

COMPOUND SEMICONDUCTOR

October 2002 Volume 8 Number 9

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MOBILE HANDSETS Color displays and cameras promise to lift the market

ALSO INSIDE

**Reflective mood
prevails at ECOC**

**CS-MAX timetable
and showguide**

**Modeling of GaN
MOCVD growth**

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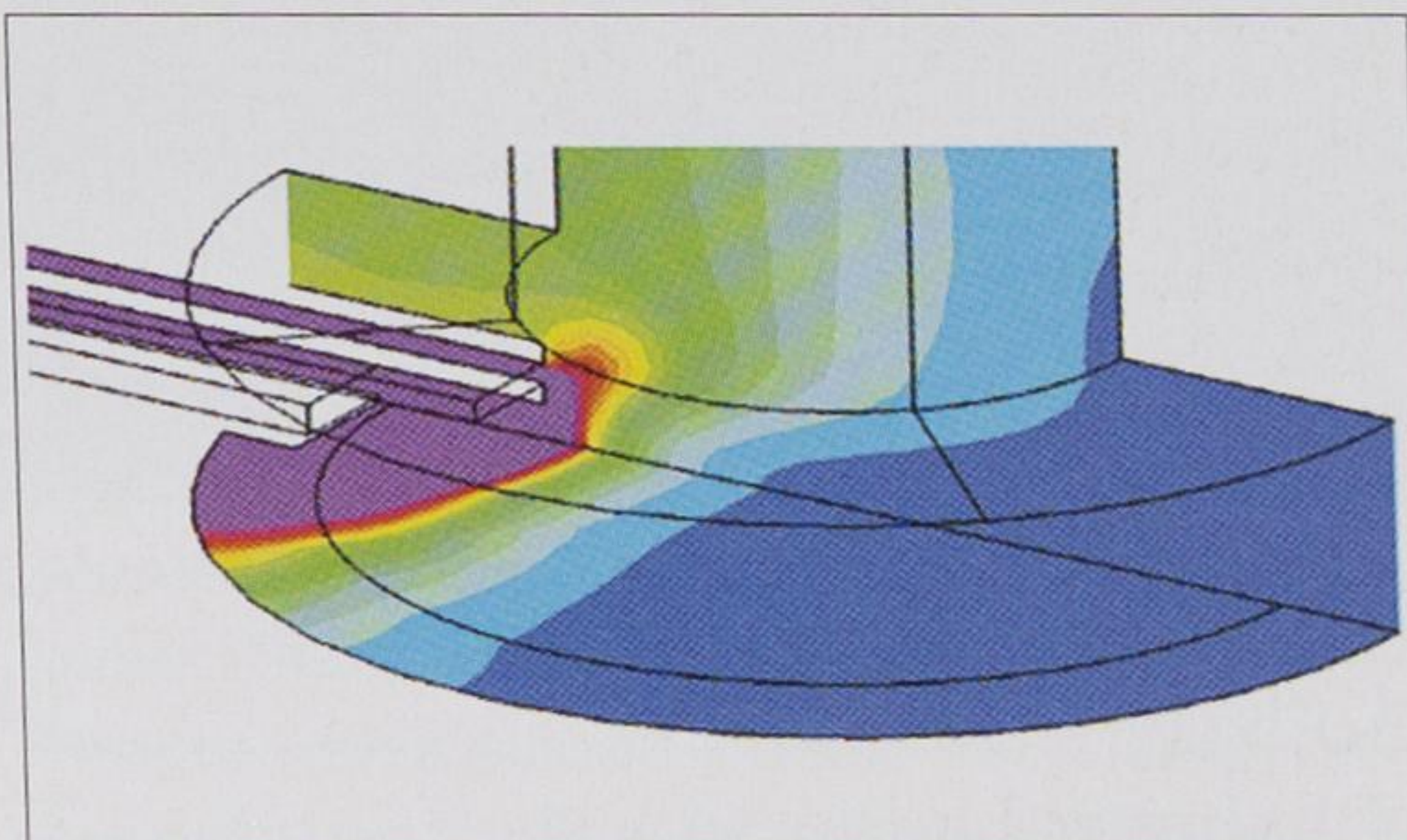
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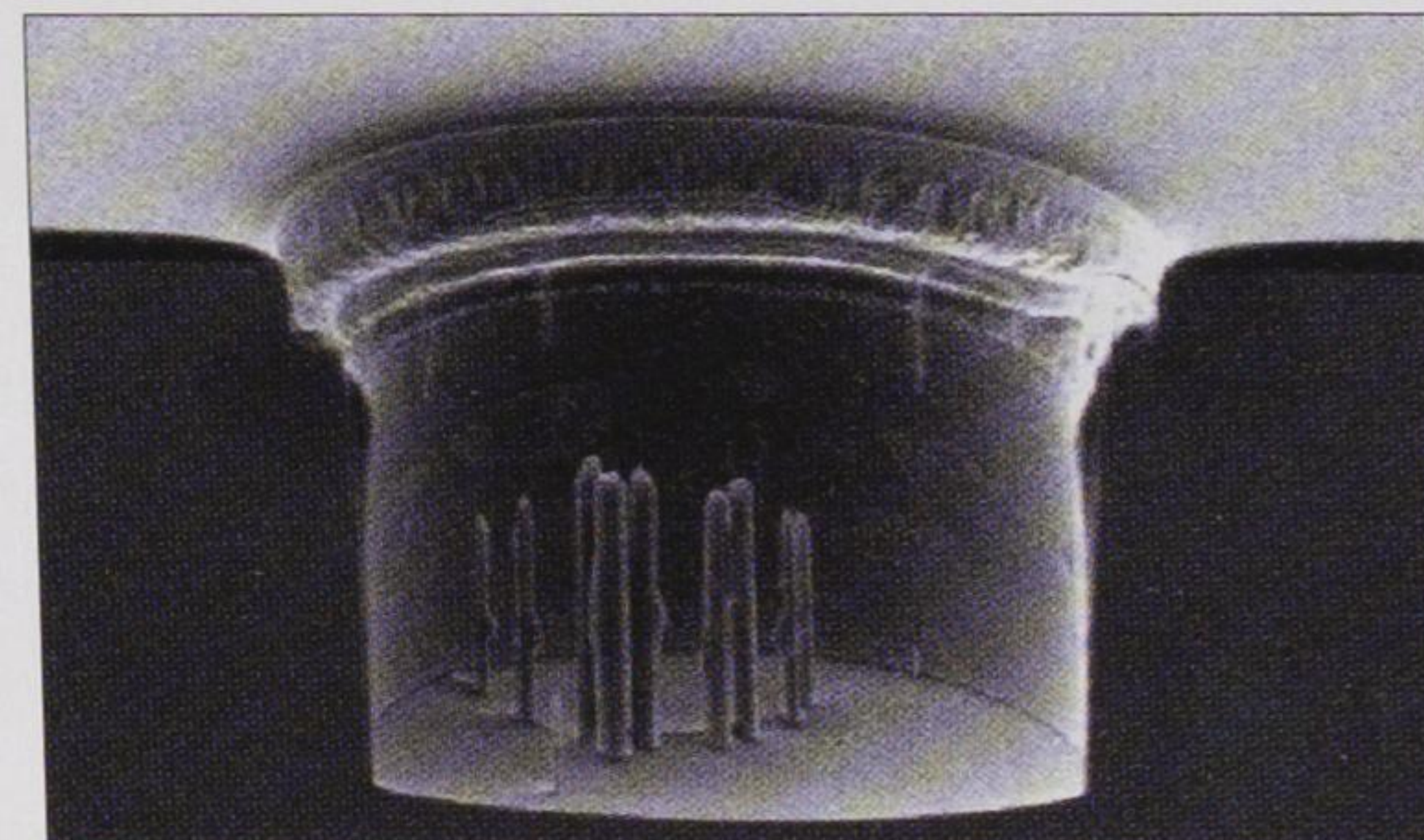
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Reflective mood prevails at ECOC

By Jon Newey

The dearth of product and company news in the days leading up to the European Conference on Optical Communications (ECOC), held September 8–12 in Copenhagen, Denmark, did not inspire great confidence that the event itself would be much better. Attendees returning from Copenhagen described the exhibit hall as being relatively quiet compared with last year's event when the fiber-optic industry was already well into its current recession. One year on and everyone is still trying to predict when things will bottom out. Recent news such as that of Agere and ADC axing their optical components units indicates that the industry may still have some way to fall.

Reducing costs

In the opening session of the conference, David Payne, director of the Optoelectronics Research Centre at the University of Southampton, UK, described how the major areas of interest for the industry have shifted from the long-haul to areas such as metro networks and fiber-to-the-home. These applications may be component hungry, but they are also cost conscious. "Cost reduction is now the single most important issue," said Payne. To achieve this, Payne's view is that tunable



Alcatel Optonics' receiver combines InP-based SOAs (seen at the bottom left of the image) with a silicon-based AWG (seen on the right) on a silica-on-silicon platform.

devices and hybrid integration will be the key technologies, and that component makers will need to invest in automated assembly to help keep manufacturing costs down.

In the exhibition halls the atmosphere was somewhat subdued. "The industry is very inward looking right now," said fiber-optic industry analyst Jeremy Mills, speaking to *FibreSystems Europe* magazine. "Everyone's in maintenance mode. It's just like what happens at a company when staff know there are going to be layoffs. There's lots of gossip and rumors, with many of the exhibitors here [at the show] looking around and asking who's going to be the next to go out of business."

There are numerous companies working with technologies that they believe will enable them to deliver cost savings to network builders. One of the companies aggressively pursuing this strategy, through device integration, is France's Alcatel Optonics. "We have always championed integration as the only solution for cost and size reduction," said Philippe Bregi, COO of Alcatel. "This directly impacts not only the component world but, more importantly, the system and operator domains."

Backing up these comments, Alcatel demonstrated two new products that combine semiconductor active and passive components onto a silica-on-silicon platform. The first was a transmitter that monitors and adjusts eight wavelength channels before combining them. According to Alcatel, the combiner integrates 41 functions, including VOAs, monitoring photodiodes and a passive combiner, onto a silica-on-silicon platform.

Alcatel's second new product to demonstrate high levels of integration was a wavelength-division demultiplexer for extracting 8×10 Gbit/s channels with 50 GHz wavelength spacing. The device uses an InP-based semiconductor optical amplifier (SOA) with an AWG on a single silica-on-silicon platform.

Manufacturers reshape to cope with difficult market conditions

By Richard Dixon and Jon Newey

Lower spending on wireless handsets and optical communications equipment has led to lower sales, forcing equipment and component makers to slash jobs and restructure their operations. In recent weeks the compound semiconductor sector has seen a number of companies announce restructuring programs as they deal with current and anticipated future market conditions.

TriQuint and IQE take tough action

Following the consolidation of its Texas operations and a wafer upgrade in Oregon, TriQuint will reduce its global workforce of 1600 employees by 7%. The changes have affected about 15% of the 465 employees in Hillsboro, OR, where the company recently upgraded its GaAs fab to handle 6 inch wafers (*Compound Semiconductor* April 2002 p59).

Also affected are about 10% of the 425 employees in Richardson, TX, where the company recently consolidated its various manufacturing facilities.

"This is a difficult but necessary action impacting a loyal and hard-working team of employees," said TriQuint's Ralph Quinsey, president and CEO. "However, with the continued impact of slow telecommunications spending, we are adjusting our workforce at these locations in order to better match capacity with demand."

Quinsey added that TriQuint's SAW filter business at Sawtek, located in Orlando, FL, and Costa Rica, continues at record production levels, and that no reductions in force are planned for these locations.

One of the many companies rethinking its strategy is epiwafer vendor IQE, which has undergone a "comprehensive strategic

review" of its business. One of the outcomes of this is the placing of a renewed emphasis on the wireless, solid-state lighting, optical storage and strained silicon markets.

The review has also led to significant cost control/reduction actions, including around 60 redundancies that have reduced the company's total workforce to 310. IQE has also announced changes to its directorate (see People news p21).

"Notwithstanding the weak industry outlook, we continue to make significant product progress, particularly with regard to our leading position with strained silicon, which is quickly becoming recognized as the key material for next-generation microprocessors," said Drew Nelson, IQE's president and CEO.

Endwave goes offshore

One of the ways that companies can reduce overheads is to move manufacturing to lower cost areas of the world. Endwave, a producer of microwave and millimeter-wave subsystems, has signalled its intention to go to >>

offshore manufacturing, and is restructuring with the loss of 40% of its workforce. The cuts will affect Endwave's sites in Sunnyvale and Diamond Springs, CA, and will leave the company with about 130 employees.

"These changes reflect our belief that no recovery of the telecom market will occur before 2004. The changes will position the company to realize significant cost savings in the fourth quarter and further ahead," said CEO and president Edward Keible.

Tool manufacturers not immune

Those producing manufacturing equipment have suffered the knock-on effects of their customer's reduced output and scaled-back capital investment plans. Trikon, a manufacturer of semiconductor processing equipment based in Newport, UK, plans to reduce its head count by around 20%. The company, which currently employs around 400 people

"These changes reflect our belief that no recovery of the telecom market will occur before 2004."

worldwide, hopes to achieve cost savings of around \$1 million per quarter.

Trikon's president and CEO Nigel Wheeler said the reductions would only minimally affect product and process development and the support of strategic programs.

Newport Corporation, a supplier of automated assembly and test systems, has restructured its two operating divisions. The company's former Fiber Optics and Photonics Division (FPD) has now been reorganized into the Advanced Packaging and Automation Systems Division (APAS), which

will cover all of the company's automation equipment technology.

The Industrial and Scientific Technologies Division (ISTD) will focus on instruments and subsystems for optical, optomechanical, vibration isolation and motion control. Several facilities will be consolidated and between 225 and 275 jobs will be lost, resulting in annualized savings of between \$12 million and \$14 million.

"While we still strongly believe in the long-term prospects of the fiber-optic industry, we currently do not see a return to growth for us in this market until at least 2004," said Robert Deuster, president and CEO. Orders from the company's semiconductor capital equipment customers have remained strong in the last six months, but Newport's management team remain concerned about uncertainty in the marketplace related to the timing of the recovery cycle.

Gore Photonics puts VCSEL business up for sale

Gore Photonics, a manufacturer of VCSEL-based transceivers, is on the market. Parent company W L Gore & Associates has decided to sell its fiber-optic business as part of its strategy to focus on electrical interconnects.

Gore Photonics supplies VCSEL-based parallel optic arrays for very-short-reach interconnection between electronic components and systems. In addition to Gore's 850 nm VCSEL technology, the company has demonstrated optically pumped 1310 nm VCSEL structures targeting longer reach applications.

"We are refocusing Gore's electronic components business on high-performance electrical interconnects and materials," said Russell Shaller, general manager of Gore Photonics. "As we seek interested buyers for the fiber-optic business, we will continue to fully support the needs of our customers and meet our commitments to them."

Despite the current industry downturn, Gore Photonics says that it is experiencing "robust sales growth" for its nLighten parallel optic products. Last year the company

outsourced packaging of the nLighten modules to Flextronics, a Singapore-based contract manufacturer (*Compound Semiconductor* August 2001 p18).

Gore claims to be one of only two manufacturers to have successfully launched 12 x 1.25 Gbit/s modules, which are currently being shipped for use in production systems.

Gore acquired its 850 nm VCSEL technology through its purchase of Optical Concepts, a spin-off from the University of California at Santa Barbara.

Uniroyal aiming to restructure under Chapter 11 code

Uniroyal Technology has filed for reorganization under Chapter 11 of the US bankruptcy code, just weeks after the company was cited in several class action lawsuits for allegedly misleading investors. Chapter 11 allows a company a window of time, free from the demands of creditors, in which to reorganize its business to better deal with its financial difficulties.

Uniroyal says the petition, filed at the District Court of Delaware in Wilmington, should enable it to continue with no impact on customers, employees or operations, and will allow a restructuring of debt and relieve

cash-flow issues. Uniroyal received a commitment for up to \$15 million of debtor-in-possession financing from The CIT Group to ensure that customer and vendor relationships remain intact during the process.

The company also said the court had approved orders to pay pre-petition claims in full to vendors who agree to continue supplying the company's strongest operating unit, Uniroyal Engineered Products, and to critical subcontractors of its Sterling Semiconductor subsidiary. Pre-petition claims for the company's Uniroyal Optoelectronics and NorLux subsidiaries will be resolved through the Chapter 11 process.

