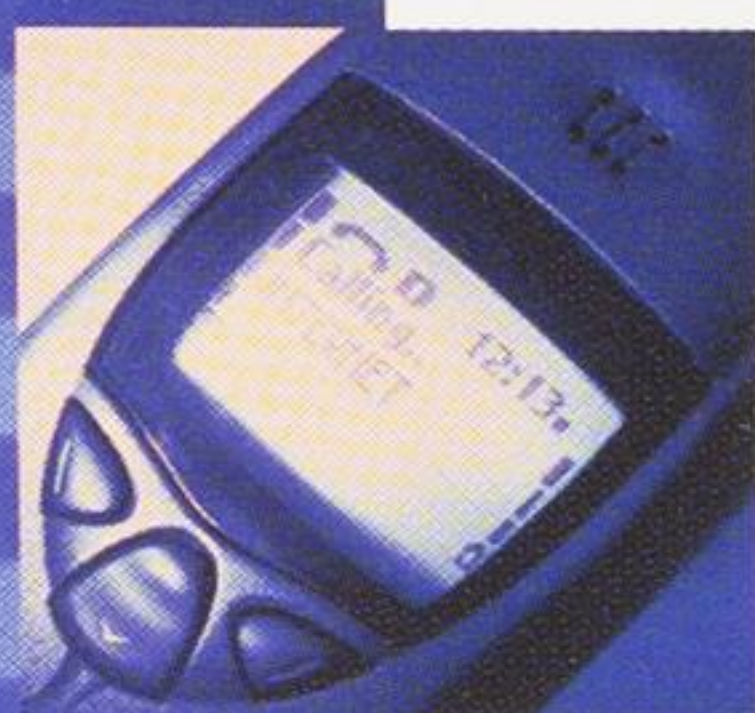
www.compoundsemiconductor.net

Advertisers' Index

Addon	50	IntelliEPI	58
Advanced Ceramics	42	IQE	18, 19
Aeronex	26	LayTec	22
Aixtron	5	Modulight	6
ATMI	33	Nitride Semiconductors	9
Atomergic	58	Praxair	OBC
AXT	52	QinetiQ	23
Bandwidth Semiconductor	23	Raboutet	15
Bede	16	Riber	28
CS-MAX conference and expo	8	Rubicon Technology	14
DCA	44	SAES Pure Gas	51
Emcore	13	Samco	47
Epichem	31	Shipley Metalorganics	IBC
EV Group	24	Tekcore	47
Freiberger	38	Thomas Swan Scientific Equipment	41
GaAs IC symposium	58	Umicore	48
GEO	34	Unaxis	10
Gigacomm	IFC	Veeco-Applied Epi	20
Henry Butcher	36	Veeco Instruments	55

Our name
has changed.
Our reputation
for quality,
has not.

www.metalorganics.com



Rohm and Haas Metalorganics is now

Shipley Metalorganics

SOURCES FOR SUPERIOR DEVICESSM

WE DELIVER

Performance

Epi-certified TMGa,
TMIn and TMAI.

WE PROVIDE

Consistency

Highest purity with
every cylinder.

WE GUARANTEE

Service

Unsurpassed technical
and customer service.



North America

Shipley Company, L.L.C.
60 Willow Street
North Andover, Massachusetts
01845 USA
Tel: 978-557-1700
Fax: 978-557-1701

Taiwan

Shipley Taiwan Company Ltd.
No. 6 Lane 280
Chung Shan North Road
Ta Yuan Industrial Zone
Ta Yuan Hsiang
Taoyuan Hsien, Taiwan
Tel: 886-3-385-8000
Fax: 886-3-385-5989

Japan

Shipley Far East Ltd.
Sanbancho UF Building
6-3, Sanbancho
Chiyoda-ku
Tokyo 102-0075 Japan
Tel: 81-3-5213-2924
Fax: 81-3-5213-2948

Europe

Shipley Europe Ltd.
La Tour de Lyon
185 Rue de Bercy
75012 Paris, France
Tel: 33-1-40-02-54-37
Fax: 33-1-40-02-54-07

South Korea

Shipley Korea Ltd.
Kyungmok B/D 3F
1354-5, Seocho-dong
Seocho-ku
Seoul 137-070 Korea
Tel: 82-2-3474-2179
Fax: 82-2-3487-1767

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**