According to a recent SEC statement, the company saw sales growth in high-brightness LEDs up to the end of June, particularly for UV devices used in equipment for counterfeit detection. However, the company has suffered

"severe liquidity constraints" from the costs associated with developing the high-brightness LED business and its SiC technology through Sterling. Uniroyal continues to seek a buyer for Sterling following the recent failure of the deal with Umicore (see *Compound Semiconductor* July 2002 p3).

"Today's action provides us with time to restructure our balance sheet while continuing to operate our businesses without interruption," said Uniroyal chairman and CEO Howard Curd. "We hope to emerge from this process quickly as a stronger, more competitive organization."

Events took a further turn for the company when it was delisted from the Nasdaq Small Cap index on September 5. A day later, the shares were trading through the National Quotation Bureau at a new 52 week low of \$0.03.

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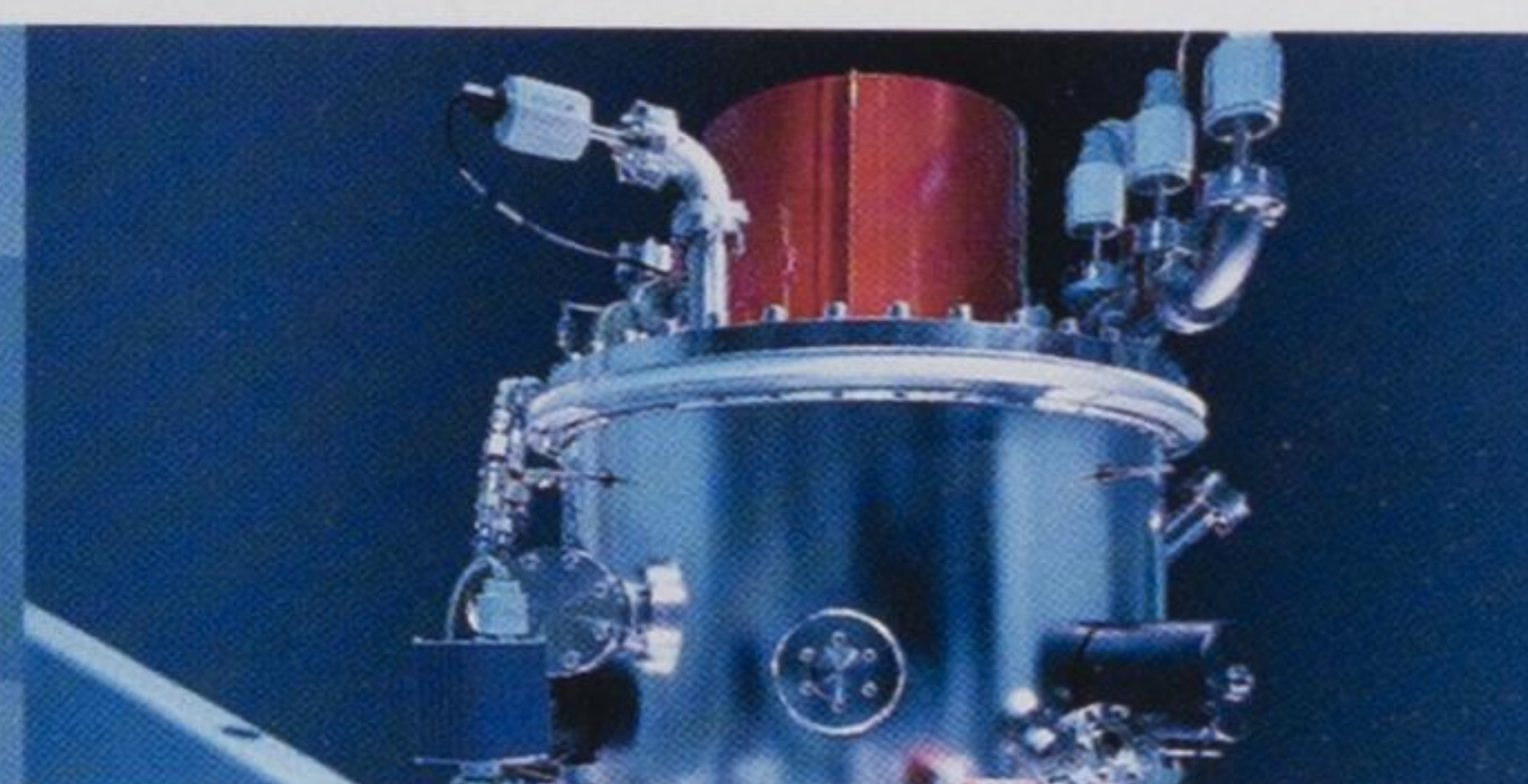
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GCS allies with Plextek to boost design resources

Global Communication Semiconductors (GCS) has formed a strategic alliance with Plextek, a circuit and systems design consultancy located in Great Chesterford, UK. Under the terms of the alliance Plextek will have access to GCS's fab, enabling it to provide its customers with compound semiconductor foundry services. Plextek will assist GCS as the company's UK resource for IC design services. Plextek has experience in the design of GaAs ICs for GSM handsets and broadband wireless access.

"In this dynamic economic climate we

continue to see the disintegration of the traditional integrated device manufacturer, which has given birth to businesses that specialize and reduce the total costs to bring ICs to market," said Owen Wu, founder and chief strategy officer at GCS.

Wu believes that the availability of compound semiconductor foundry services provided by GCS, coupled with Plextek's design consultancy expertise, will allow fabless companies to move quickly and cost effectively to address the wireless and high-speed telecommunications markets.

Skyworks releases 2.4 GHz HBT PAs

Wireless LAN applications are being targeted for Skyworks' new 2.4 GHz linear power amplifier. The AP157-317 linear PA is fabricated using Skyworks' GaAs HBT process, and supplies 27 dBm of linear output power with 802.11b modulation at 11 Mbit/s. The device is housed in surface-mount packaging, making it suitable for design into WI-FI wireless LANs, 2.5 GHz spread spectrum transmitters and other ISM band devices. The second device, the AP163-317, provides 23.5 dBm of linear output power. Both devices deliver an output power of 31 dBm and small signal gain of 18 dB across the 1.8 to 2.5 MHz range.

Packaged in a 16-pin 4 x 4 mm micro lead package, each device operates with power



Skyworks' new GaAs HBT PAs are designed for ISM band applications at 2.4 GHz.

supplies ranging from 2.7 to 4.5 V, to accommodate access points and battery-powered wireless devices such as notebook PCs.

WJ Communications expands mixer series

WJ Communications (San Jose, CA) has augmented its MMIC mixer line with two new devices. The MH203 and MH205 are GaAs MESFET mixer ICs and are the first of the company's mixer products to target cellular frequency bands from 800 to 960 MHz in surface-mount SOIC-8 packages. Features include a high IIP3 of +32 dBm, conversion loss of 8.5 dB, and a noise figure of 9.0 dB. Targeting GSM, TDMA, CDMA, EDGE and CDMA 1x systems, volume production is planned for December 2002.

RSC unveils GaAs DAC converter IC

Rockwell Scientific Company (RSC) has released a new 12-bit digital-to-analog converter (DAC) intended for commercial and defense markets. The RDA012 is a mixed-signal IC that exhibits a 65 dBc dynamic range at 333 MHz output frequency with a 1 GHz clock.

The DAC is fabricated using RSC's GaAs technology and is highly linear at a high IF, enabling direct up-conversion without the use of linear mixers. Target applications include radar systems, cellular base stations, satellite terminals and point-to-multipoint links.

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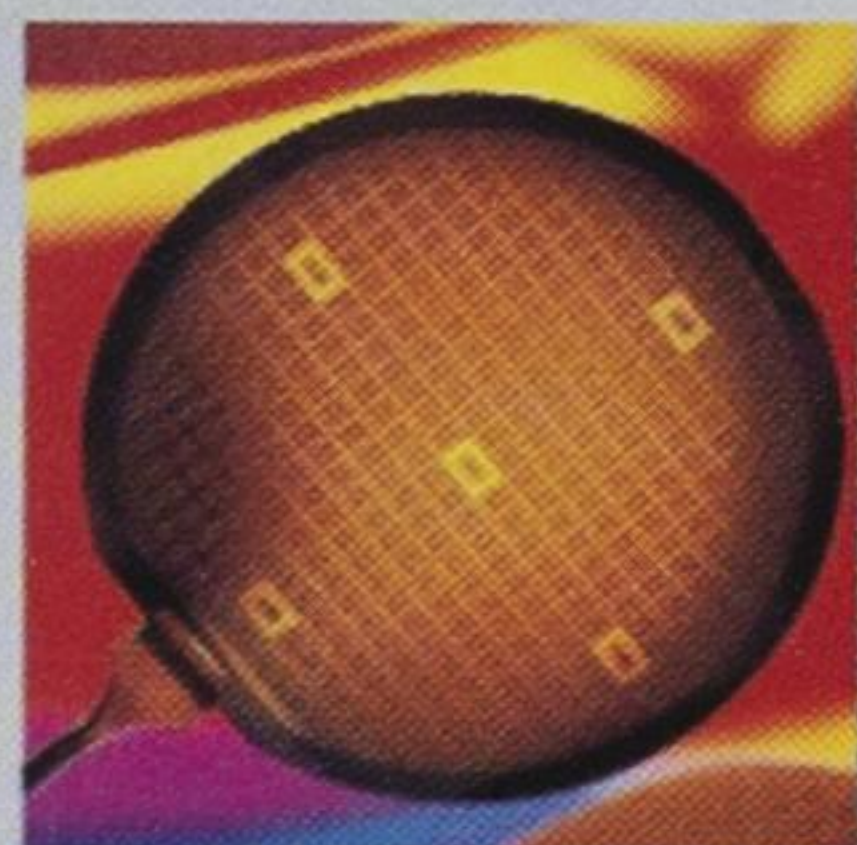
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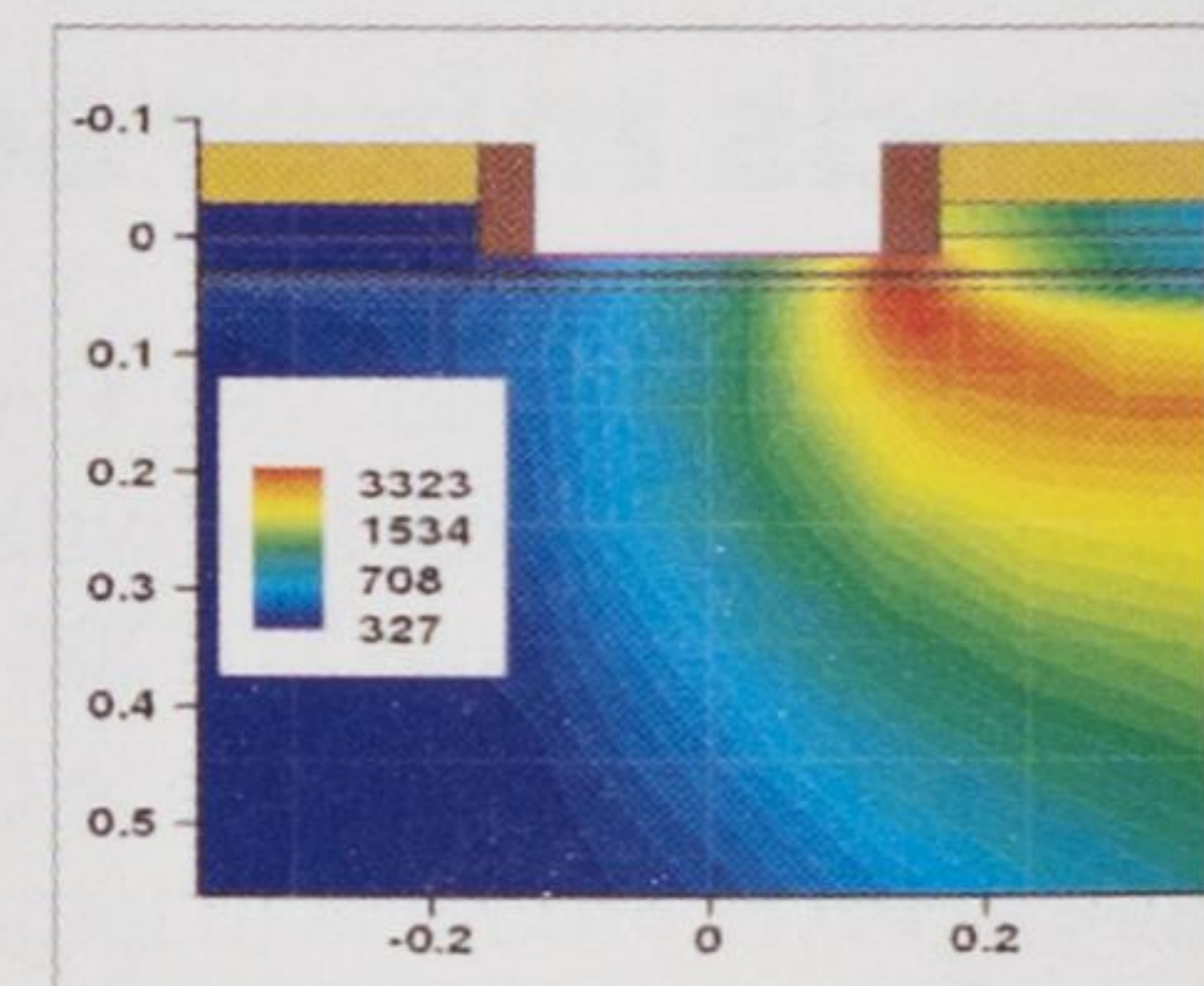
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Osram Opto sheds some light on the boardroom



OSRAM OPTO SEMICONDUCTORS

Osram Opto Semiconductors' LED modules have been used in the five panels above the board table. Each panel contains 128 modules, giving a total of 4096 LEDs per panel.

White Linearlight LED modules from Osram Opto Semiconductors have been used in lighting fixtures by the designers of a new boardroom at the Swiss Kantonalbank in Lucerne. The design called for the board table to be lit by five thin panels suspended above the table, each measuring $1 \times 1 \text{ m}^2$. Using the LED modules, which contain Osram Opto's 5 mm thick

TOPLEDs, allowed the thin design criteria to be met.

Each of the suspended panels comprises 128 of the Linearlight modules, giving a total of 4096 white LEDs per panel. The panels can be dimmed and give off a maximum 400 Lux each, at a distance of 1.2 m from the table.

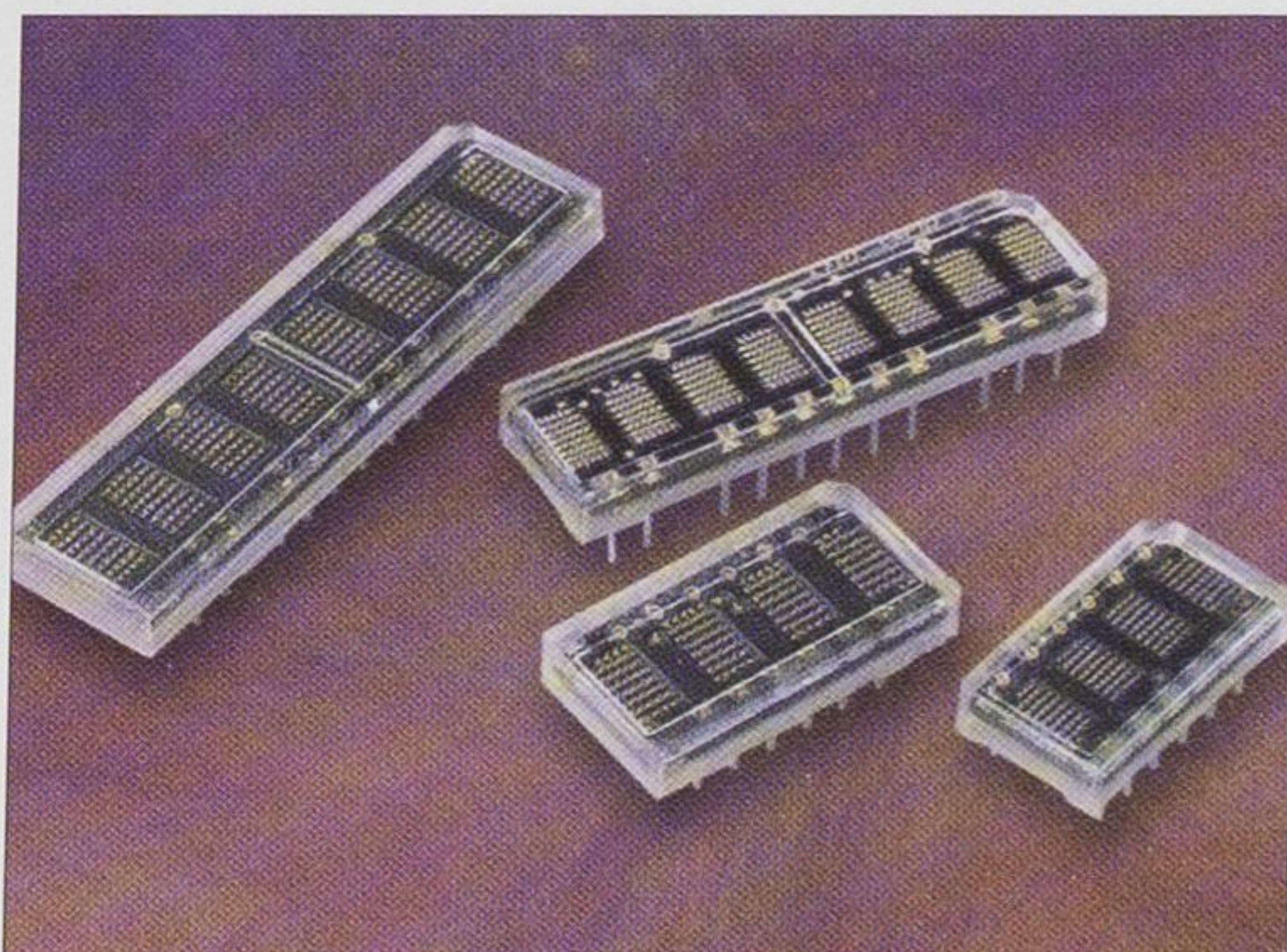
Agilent reveals dot-matrix LED displays operating at 3.3 V

Agilent Technologies has introduced the industry's first LED dot-matrix alphanumeric displays operating from a 3.3 V supply.

The HCMS-39XX series is compatible with standard 3.3 V microprocessors and logic circuits, and interfaces directly with the microprocessor or microcontroller, simplifying power supply design and reducing board space and costs. The 5×7 pixel format panels can be stacked in both x- and y-directions to create compact high-density information displays.

"With the delivery of the first 3.3 V smart LED displays, we have simplified new system design by eliminating the need for a separate 5 V supply," said Soo-Ghee Lee, VP and general manager of Agilent's Opto-electronic Products division.

Agilent's new units are supplied in four- and eight-character versions, each with a



AGILENT

Agilent's new 3.3 V LED dot-matrix displays are compatible with standard electronics and simplify power supply design.

choice of 0.15 or 0.20 inch character height and standard red, orange and green LEDs. AllInGaP LED displays are also available for applications requiring extra brightness.

Toyoda Gosei and Nichia settle dispute

On September 17, rival Japanese GaN LED makers Nichia and Toyoda Gosei announced details of their agreement to finally settle their long-running patent dispute (see *Compound Semiconductor* September 2002 p3 for further details). The companies have agreed that each is free to use existing patents belonging to the other party, and that all outstanding patent litigation proceedings will be dropped.

Toyoda Gosei has agreed to pay a royalty fee to Nichia in respect of future white LED products that use YAG phosphors, and the companies will negotiate "reasonable" royalties if either wishes to use future patents belonging to the other.

Luxeon LEDs chosen by Color Kinetics

Lumileds Lighting (San Jose, CA) has been selected by Color Kinetics to provide LEDs for three of its intelligent color-changing LED fixtures. Lumileds' Luxeon LEDs will be incorporated into Color Kinetics' ColorBlast range of indoor/outdoor wall-washing fixtures, and also a spotlight product.

The new fixtures are scheduled for release in the fall. The ColorBlast 12, the largest of the three units, uses 36 of Lumileds' 1 W emitters to produce the same light output as 360 conventional high-brightness LEDs.

Kyocera introduces ceramic packages

Kyocera has developed the LED industry's first surface-mount ceramic package, in response to the continuing trend for high-brightness LEDs to be surface mounted in thin packages. Heat dissipation from small high-brightness devices is an important consideration in maintaining device reliability. Kyocera's ceramic multilayer package is designed to maximize the heat dissipated from the LED chip, while keeping its size to a minimum.

The LED packages are available in a number of shapes and sizes, and use ceramics such as alumina and aluminum nitride, which tolerate high heat loads and offer more efficient heat dissipation than resin materials. They can also be surface coated with reflective materials to improve light extraction from the LED chip.

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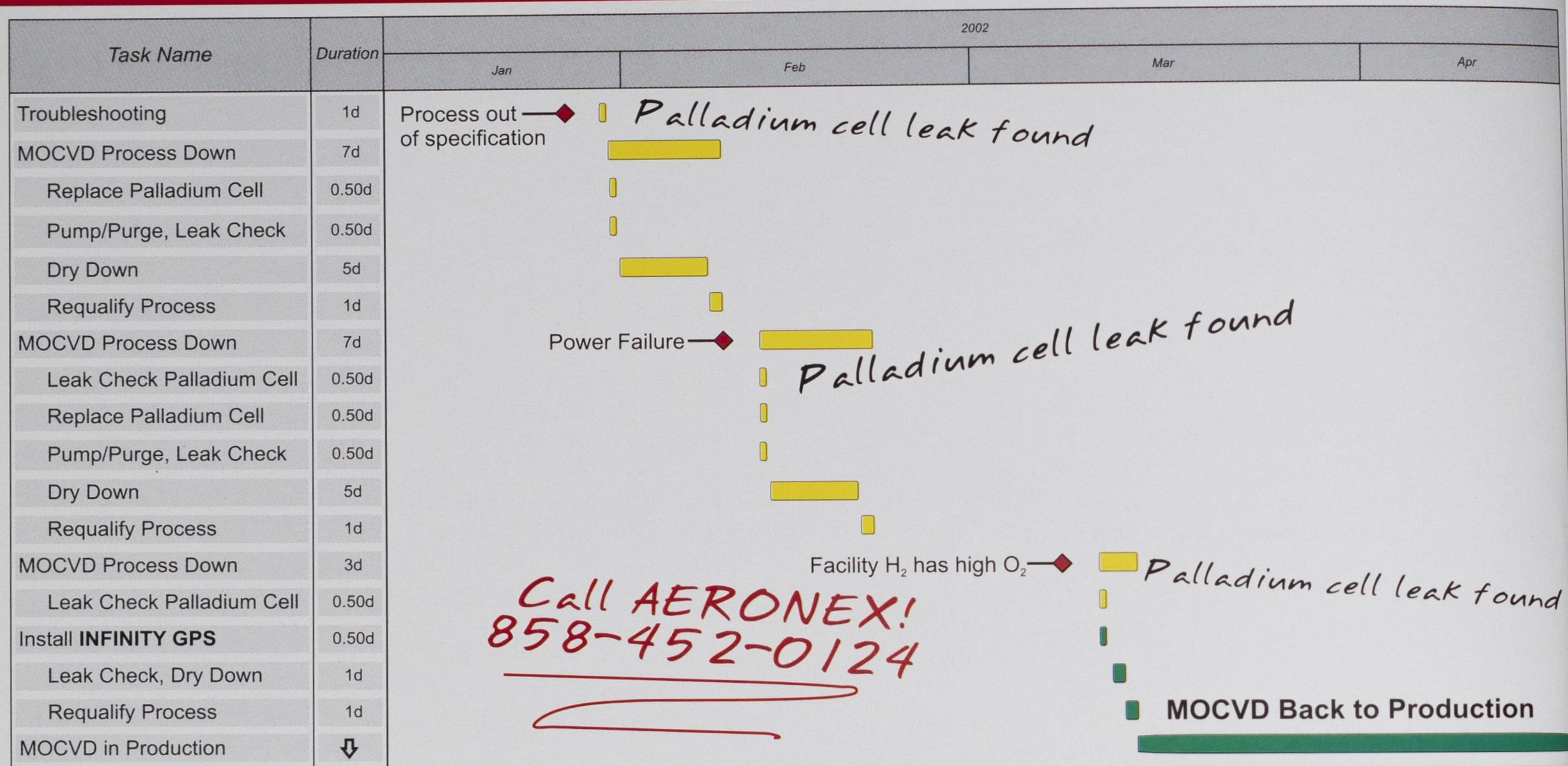
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Toshiba, NEC create rival DVD format

By Tim Whitaker

Toshiba and NEC have joined forces to create a new standard for next-generation optical storage systems. The technology, which uses 405 nm violet lasers, will compete directly with the Blu-ray Disc announced in February of this year (see *Compound Semiconductor* April 2002 p3).

The Toshiba-NEC format has been jointly proposed to the DVD Forum, an industry-wide group that includes producers of films and computer software. By disclosing the technical specifications of the standard, NEC and Toshiba are likely to win support from other manufacturers that have not joined the Blu-ray camp. The Blu-ray Disc is supported by nine leading manufacturers, namely Hitachi, Matsushita, Pioneer, Sharp and Sony in Japan, LG and Samsung in Korea, and Philips and Thomson in Europe.

The proposed Toshiba-NEC format will increase the capacity of read-only DVD

discs from 4.7 to 15 GB for a single-sided, single-layer disc, and from 8.5 to 30 GB for single-sided, dual-layer discs. Single-sided, single-layer read-and-write discs will have a capacity of 20 GB, and a forthcoming single-sided, dual-layer read-and-write disc will be able to store 40 GB of data, the equivalent of about four hours of high-definition television broadcasts or about 25 hours of regular television broadcasts.

The discs used by the Toshiba-NEC format will use the same disc technology as current DVDs, i.e. back-to-back bonding of two 0.6 mm thick discs with a diameter of 120 mm. This is likely to keep disc production costs relatively low. Also, the Blu-ray discs will require a protective cartridge.

The two new 405 nm standards are incompatible, which could hamper the widespread adoption of next-generation optical storage technology. Recordable DVD has suffered because of the development of three separate

standards. In a news article on *Yahoo.com*, Jean Charles Hourcade, CTO of France's Thomson Multimedia, said it would be wrong to "repeat the mistake the industry has made with recordable DVDs".

In fact, major media companies such as Disney and AOL Time Warner are likely to decide the fate of the two violet laser DVD formats. "In the pre-recorded market there is a powerful third party we all have to work with and that's the content industry," said Hourcade. "Whatever the media owners say is decisive."

It is highly unlikely that media companies will sell their films on competing violet laser DVD formats alongside the existing DVD format, which will remain on sale for a while. A similar situation occurred in 1995; Toshiba and Sony headed two consortia with different red laser DVD formats, but Hollywood's movie industry forced them to agree on a single standard.

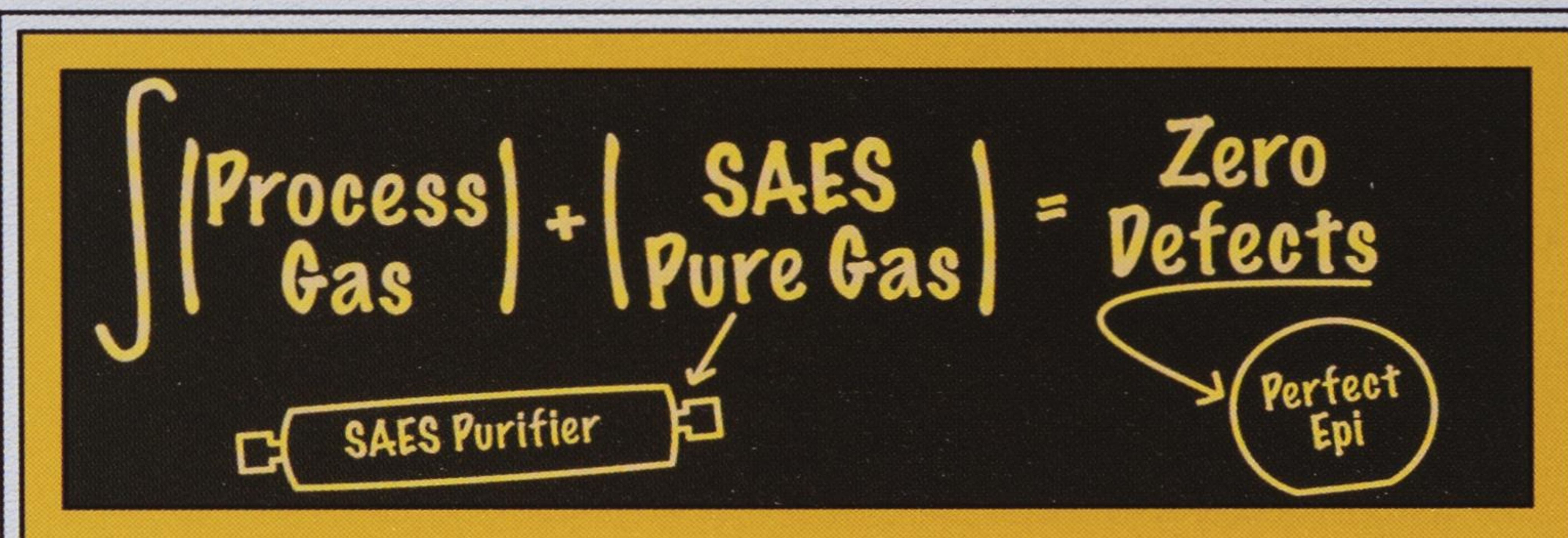
QD researchers win accolades in Europe

Several of the leading researchers involved in the European Union-funded project Quantum Dot Lasers for Optoelectronic Information Communication, also known as DOTCOM, have received prestigious awards for their work on GaAs-based quantum dots for next-generation optical communication devices.

Dieter Bimberg of the Technical University of Berlin, Zhores Alferov (winner of the 2000 Nobel prize for physics) of the Ioffe Institute in Russia and other co-workers have received the 2001 State Prize of Science and Technology from the Russian Federation.

"I am deeply honored by this award as it is always gratifying to receive external recognition for pioneering research," said Bimberg. "Of course, this award reflects our effort over the last few years, but there are still many exciting discoveries to be made in quantum dots. Our participation in the DOTCOM project will help accelerate these discoveries and identify commercial possibilities for these structures."

Bimberg's colleague Sven Rodt received the best student paper award at the International Semiconductor Physics Conference, held in Edinburgh, UK, in August, for his presentation "Antibinding excitons in self-organised InAs/GaAs quantum dots".



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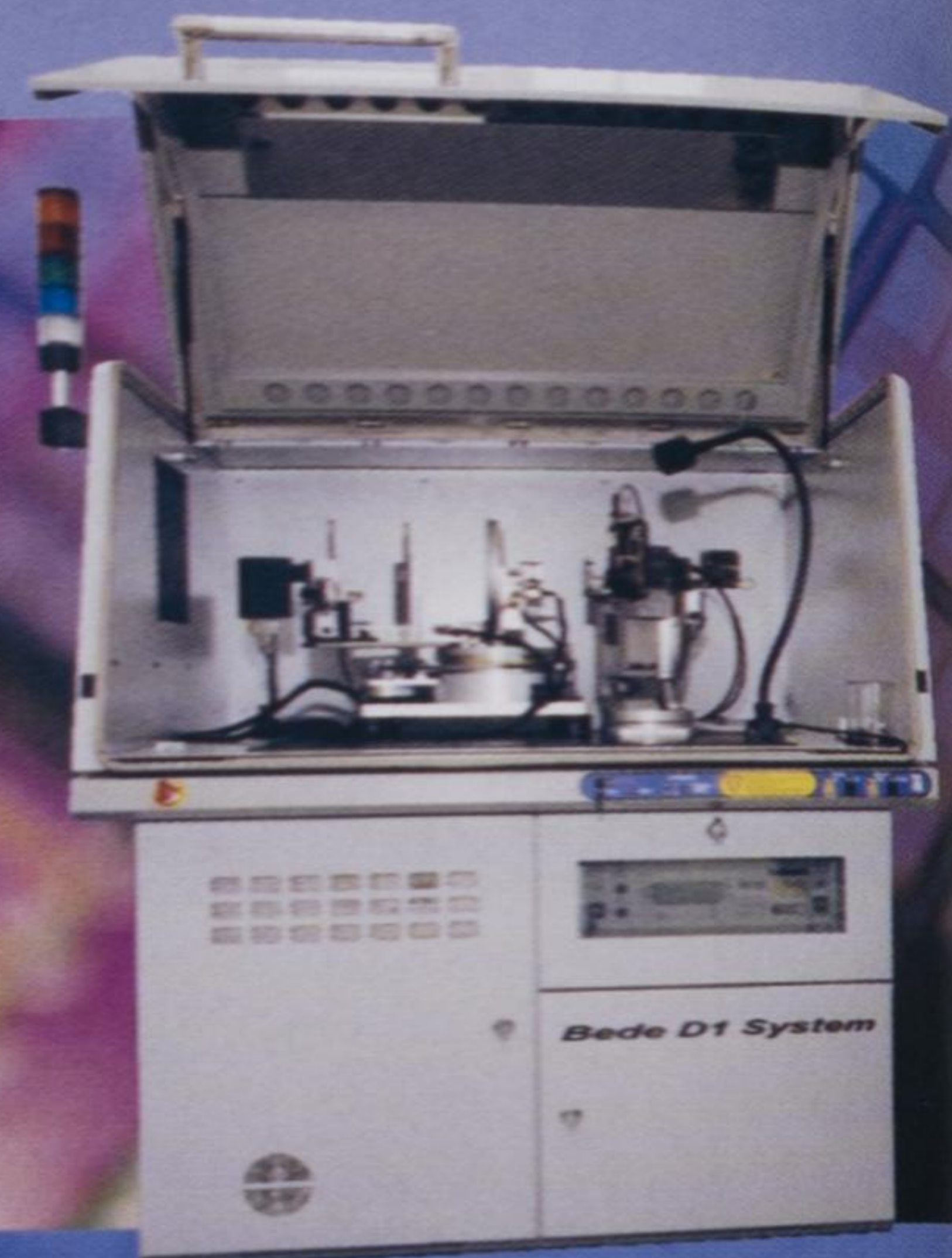
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Agility and Iolon receive tunable laser contracts

Agility Communications and Iolon are celebrating some long-awaited positive news for tunable lasers. Agility has received a contract to supply tunable transmitters to Lightscape Networks for use in metro networks. Unlike some previous announcements of partnerships or supply agreements, this is a positive sign that tunable lasers are gaining acceptance with network equipment suppliers.

Agility will supply its 4245 EML widely tunable transmitter to Lightscape. This transmitter integrates three devices – a tunable laser, a semiconductor optical amplifier and a modulator. Lightscape will use the module in its XDM hybrid optical networking platform, creating a tunable linecard that supports 50 and 100 GHz channel spacing. The linecard will appear in Lightscape's products by the end of this year.

"This technology integration from a top-tier, publicly held company such as Lightscape Networks is believed to be an industry first for metropolitan-based converged networking platforms," said Ron Nelson, president and CEO of Agility. "The metro market requires operators to decrease capital and operating expenditures, while still furthering the development of advanced network applications. We're thrilled Lightscape recognizes the huge benefits widely tunable lasers will bring to carriers and look forward to delivering those benefits to the marketplace."

"We're thrilled that Lightscape recognizes the huge benefits widely tunable lasers will bring to carriers."

In further positive news for tunable laser manufacturers, Lucent Technologies is to incorporate Iolon's tunable lasers into its LambdaXtreme DWDM platform. At present, it seems unlikely that Iolon will be shipping its lasers to Lucent in any significant volume. The LambdaXtreme is still in the sampling and trials phase and Lucent will be looking for an upturn in demand from the long-haul sector before raising production volumes.

Iolon and Agility have different approaches to making tunable lasers. Iolon takes an InP-based laser chip and combines it with an external tuning cavity. The position of the mirror in the cavity is altered using a Si MEMS electrostatic actuator (*Compound Semiconductor* December 2001 p41).

In contrast, Agility uses front- and rear-sampled grating DBRs monolithically integrated with the laser chip. Each mirror has a number of reflectivity peaks selected by the application of a current. The laser emits at a wavelength where the peak reflectivities of the two mirrors are aligned.

Intense Photonics raises \$16 m

Intense Photonics has secured a second round of financing for its quantum-well intermixing (QWI) technology (*Compound Semiconductor* September 2001 p63). Located in High Blantyre, Scotland, the company has closed a \$16 m series-B funding round, which adds to the \$11 m won in the first round (*Compound Semiconductor* August 2001 p14).

Cazenove Private Equity led the funding with a syndicate containing first-round investors 3i and ACT Venture Capital, plus two additional European venture companies. The company will use the funds to accelerate the development of its product range and strengthen its marketing effort.

"The many current and potential appli-

cations of Intense Photonics' QWI techniques have given us the confidence to invest in the company at a time when most photonics companies are struggling and market visibility remains poor," said Tod Bensen, CEO of Cazenove Private Equity.

Intense Photonics uses its QWI process to selectively modify a semiconductor's band-gap, thereby enabling multiple functions to be integrated on a single chip.

Intense is not the only start-up pursuing QWI as a route to manufacturing optical components. DenseLight Semiconductors of Singapore has also received backing from 3i and is fabricating components using its own method of QWI.

Kamelian wins \$1 m order for amplifiers

Kamelian of Oxford, UK, has begun shipping an order worth \$1 m for one of its semiconductor optical amplifier (SOA) products. The order, from an undisclosed customer, is for Kamelian's new 1310 nm SOA, which was recently added to its 1550 nm optical power booster and optical pre-amplifier products. Such amplifiers fulfill a need for amplification that cannot be met by EDFAs.

Also, Kamelian has collaborated with u²t Photonics of Berlin, Germany. The companies combined an ultrafast photodiode manufactured by u²t with Kamelian's high-gain, low-noise SOA to demonstrate a 40 Gbit/s receiver with better than -17 dBm sensitivity at a bit-error-rate of 10⁻⁹. The high sensitivity removes the need in some applications for an integrated transimpedance amplifier. The receiver has a wide dynamic range of 15 dB and withstands high input signal powers of more than 10 mW.

In brief...

Honeywell, Genoa boost distribution networks

Honeywell's VCSEL products division has signed an agreement with Richardson Electronics to distribute its line of laser products. Richardson will have distribution rights in Europe, the UK, Africa and the Middle East. Honeywell manufactures standard and custom VCSEL packages including arrays, TO-can, LC, SC, optical subassemblies and optical front-end transmitters and detectors.

Meanwhile, linear optical amplifier manufacturer Genoa Corporation has established new distribution partnerships. Genoa is now represented throughout Europe by Laser 2000 and in Korea by CoreTech Corporation, while Optiwa handles its Japanese distribution.

Zia Laser receives ISO 9001:2000 certification

Zia Laser, a manufacturer of 1310 and 1550 nm quantum-dot lasers based in Albuquerque, NM, has won ISO 9001:2000 certification. The certification covers all aspects of the development, design and manufacturing of Zia's products.

Opticis expands VCSEL transceiver production

Opticis, a Korean manufacturer of VCSEL-based transceivers, has expanded into new facilities in Sungnam City. The facility nearly quadruples its original space to 11,000 sq. ft.

The move will provide additional facilities to increase the production of transceivers and optical cables, and to give more flexibility in meeting customer requirements. Opticis will also transfer and consolidate its VCSEL fabrication line at the site, which will include assembly and packaging operations.

In addition to 850 nm VCSELs, Opticis designs and manufactures *pin* photodiodes, which the company says allows it to maintain



Opticis manufactures transceivers using its own 850 nm VCSELs and *pin* diodes, so it has tighter control over costs and quality.

control over transceiver packaging costs.

“With a short foundry lead time and flexible manufacturing, the customer receives the benefits of complete life-cycle control,” said Il Kim, Opticis’ CTO and co-founder. “This ensures a reliable and consistent product not subject to variations resulting from sub-contracted technology.”

The company has also begun shipping 2.5 Gbit/s small-form-factor pluggable optical transceivers. The M3-250-PAT contains an 850 nm VCSEL, is IEEE 802.3z compliant and serves InfiniBand, Fibre Channel and Gigabit Ethernet applications.

Devices from Inphi, u²t, ThreeFive Photonics, Spectrolab, Mitsubishi Electric, AOI, JDSU and Alcatel

Receivers

● **Inphi and u²t Photonics AG** of Berlin in Germany have collaborated on an InP receiver. The XPRV2021 consists of u²t Photonics’ waveguide-integrated *pin* photodiode and Inphi’s 4334TA transimpedance amplifier, and offers a bandwidth of 43 GHz. The device exhibits an input sensitivity of -10 dBm, a bit-error-rate of 10^{-9} and operates at 3.3 V in a surface-mount package.

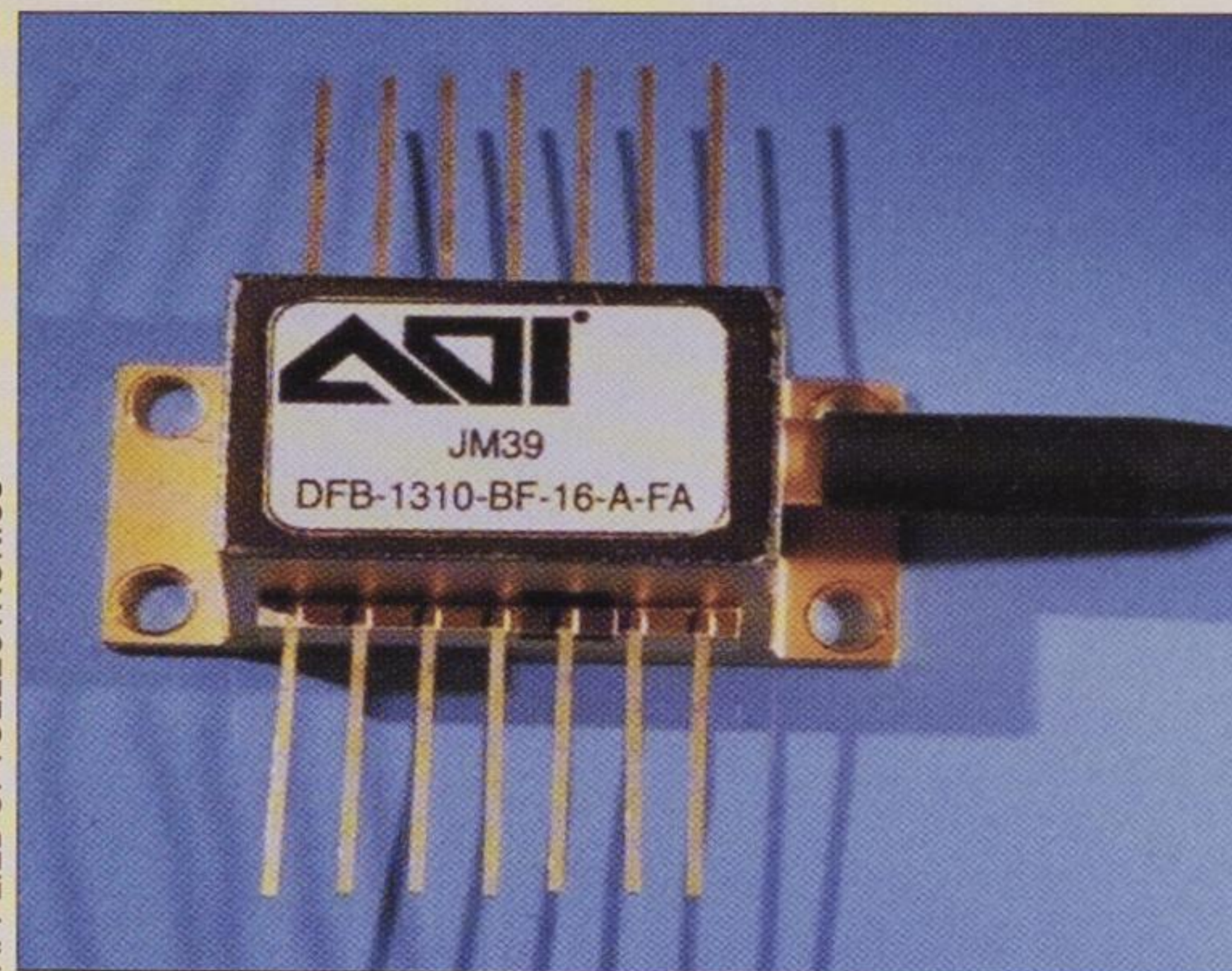
● **ThreeFive Photonics** is offering a 10 Gbit/s version of its 2.5 Gbit/s multi-wavelength receiver. The A4D10 features four channels operating at 10 Gbit/s, and provides a fourfold increase in capacity without increasing the footprint.

● **Spectrolab** has unveiled new 2.5 and 10 Gbit/s InAlAs/InGaAs APDs with a responsivity of 8 A/W at 1550 nm and 7 A/W at 1310 nm. The devices incorporate an avalanche layer made of InAlAs rather than InP material, which the company says lowers noise and improves sensitivity.

Lasers

● **Mitsubishi Electric** has introduced a singlemode DFB laser that delivers 60 mW (CW) over a temperature range of 0–50 °C using a 10 Gbit/s external modulator. The company’s ML9XX37 is powerful enough to transmit across 100 km links and operates in five channels in the C-band (1530–1565 nm) with 0.8 nm wavelength ITU-grid spacing between the channels.

● **Applied Optoelectronics** is offering a new line of cooled 1310 nm DFB lasers. The devices provide up to 25 mW output power and are suitable for both forward- and return-path CATV applications. The



Applied Optoelectronics’ new 1310 nm DFB laser is intended for CATV applications.

DFB-1310-BF series of lasers are housed in industry-standard 14-pin butterfly packages and are OC-48 pin compatible. Integrated isolators reduce the signal distortion in links over 40 km, while an integrated TE cooler maintains wavelength stability from -20 ° to 65 °C.

● **JDS Uniphase**’s newest DBR laser offers a CW power output of 20 mW and is tunable over 24 channels with 50 GHz spacing. The CQF 310 is available in eight wavelength ranges covering the C- and L-bands and uses temperature tuning. The laser uses an integrated etalon wavelength locker and has been designed to reduce

inventory in metro, hybrid fiber-coax and CATV applications.

Pump lasers

● **Mitsubishi Electric** has unveiled two 980 nm pump laser diodes for DWDM applications. The ML861E5S delivers 1.1 W of power (750 mW kink-level) without risking catastrophic optical damage. The design includes a window structure developed using a quantum-well intermixing process. An uncooled version (ML8627S) uses facet coatings to stabilize the wavelength (980 ± 10 nm) over a temperature range of 5–85 °C. The output power at 25 °C is 200 mW and the threshold current is 70 mA.

● **Alcatel Optonics**’ new coolerless 980 nm terrestrial pump – the 1998 PLM Coolerless – delivers up to 150 mW of power. The laser is housed in a 14-pin butterfly package with the fiber Bragg grating pump-wavelength stabilizer included in the fiber pigtail.

Drivers

● **Inphi** has a new 12.5 Gbit/s GaAs-based differential Mach-Zehnder driver that targets SONET OC-192 linecards and transponders. The 2020DZ is designed for RZ and NRZ applications, and exhibits rise and fall times of 17 ps, jitter of 0.5 ps RMS and pulse widths of 30 ps. The driver operates from 5 and -5.2 V DC power supplies and is available in a 22-lead surface-mount package.



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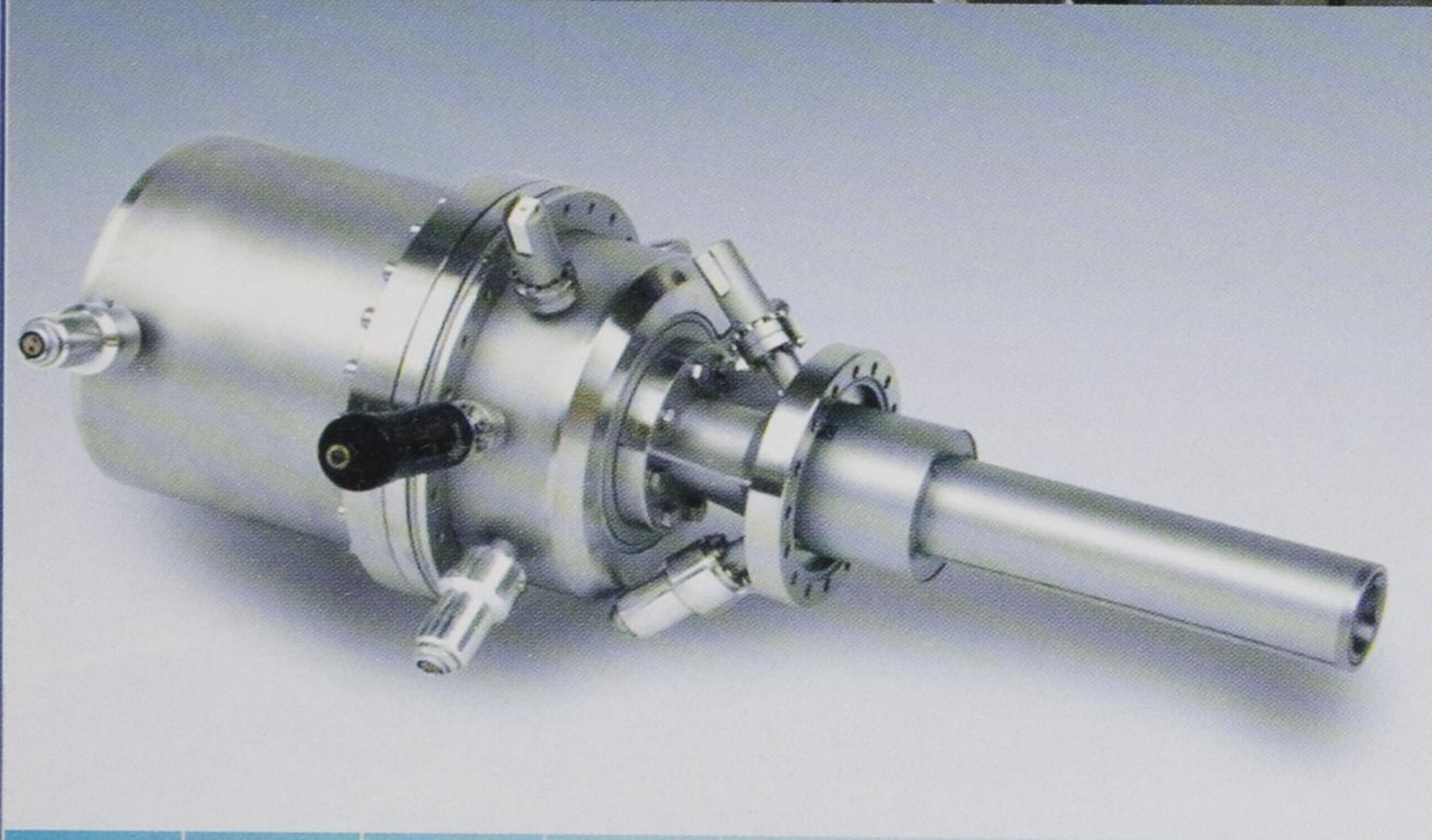
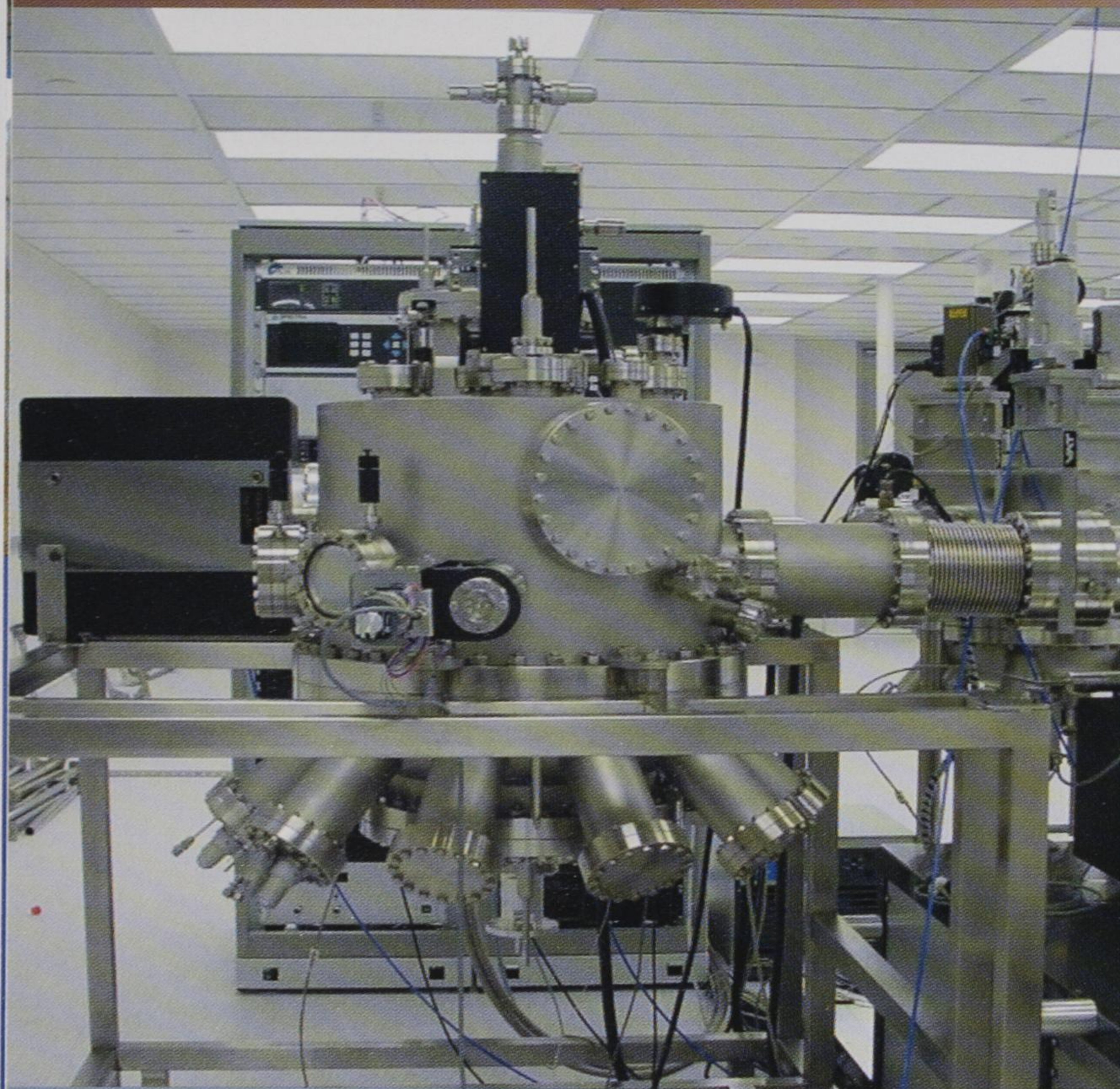
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Sanyo Electric plans violet laser production

According to news reports in Japan, Sanyo Electric is planning to start the mass production of violet laser diodes in April 2003, mainly for use in next-generation, high-capacity optical storage applications. The company will be investing around ¥5 billion (\$43 million) in order to install production lines at its Tottori Sanyo Electric subsidiary in Tottori prefecture, and plans to establish a maximum monthly output capacity of two million units.

At present, Nichia is the only commercial supplier of violet lasers, although Cree and Toyoda Gosei are close to market and Sharp has announced plans to launch a commercial product late next year (see *Compound Semiconductor* September 2002 p25).

In order to avoid patent infringement issues, Sanyo has developed an alternative to Nichia's GaN-on-sapphire approach. Sanyo's laser uses a GaN substrate and has a vertical structure with top and bottom electrodes. The device also employs ion implantation in the p-type GaN cladding layer, which stabilizes the laser's output without the need to fabricate a ridge waveguide (see *Compound Semiconductor* May 2002 p10).

Sanyo is currently the third-largest supplier of red and infrared laser diodes in the world. The company produces approximately 13 million units a month for use in CD and DVD drives.

Fuji Xerox launches 10 Gbit/s VCSELs

Fuji Xerox plans to mass-produce 10 Gbit/s VCSELs suitable for emerging 10 Gigabit Ethernet applications. The new AlGaAs/GaAs devices operate at 850 nm with a maximum output power of 4 mW, and consume 10 mW of power when operating at 2 mW output power. The unit price is ¥5000 (\$43).

Toshiba set to boost LED production

Toshiba is to invest about ¥10 bn (\$85 m) to increase its output capacity for LEDs and Si MOSFET-based devices. The combined monthly output of LEDs at its factories in Fukuoka prefecture, Japan, and Thailand, will increase from 70 million to 100 million by fall 2003.

More global orders for color LCD panels

Major Japanese liquid-crystal display (LCD) manufacturers such as Sharp, Seiko Epson and Seiko Instruments are set to expand their production of small color LCD panels in response to large orders from mobile phone makers in Europe and the US. For example, Nokia has asked for a monthly supply of 7–8 million LCD panels from this fall for use in its new range of color phones.

Demand for mobile phones with color LCDs is growing in the US, Europe and South Korea, while "almost 100%" of mobile phones in the Japanese market offer color, a Sharp spokesman said. Color LCDs require white LEDs as backlights, while monochrome



As mobile phone manufacturers such as Nokia and Motorola introduce new handsets with color screens, Japanese LCD makers are ramping their production capacity.

(e.g. blue or green) displays use LEDs of the appropriate color.

Japanese LCD makers are expected to maintain the upper hand in the small color LCD market, though they remain stuck in fierce competition with South Korean and Taiwanese rivals in the market for larger LCDs for use in personal computer monitors.

Sharp will raise its monthly output of 2 inch super-twist nematic (STN) color LCDs to 2.3 million units by the end of the year, from the current 1.6 million. Meanwhile, Seiko Epson is to accelerate output at its plant in Suzhou, China, in response to the expansion of cellphone production in the country by Nokia and other companies. The firm will convert 30% of its monochrome LCD facilities at the plant to make them ready for color display output by the end of the year.

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Blue LEDs still strong in Taiwan

Due to continued and growing demand from mobile handset manufacturers, the market for blue LEDs in Taiwan is expected to remain healthy during the second half of the year. Samsung and other handset makers are moving over to the use of blue LEDs for monochrome displays and white LEDs for full-color displays. Huan Kuo-Hsing, president of United

Epitaxy, has estimated that the global demand for blue and green LEDs is about 500 million units per month. An ongoing problem is a shortage of blue LED die due to the low yield of the manufacturing process. In order to focus more on epitaxial growth and device processing, Epistar has outsourced the polishing, cutting and inspection steps for blue LED die.

There are still only a small number of blue LED chip manufacturers in Taiwan, despite the strong demand at present. One major issue is the lead time for new companies to enter the market. It generally takes at least one year from placing the equipment orders for a company to be ready to enter production. Due to the difficulties of the nitride LED manufacturing process, it can take even more time for the company to improve its yield and device performance to acceptable levels.

In brief...

Shanghai park to develop optoelectronics industry

An optoelectronics science and technology park to be built in Shanghai, China, will become the main industrial zone for the future development of the optoelectronics industry in the region. The National Chiading High-tech Industrial Park will host business start-ups and R&D companies in areas such as

displays, optical communications and optical storage. The park's role will be to develop key technologies and products, with the eventual goal to become China's "optical valley".

Hamamatsu speeds up laser-cutting technology

Hamamatsu Photonics has developed a wafer-dicing technology using a laser that is

capable of cutting silicon wafers at a speed of 30 cm/s, which is five times faster than conventional rotating cutting blades. The technology, which can also be applied to compound semiconductors and other materials, allows silicon chips to be spaced only 1 μm apart, while blades require a separation of 30 μm . This can increase the yield of $0.4 \times 0.4 \text{ mm}^2$ chips on an 8 inch silicon wafer by 15%.

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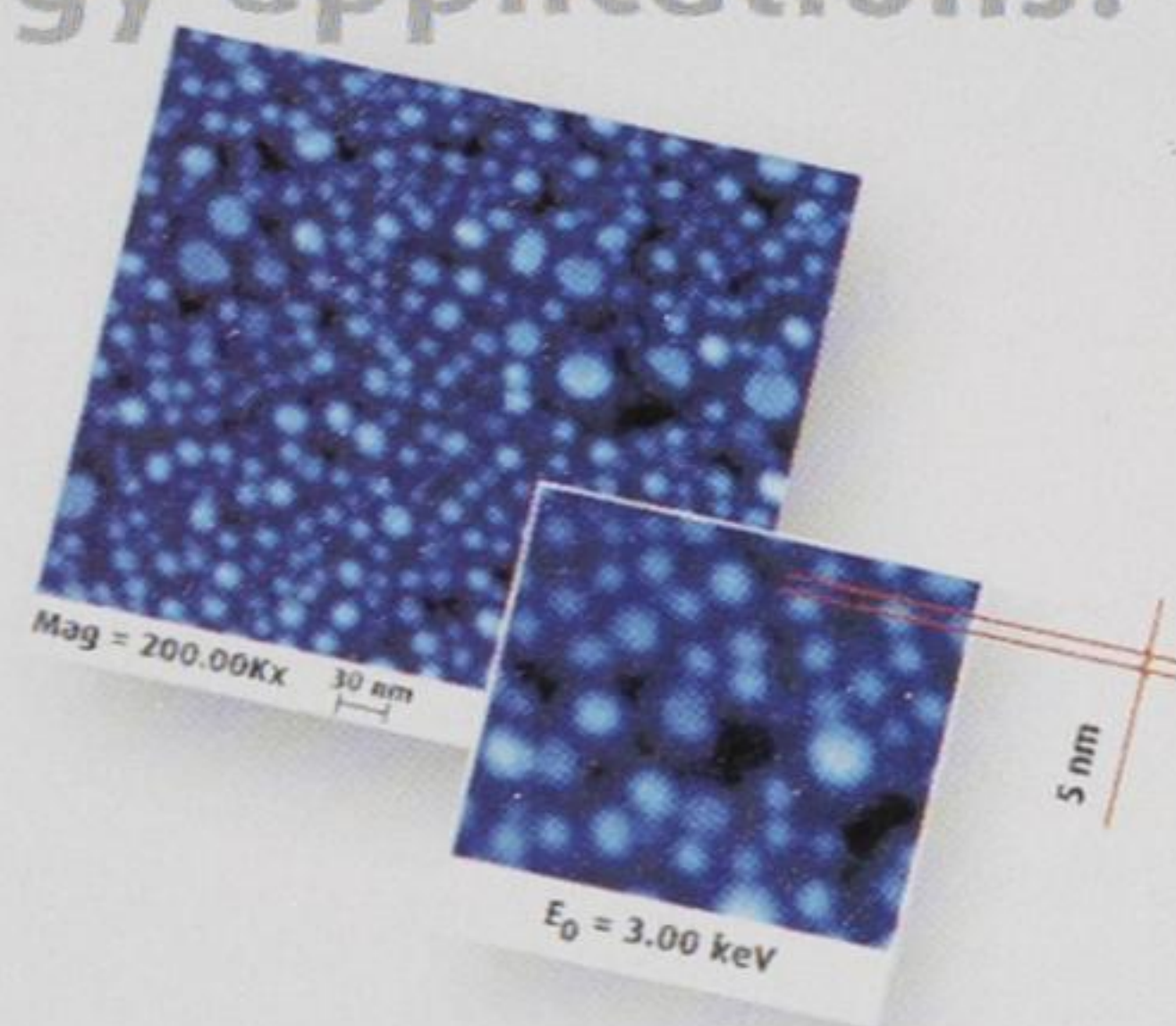
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Okmetic and Epigress sign SiC growth equipment deal

SiC CVD equipment maker Epigress of Lund, Sweden, has signed a letter of intent with Okmetic of Finland to license Okmetic's proprietary high-temperature chemical vapor deposition (HTCVD) technology. Under the terms of the agreement, Epigress will have exclusive access to the HTCVD technology in order to develop, market and sell equipment for the manufacture of bulk SiC material. Okmetic will be granted preferential

customer status with Epigress.

Okmetic developed its proprietary HTCVD technology in conjunction with Linköping University in Sweden, and is currently finalizing plans to expand its manufacturing capacity for SiC into a full-scale industrial process. Most bulk SiC material is grown by sublimation, while in HTCVD the material is grown directly from gas-phase precursors (silane and ethene) at temperatures above 2000 °C.

Aixtron Group and EV Group bolster presence in Asia

The Aixtron Group has opened a new service office in Shanghai, China, offering service, local spare parts supply and process support for the entire Aixtron Group product range. This includes the systems manufactured by Aixtron AG, Thomas Swan Scientific Equipment Ltd and Epigress AB. A team of service engineers will provide customer support, and a comprehensive consignment stock for all of the MOCVD tools offered by the Aixtron Group will be installed in the near future.

"We can now offer our Chinese customers a fast, reliable and high-quality local service for all products of the Aixtron Group,

which is an essential prerequisite for coping with the increasing demands of the strongly growing MOCVD market in China," said executive vice-president and COO Steve Perry, who is responsible for Aixtron's Global Service Operations.

Meanwhile, EV Group, a manufacturer of MEMS and semiconductor wafer processing equipment, has formed a joint venture company, called EVG-Jointech Corp, in Taiwan. The company, which will be located in Taoyuan, includes personnel from EVG and from EVG's representative company in Taiwan.

"Our expanded presence in Taiwan gives us the ability to provide quicker, better and more qualified on-site service to our Taiwanese customers," said Peter Podesser, CEO of EVG. "Our goal is to work as closely as possible with customers by combining local expertise with the European knowledge base."

Nikko Materials hits the quality mark

Nikko Materials USA, a supplier of InP and CdTe wafers, has achieved ISO 9002:1994 certification for its quality management system. The registration brings the company's facility in Chandler, Arizona, in line with its parent company's plant in Isohara, Japan.

Equipment sales

- **Santur Corporation** has ordered an **Emcore D180LDM** (laser diode machine) for use in the company's laser manufacturing process. Headquartered in Fremont, CA, Santur makes tunable sources based on an array of DFB lasers on a single InP chip.

- **Light Chain Technology**, located in Hsinshu, Taiwan, has ordered an **Aixtron AIX P60** diamond microwave CVD system. The reactor will be used to deposit thin diamond films used in diverse applications such as surface acoustic wave devices, high-frequency wireless data transfer, thermal heat sinking (e.g. for cooling high-power LEDs/lasers) and free-standing optical windows. Scaling from 2 to 6 inch substrates, the diamond reactors were developed at the Fraunhofer Institute for Solid State Physics in Freiburg, Germany and manufactured under license by Aixtron.

- **Aixtron** has sold an **AIX 2600G3 HT MOCVD reactor** to **LED Expert Corporation** (Ledex) of Taiwan. Ledex will use the machine to mass-produce GaN-based material and ramp up its capacity for GaN-based high-brightness blue and green LED chips. The AIX 2400/2600G3 HT has a capacity of up to 24 × 2 inch or 7 × 3 inch wafers. This sale will bring Aixtron's installed base of MOVCD tools in Taiwan to 40, 10 of which are high-capacity GaN systems.

- Citing extremely high market demands for its products, Taiwanese epiwafer supplier **Epitech Technology Corporation** will buy two additional **Aixtron AIX 2600G3 MOCVD** production reactors with a capacity of up to 35 × 2 inch wafers. Both systems will be used to manufacture wafers for high-brightness AlGaInP LEDs and will be installed at Epitech's facility at the Tainan Science-based Industrial Park.

People news

- **IQE's CFO Richard Clarke** and president of US subsidiary **IQE Inc Scott Massie** have left IQE and resigned their posts as directors. **Tim Hawkes**, who joined IQE in March from Marconi, has been appointed as acting CFO. **Howard Williams**, who has been with IQE since 1988, will act as the temporary general manager of IQE Inc.

- **Santur Corporation** has named **Julian Osinski** as VP of product marketing. Osinski has held positions at SDL and managed the product launch of 14xx nm pump lasers for Raman amplification systems at JDS Uniphase.

- **RF Micro Devices** has named **Daniel DiLeo** as a new member of its board of directors. DiLeo previously served as the executive VP of the Optoelectronics Group at Agere Systems.

- **Gerhard Kleineidam** has been named the new CEO of **Leica Microsystems** (Wetzlar, Germany). Kleineidam, who joined the company in February, replaces Horst Wegener.

- **Bob Chaney**, former CEO of Nanovation, has joined **ATMI** as senior VP and general manager of ATMI's Epitaxial Services division based in Phoenix, AZ.

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SILICON COMPOUNDS

SiGe:C sets device records

The progress of SiGe bipolar technology took another step forward when two German companies revealed that they have developed a SiGe:C BiCMOS process that has yielded record-breaking devices. Communicant Semiconductor Technologies, and Innovations for High Performance Microelectronics (IHP), both of Frankfurt, Germany, have jointly developed a SiGe:C BiCMOS process that has yielded ICs with a ring oscillator gate delay of 4.2 ps. This is the fastest yet reported for a BiCMOS technology. The high-performance HBT modules had f_t and f_{max} values of 200 and 170 GHz, respectively, with a BV_{CE0} of 2.0 V.

The process uses a low number of additional lithography levels, eliminating complex pro-

cesses such as sub-collector epitaxy and deep trenches. The inclusion of carbon into the base of SiGe HBTs prevents the out-diffusion of boron dopant atoms during post-growth processing. A sharper doping profile means that the base region can be made thinner and more heavily doped to give a higher f_t .

The benchmark circuits fabricated included 53-stage CML ring oscillators, static and dynamic dividers, and LC oscillators; the latter ICs substantially exceeded the previously reported highest speeds for silicon-based ICs. Further details of the process and device performance will be revealed in a presentation at the International Electron Devices Meeting (IEDM) in San Francisco in December.

Big Bear to use IBM's process technology

Big Bear Networks has adopted IBM's SiGe process technology for incorporation into its Photronic Signal Processing (PSP) family of 10 and 40 Gbit/s transponders and sub-assembly products. The two companies have been working together for about 18 months. IBM's SiGe technology was selected after Big Bear evaluated various competing process technologies, including InP.

"In our early development phase we implemented several designs in both SiGe and InP, initially believing that the inherently higher speeds of InP would be required for high-performance 40G products," said John Paul Mattia, co-founder and CTO of Big Bear. "However, after side-by-side comparison, we found that SiGe not only produces circuits that achieve the mandatory high performance, but

also lets us easily integrate the active intelligence needed to overcome fiber impairments."

According to Mattia, the ability of SiGe to integrate millions of transistors on a chip was a key factor in its selection, particularly since Big Bear's PSP technology incorporates a high degree of embedded intelligence.

"Since InP circuits are presently limited to 5000 transistors, this clearly was not the process platform of choice to integrate all the functionality required by the intelligent optoelectronic physical layer," said Mattia. "SiGe lets us augment standard functions such as clock and data recovery at 10 and 40G with the integrated signal processing necessary to address the impairments associated with high-speed fiber transmission."

● Big Bear Networks recently received funding from the venture-capital unit of Agilent Technologies, as a follow-on to Big Bear's series B round of funding, which raised over \$40 m in equity.

Tricent machine improves memory

The University of Magdeburg, Germany, has installed an Aixtron Tricent reactor at its new cleanroom facilities. The university and Aixtron will jointly undertake research activities on new precursors and related physical properties for the materials strontium bismuth tantalate (SBT) and lead zirconium tantalate (PZT) for future non-volatile memory applications. Based on the ferroelectric effect, FeRAMs are expected to replace the many different memory types used today.

Chartered licenses SiGe from IMEC

Chartered Semiconductor Manufacturing, one of the world's top three silicon foundries, has licensed a 0.18 μm SiGe BiCMOS process from IMEC, an independent R&D center for microelectronics located in Belgium. Chartered will offer SiGe manufacturing capabilities by the second half of 2003, complementing its mixed-signal and RF CMOS technologies. The process has a peak f_{max} of 100 GHz and is optimized for low-power, low-noise RF applications in the 2–5 GHz range.

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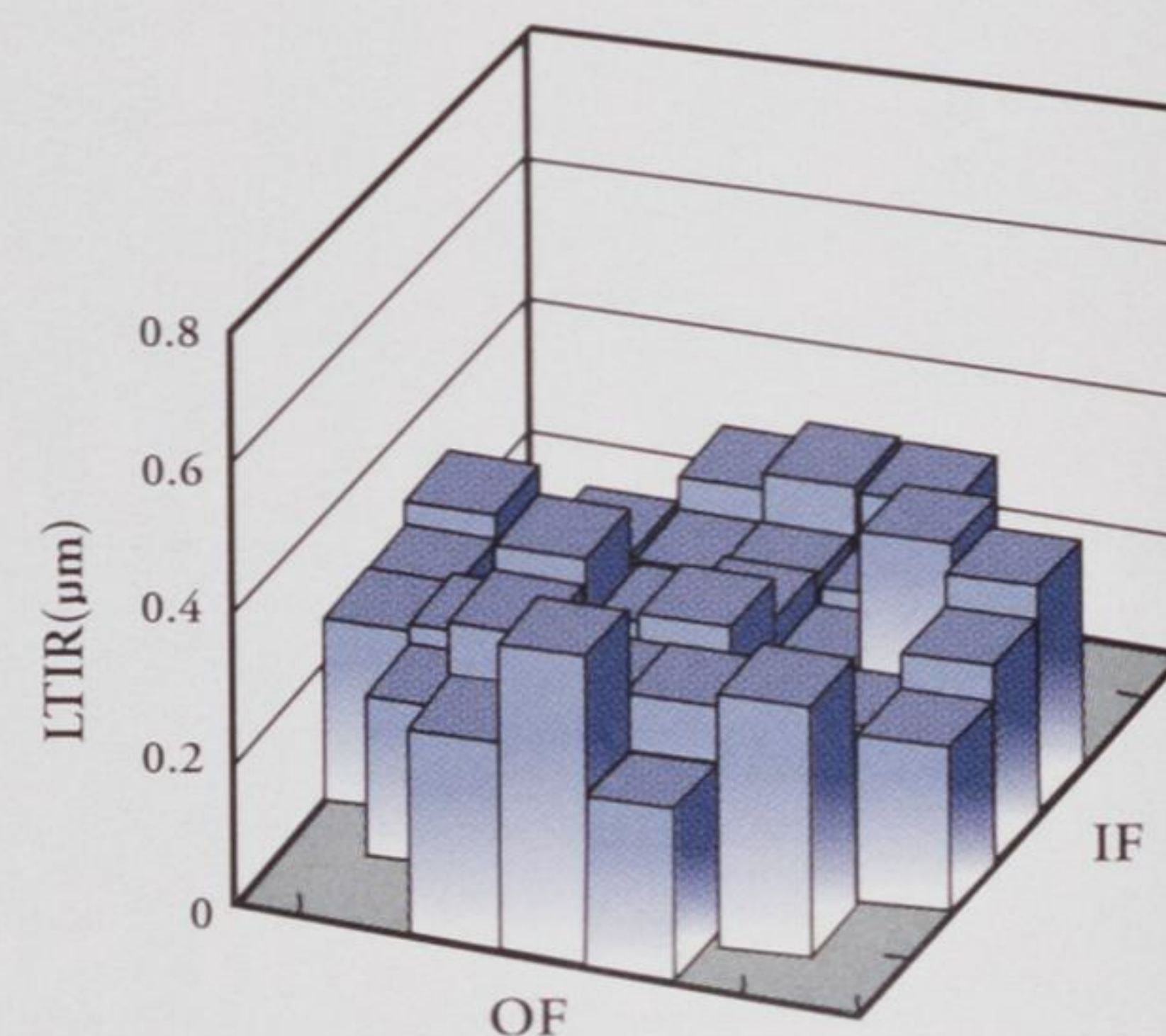
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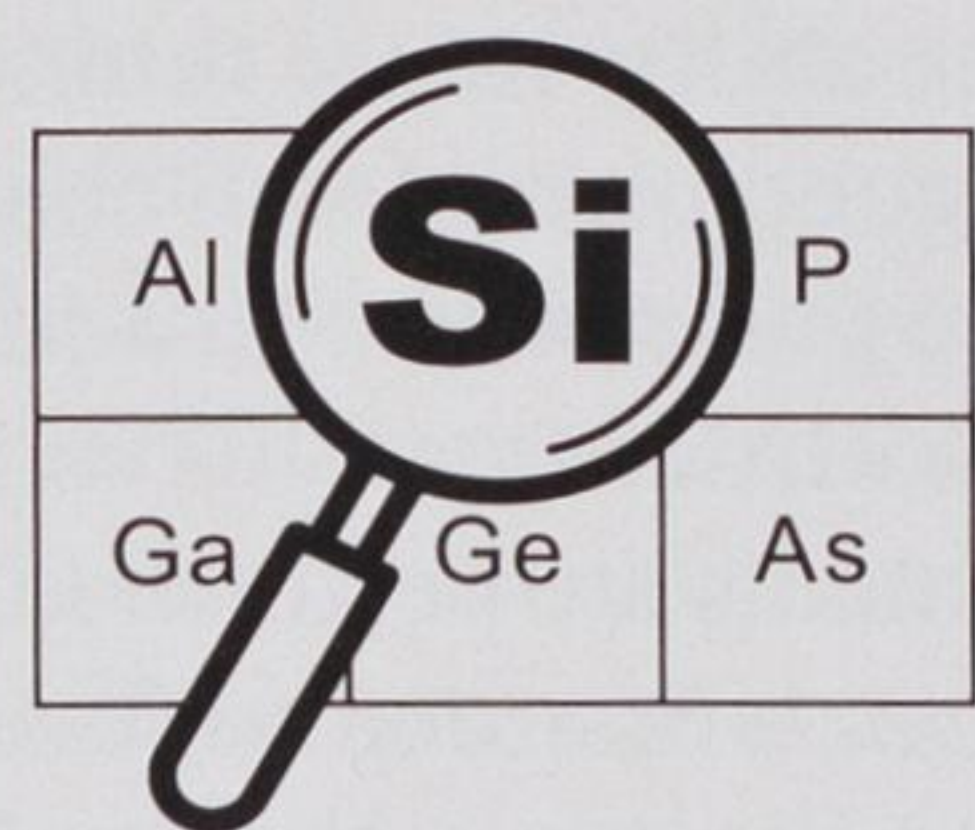
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Old dogs and new tricks

The ubiquitous gate oxide material from the silicon industry, SiO_2 , has been successfully used to demonstrate GaN-based MOSFETs that rely on the properties of the GaN- SiO_2 interface.



A first step has been taken, combining the workhorse of the silicon industry with the newest device material.

The remarkable chemical and physical nature of the SiO_2 -Si interface has been critical to the growth of the IC industry. Not only can SiO_2 withstand incredible breakdown fields in the order of 1×10^7 V/cm (resulting in breakdown voltages of 10–20 V for an SiO_2 thickness of only 10 nm), but it also has a mid-gap interface-state density of only $2 \times 10^{10}/\text{cm}^2\text{eV}$. These characteristics have made it the perfect interface at which to store, inject and manipulate charge, making all CMOS operations possible.

Unfortunately, such a high-breakdown, low-interface-density oxide does not exist for III-V compounds. III-V devices are therefore not fabricated around an insulator-semiconductor interface, but employ metal-semiconductor interfaces, or interfaces between semiconductors of varying bandgaps. A quality oxide-III-V interface would only further improve the impressive capabilities and applications of III-V devices.

The usual suspect

Does such an oxide exist? Perhaps. Researchers are beginning to wonder if the ideal candidate might be that old favorite – SiO_2 . In a rather ironic fashion, the III-V material system that is giving this veteran oxide a look is the very newest device-material system – GaN.

Despite the rapid improvement in GaN devices,

almost all of which rely upon the AlGaN-GaN hetero-interface to modulate and control charge, an ongoing limitation, and challenge to further device improvements, is GaN surface passivation. This issue must be resolved to improve surface breakdown voltages further and to reduce leakage currents (critical parameters for both high-power and RF applications).

When fabricating GaN Schottky diode photodetectors, Asif Khan and coworkers found that record-low leakage currents could be obtained by using SiO_2 to passivate the GaN surface. This led to the incorporation of SiO_2 beneath the gate of a conventional AlGaN-GaN HFET (Khan *et al.*). Using a 13 nm PECVD-deposited SiO_2 layer between the otherwise standard gate and AlGaN layer, the resulting device exhibited gate-leakage currents that were six orders of magnitude lower than those of the control HFET (identical to the MOS-HFET except for the insertion of the 13 nm SiO_2 layer). This also allowed for a larger gate voltage swing and higher linearity, which should enable a device with less intermodulation distortion, less phase noise and a larger dynamic range. While these improvements are certainly desirable, the actual MOS-HFET is still essentially an HFET where current transport takes place at the AlGaN-GaN interface, and the SiO_2 layer is used to passivate the surface of the AlGaN.

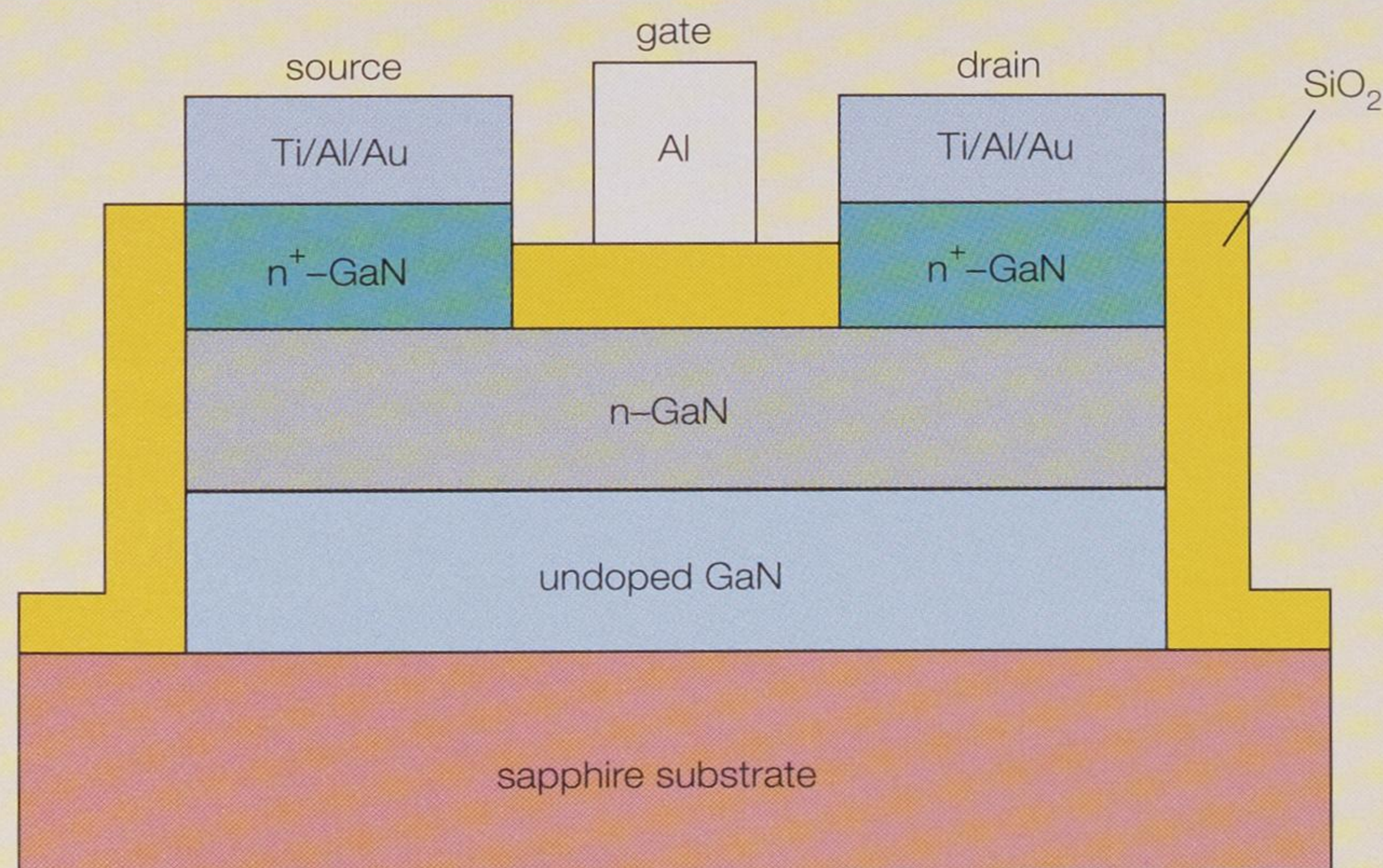
With these initial successes, researchers are beginning to explore the possibility of a true GaN MOSFET, where the SiO_2 -GaN interface is integral to the charge transport through the device (see figure). Fabricated by a research group from the National Cheng Kung University in Taiwan, this device relies on the quality of the SiO_2 -GaN interface. Furthermore, a novel liquid-phase deposition (LPD) process is used to deposit the SiO_2 , rather than relying on a PECVD SiO_2 layer as typically used by III-V workers (Lee *et al.*).

Liquid-phase deposition

LPD requires little more than a temperature controller, a pH meter, a substrate holder and a Teflon container. A supersaturated hydrofluosilicic acid aqueous solution (H_2SiF_6 – 0.4 molar) acts as the Si-source liquid and a boric acid aqueous solution (H_3BO_3 – 0.01 molar) is used to control the deposition rate. These solutions are used to deposit SiO_2 at 40 °C and an approximate rate of 50 nm/h.

The highest-quality oxides are achieved for the lowest growth rates. For the device illustrated in the figure, MOCVD was used to first grow a 1.0 μm undoped

GaN MOSFET with SiO_2 gate



Schematic structure of an n-channel depletion-mode GaN MOSFET, in which the SiO_2 -GaN interface is integral to the charge transport through the device. SiO_2 is deposited selectively by LPD onto the GaN channel and mesa sidewalls.

Despite the improvement in GaN devices, an ongoing limitation, and challenge to further device improvements, is GaN surface passivation.

buffer, followed by a 200 nm Si-doped ($5 \times 10^{17}/\text{cm}^3$) channel layer, and lastly a 20 nm heavily Si-doped ($2 \times 10^{18}/\text{cm}^3$) contact layer. Device isolation and GaN etching to define the contact regions were performed by photo-enhanced chemical etching using KOH with a pH of 13.5, under a light intensity of $25 \text{ mW}/\text{cm}^2$, resulting in an etching rate of 50 nm/min. Ti/Al/Au was used for contact metallization, followed by LPD of SiO_2 that proceeds selectively only on the exposed GaN. This not only coats the channel area, but also passivates the exposed GaN-mesa sidewall.

Excellent performance

The SiO_2 used in this device was 85 nm thick, exhibiting an RMS surface roughness of 5.2 nm, a breakdown field in excess of 5 MV/cm and an interface-state density of about $2 \times 10^{11}/\text{cm}^2\text{eV}$. The leakage current of $1 \times 10^{-7} \text{ A}/\text{cm}^2$ is comparable to that observed in the MOS-HFET. The breakdown field is half of that observed for SiO_2 grown on Si, and the interface-state density is approximately an order of magnitude greater – excellent values compared with those obtained in many other efforts to form SiO_2 -III-V interfaces.

Using a gate that is relatively long (8 μm) and 40 μm wide, the gate bias was ramped from 6 to -8 V. The

device exhibited a transconductance (g_m) of 48 mS/mm and a drain current density (I_{ds}) of 250 mA/mm at a V_{gs} of 4 V and a V_{ds} of 20 V. The g_m is almost twice that of a GaN MESFET control device of similar structure.

While these devices do not yet measure up to those reported in AlGaIn/GaN HEMT structures, this represents the first reported attempt at using the SiO_2 -GaN interface in such an FET device. The performance can undoubtedly be improved by optimizing the SiO_2 quality (especially critical will be the ability to use thinner gate oxides, while maintaining good breakdown characteristics) and reducing device geometries. In addition, the true potential of such structures will only become clear once RF measurements are performed.

Despite these outstanding issues, a first step has been taken, combining the standard oxide that is the workhorse of the semiconductor industry with the newest semiconductor device material. ●

Further reading

M Khan *et al.* 2000 AlGaIn/GaN metal oxide semiconductor heterostructure field effect transistor *IEEE Elec. Dev. Lett.* **21(2)** 63.

K Lee *et al.* 2002 GaN MOSFET with liquid phase deposited oxide gate *Elec. Lett.* **38(15)** 829.



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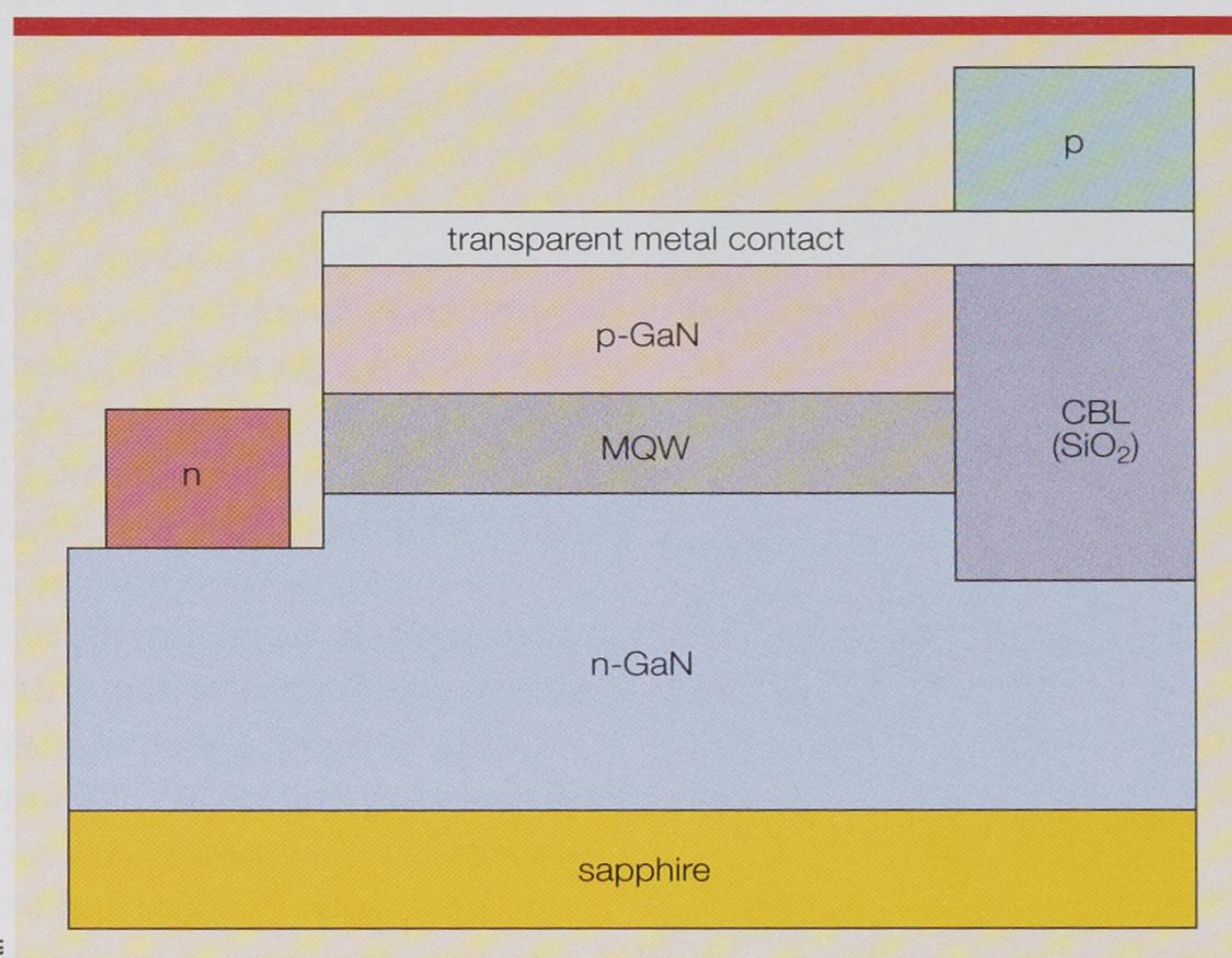
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Current blocking makes brighter LEDs

A general requirement of GaN-based LEDs is that both n- and p-type electrodes are formed on the same side of the epitaxial layer, because of the insulating properties of sapphire substrates. Some loss of light is therefore inevitable owing to photon absorption near the p-pad electrode of the device.

Another problem that arises from the lateral structure of GaN-based LEDs is current crowding around the p-pad electrode caused by the resistive p-GaN layer. This may decrease the efficiency of light generation, and reduce the reliability of LEDs thanks to the high electrical carrier density in a localized area of the device.

A number of methods to improve current spreading are being investigated including the use of tunnel junctions and superlattice contact layers. A group at the Kwangju Institute of Science and Technology in Korea has investigated the use of a current-blocking layer (CBL) beneath the p-contact. This reduces current crowding below the contact and improves current spreading



The current-blocking layer (CBL) below the p-contact pad reduces the downward flow of current. The current follows a lower-resistance path through the light-transparent metal contact layer.

across the active area of an InGaN/GaN MQW LED (*J. Appl. Phys.* 2002 **92**(5) 2249).

To insert the CBL, the surface region of the p-GaN layer beneath the p-pad electrode was partially etched by means of an inductively coupled $\text{CH}_4/\text{Cl}_2/\text{H}_2/\text{Ar}$ plasma until the n-GaN layer was exposed. An insulating SiO_2 layer was then grown using a PECVD system.

The light-output power at 20 mA of the chip with the CBL was 62% higher than that of the conventional InGaN/GaN MQW LED chip, although the light-emitting active area was reduced because of the insertion of the CBL region into the LED structure.

The researchers attributed this improvement to the increase in current injection into the entire active

area of the LED through the transparent electrode. The parasitic optical absorption at the thick p-pad electrode was also reduced. This resulted in a further improvement in the light output of the LED chip with a CBL.

InGaAsN base layer reduces power consumption

In HBT technology, reducing the turn-on voltage by adopting a low-bandgap material in the base is essential to maintaining a good PAE under low-bias conditions. Researchers at Sandia National Laboratories and Emcore have reported the fabrication of DHBTs using quaternary InGaAsN material to form a low bandgap energy (E_G) base region. This reduces the operating voltage in GaAs-based electronic devices (*Trans. Elec. Dev.* 2002 **49**(8) 1329).

InGaP/ $\text{In}_{0.03}\text{Ga}_{0.97}\text{As}_{0.99}\text{N}_{0.01}$ /GaAs DHBTs giving improved band-gap engineering at both heterojunctions exhibited a DC peak current gain of more than 16 with a small active emitter area. The use of the lattice-matched $\text{In}_{0.03}\text{Ga}_{0.97}\text{As}_{0.99}\text{N}_{0.01}$ ($E_G = 1.24$ eV) base layer allowed the turn-on voltage to be reduced significantly – by 250 mV compared with standard InGaP/GaAs HBTs. Good high-frequency performance was achieved with f_t and f_{max} values of 40 and 72 GHz respectively.

Although the InGaAsN DHBTs did not achieve the peak frequencies observed with InGaP/GaAs control devices, they did provide better RF performance at lower base-emitter bias conditions.

The combination of low turn-on voltage, good breakdown voltage ($\text{BV}_{\text{CE0}} > 14$ V) and good microwave performance makes this a promising material system for increasing the efficiency and reducing the power consumption of the next generation of GaAs-based HBT power amplifiers for wireless handsets. The material and device fabrication processes are also compatible with mature GaAs foundry and processing technologies.

The researchers are now working to optimize the quality of the base material, and to use more aggressive base designs so that they can reduce the transit time and base-sheet resistance and further improve the DC and RF performance.

How capping layers can disrupt quantum dots

There have been many studies into the formation of quantum dots (QDs) and how their size and shape are influenced by growth parameters. Less is known about the effect that the capping layer, required to make a functioning device, has on the dots. Now Fariba Ferdos and colleagues at Chalmers University in Sweden have systematically studied the changes in InAs dot size and shape during the initial stages of encapsulation with GaAs (*Appl. Phys. Lett.* 2002 **81**(7) 1195).

The group used AFM to monitor, and propose a model for the evolution of, the dots as up to 16 monolayers (MLs) of GaAs were deposited. They observed that the height and density of the QDs reduced rapidly as up to 4 MLs of GaAs were deposited, and that GaAs plateaus began to form. At 8 MLs the GaAs plateaus began to merge and holes appeared in the plateaus above the InAs dots. Photoluminescence measurements showed a shift to shorter wavelengths as the GaAs built up, indicating that the reduction in dot height changes the emission wavelength. Also it is known that reduced dot density limits the modal gain of a QD laser, so the QD capping material must be chosen carefully to maintain dot height and density.

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In alliance with the future

QD lasers break the 10 W barrier for the first time

Researchers at the Technical University of Berlin in Germany have made a quantum-dot (QD) laser with an output power of more than 10 W (*Elec. Lett.* 2002 **38**(16) 883).

The device was grown by MOCVD on a GaAs substrate. The active region consisted of six repeats of an InGaAs QD layer capped with a 30 nm GaAs layer. The laser emitted at 1135 nm with a threshold current of 650 mA, and in CW operation had a maximum output power of 4.7 W at 12 A drive current. Under quasi-CW operation (50 μ s pulses with 50 Hz repetition frequency) the maximum power was 11.7 W at 21.5 A. Catastrophic optical damage to the laser facets limited the output power. Reducing the drive current to operate the laser at 1.5 W increased its lifetime to more than 3000 h.

Using MBE-grown material, the researchers have also fabricated QD lasers operating at 1300 nm. The output power of the unoptimized devices using a preliminary mounting exceeds 3 W in CW operation – the best value yet reported at this wavelength.

K-band GaN HEMTs hit record power density

A joint effort between TriQuint and the University of South Carolina has resulted in AlGaIn/GaN HEMTs with a power density of 5 W/mm at 26 GHz, the highest yet reported for devices operating at more than 20 GHz (*Elec. Lett.* 2002 **38**(16) 924). The HEMT structures were grown by MOCVD onto semi-insulating SiC substrates. T-shaped 0.25 μ m Schottky gates were fabricated within a 4.5 μ m source-drain spacing. The HEMTs were passivated using a PECVD SiN layer.

The maximum saturation current was 1.1 A/mm at a V_{gs} of 2 V. f_t and f_{max} were 35 and 79 GHz. At 26 GHz (V_{ds} 25 V) the peak PAE was 31% at an output power of 30 dBm corresponding to a power density of 5 W/mm.

Device isolation linked to GaN HFET performance

A group at Simon Fraser University in Canada has concluded a study into the dependence of f_t and transistor delay on the gate-to-drain separation (L_{GD}) in AlGaIn/GaN HFETs (*Elec. Lett.* 2002 **38**(16) 921). Devices were fabricated on MOCVD-grown material on sapphire substrates. T-gates 0.2 μ m long were formed and gate-to-source spacing was 1 μ m. Devices isolated by wet-mesa etching and implantation were made on the same wafer.

Increasing the L_{GD} from 0.5 to 4.5 μ m reduced f_t from 55 to 35 GHz. The change in transistor delay with L_{GD} depended upon the method of fabrication. Wet-mesa etching gave a 0.32 ps/ μ m increase in delay, while implant isolation gave 0.16 ps/ μ m. Previously published data on mesas formed by RIE showed a much stronger dependence of transistor delay on L_{GD} . The researchers concluded that different fabrication processes meant different levels of surface damage in the device area. This damage affects the population of surface states between the gate and drain contacts, changing the material's carrier transport properties.

TECHNICAL PROGRAM

Show highlights processing and commercial solutions

The state-of-the-art in compound semiconductor manufacturing will be discussed at the 2002 Compound Semiconductor Manufacturing Expo (CS-MAX), to be held on November 11–13, 2002 at the McEnery Convention Center in San Jose, CA. Over 100 papers will be presented in 28 sessions.

Monday November 11

Session M1A

III-V Integrated Circuits

2:00 p.m. – 3:20 p.m.

Manufacturable Microwave Power FET Technology

Matthew O'Keefe

Filtronic Compound Semiconductor

Qualification of a Production MHEMT Process for Low Noise and High Frequency Applications

Philip Balas

Raytheon RF Components

Selective Double Recess Technology On Metamorphic HEMTs – Improving The On-State Breakdown Behavior

Jan Gruenenpuett

United Monolithic Semiconductors

The Effects Of Au Concentration, Temperature And Agitation On The Cross Wafer Resistance Uniformity Of Electroplated Backside Vias In Thinned GaAs

David Hensley

Anadigics

Session M1B

III-V Optoelectronics

2:00 p.m. – 3:20 p.m.

High Performance, High Yield VCSEL Process Technology

Hao-chung Kuo

LuxNet

Characterization of Au/Zn/Au and Au/Ti/Pt/Au Contacts to p-type InP

Jia-Sheng Huang

Agere Systems

Optimal Eutectic Bonding Techniques for Enhanced Laser Reliability

Edward Wills

Palomar Technologies

Optimization of a Planar InP/InGaAs/InP Separate Absorption and Multiplication Avalanche Photodiode with Floating Guard Rings and Zn Double Diffused Junction

Wai K Yip

Silvaco International

Session M1C

LEDs I

2:00 p.m. – 3:20 p.m.

Challenges in Low Cost Flip Chip Light Emitting Diodes for Solid State Lighting

William So

AXT Optoelectronics

Angular Variation of Radiometric and Photometric Parameters of LED Die

Curt Dodds

Op-Test

Spectroradiometric LED Characterization

Eric Bretschneider

Uniroyal Optoelectronics

Session M2A

Silicon Heterostructures

3:40 p.m. – 5:00 p.m.

BiCMOS Integration of SiGe:C HBTs

Dieter Knoll

Communicant Semiconductor Technologies AG

Road Map for Strained Si Technology

Mayank Bulsara

AmberWave Systems

SOI: Market and Technology

Carlos Mazure

Soitec SA

Plasma Process Sequence for the Manufacturing of 200 mm and 300 mm SiGe Virtual Substrates with High Ge Concentrations

Hans Martin Bushbeck

Unaxis Semiconductors

Session M2B

Front End Processing for Optoelectronics

3:40 p.m. – 5:00 p.m.

Dry-Etching in Optoelectronics Device Fabrication Using Chemically-Assisted Ion Beam Etching

Eckard Deichsel

University of Ulm

A Comparison of Production Plasma Etch Chemistries for InP and Related Materials

Andrew Goodyear

Oxford Instruments

Characterization of GaAs/AlGaAs Non-Selective ICP Etch Process for VCSEL Applications

Yao-Sheng Lee

Unaxis

Cryogenic Processing Thin Metal Films in III-V Microelectronics

Lili He

San Jose State University

TECHNICAL PROGRAM

Session M2C**Characterization I**

3:40 p.m. – 5:00 p.m.

Composition Standards for III-V Epitaxial FilmsKris Bertness
NIST**A New Method For Defect Detection And Classification On Compound Semiconductor Epitaxial Layers**Steven W Meeks
Candela Instruments**Extraction of Low Mobility, Low Conductivity Carriers from Field Dependent Hall Data**Jeffrey Lindemuth
Lakeshore Cryotronics**Estimating the Optical Thickness Errors in Vertical-Cavity Surface-Emitting Laser Structures from Optical Reflection Spectra**Bum Joon Kim
PROWTech**Tuesday November 12****Session T1A****HBTs**

9:00 a.m. – 10:20 a.m.

InGaAs/InP Single-Heterojunction Bipolar Transistor Fabrication Process with High Uniformity and High Yield for Multi-10 Gb/s Optical Communication ApplicationsMasaki Yanagisawa
Sumitomo Electric Industries**High-Speed and Large Output Voltage Swing InP-based DHBT Driver IC**Chenghui Lin
Agere Systems**Metamorphic Buffer Comparisons for M-HBT Grown by MBE**X M Fang
IQE**Throughput Optimization of HBT Ion Implant Isolation Using Doubly Charged Helium**Abdikarim Arrale
Skyworks Solutions**Session T1B****Epitaxy I**

9:00 a.m. – 10:20 a.m.

Fully Automated Cassette-to-Cassette Epiwafer ProductionPhilip Sullivan
Thermo VG Semicon**Commercial Production of Large Diameter InP-HBT Epiwafers by MBE**Dmitri Lubyshev
IQE**Metal-Organic Vapor Phase Epitaxy for the Mass Production of Novel Semiconductor Devices**Bernd Schulte
Aixtron AG**Well-Controlled MOCVD Production of DH-PHEMT Wafers**Chia-Shun Liu
Procomp Informatics**Session T1C****Back-End Processes**

9:00 a.m. – 10:20 a.m.

Plasma Etch Processes for Die SeparationJ P Almerico
Tegal**Speed of Scribe & Break vs. Saw or Laser for Die Separation**John Tyler
Dynatex International**Reversible Bonding Process for Thin Compound Semiconductor Production**Chad Brubaker
EV Group**Free-Shape Cutting of Thin Semiconductor Wafers**Natalia Dushkina
The Gem City Engineering Co**Session T2A****Front End Processes for Microelectronics**

10:40 a.m. – 12:00 p.m.

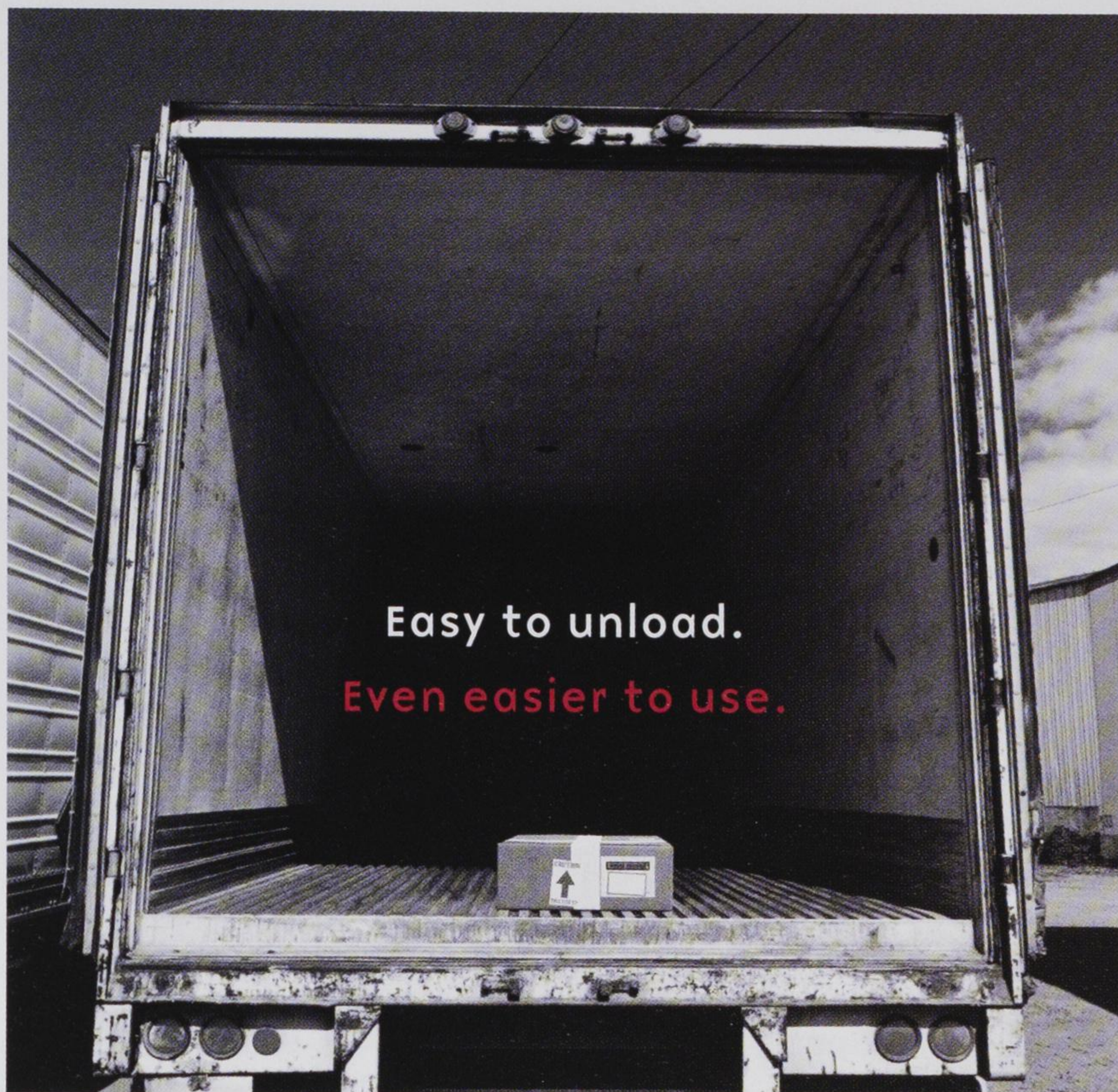
Automated Inspection for Monitoring InGaP HBT Backside Via ProcessYaozu Wang
Anadigics**Metal Lift-off on InP HPTs Using Carbon Dioxide Snow Spray**Andrea Via
Eco-Snow Systems**Plasma RIE Etching of Seed Layer Materials**Mark Rousey-Seidel
Tegal**Etching of Thin, Damage Sensitive Layers Using High Frequency Pulsed Plasma**Russ Westerman
Unaxis**Session T2B****Wide Bandgap Materials I**

10:40 a.m. – 12:00 p.m.

Atmospheric Pressure MOCVD Technology of GaN and Related CompoundsKoh Matsumoto
Nippon Sanso**Chemical Kinetics in a Well-Mixed Reactor for GaN MOVPE Growth**Zhi-qiang Li
Crosslight Software**An Integrated Solution Approach for the Use of Ammonia in Growth of GaN Based Semiconductors**Robert Torres
Matheson Tri-Gas**Photoluminescence Characterisation of Wide Bandgap Materials and Devices**Colm MacMahon
Accent Optical Technologies**Session T2C****Environmental Health & Safety**

10:40 a.m. – 12:00 p.m.

How to Characterize Hazards in Emerging Technologies – the GaN Epitaxy ExampleNicola Proust
Thales**New Technology for Removal of Arsenic and Other Metals from Waste Water**Joel Peterson
Motorola – SPS



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TECHNICAL PROGRAM

EHS Efficiency Yields Manufacturing Dividends

Eric Nielsen
Sumco USA

Safe Waste Gas Purification in Compound Semiconductor Manufacturing

Joe Guerin
CS Clean Systems AG

**Session T3A
Fab Management I**

1:30 p.m. – 2:40 p.m.

Failure Mode and Effects Analysis (FMEA): Reducing Product Time to Market in Photonic Integrated Circuits Manufacture

Bedwyr Humphreys
MetroPhotonics

Database Centered Manufacturing

Seppo Orsila
Modulight

Operational Cost Reduction in Compound Semiconductor Manufacturing

Paulos Giannoules
M+ W Zander

**Session T3B
LEDs II**

1:30 p.m. – 2:30 p.m.

LED Junction Temperature Measurement & Its Applications

Kelvin Shih
Lawrence Technological University

Method of Making High-Power LEDs

Kuang Neng Yang
United Epitaxy Company

Dicing of Nitride LED Wafers via Laser Ablation

Bryan Shelton
Emcore

**Session T3C
Gas Analytics I**

1:30 p.m. – 2:30 p.m.

Trace Water Detection in Semiconductor-grade Phosphine Gas

Kris Bertness
NIST

Ammonia Purification Measurement by FT-IR Spectroscopy

Xiaosong Jiang
Aeronex

Performance of Palladium Diffusers for Reliable Purification of Hydrogen

Hans Funke
Matheson Tri-Gas

**Session T4A
Fab Management II**

2:40 p.m. – 3:40 p.m.

A Case Study of the KMTI Model for GaAs Fab Management

Roger Yin
Global Communication Technology

Consumable and Material Tracking and Tracing Logistics Management

Dalia Vernikovsky
Eshinui

The Application of SEMI-style Equipment Development and Specification Processes to Compound Semiconductor Equipment

Eric Friedman
Veeco-Applied Epi

**Session T4B
Starting Materials I**

2:40 p.m. – 3:40 p.m.

Improvements in the Delivery of Solid and Solution MOVPE Precursors

Simon Rushworth
Epichem

GaAs Substrate Production: Optimization for Cost and Device Type

Russell Kremer
Freiberger USA

Metalorganic Sources: Value as a Combination of Precursor and Packaging

Egbert Woelk
ShIPLEY Metalorganics

**Session T4C
Gas Analytics II**

2:40 p.m. – 3:40 p.m.

Hydrogen Purification Using Nickel/Titanium Technology

Dan Alvarez, Jr
Aeronex

Monitoring Hydrogen Purifiers: An Early Warning System for the MOCVD Process

Fred Gornick
Power & Energy

Characterization And Control Of Sulfur Impurities In Arsine

Rajiv Agarwal
Air Products and Chemicals

Wednesday November 13**Session W1A
Epitaxy II**

9:00 a.m. – 10:20 a.m.

Compound Semiconductor Epi Manufacturing in Taiwan

Michael Yang
VPEC

Managing Through Cycles: A Look at the Future for MBE

Michael Levy
Riber

High Volume MOCVD Production of InGaP/GaAs HBT Wafers by Well-Controlled Materials and Devices

Yong-Yin Chen
Procomp Informatics

Low-Cost Volume Production of High-Power Diode Lasers by MBE

Tom Bird
Veeco-Applied Epi

**Session W1B
Front-End Processing for Microelectronics**

9:00 a.m. – 10:20 a.m.

Mix & Match Experiences Of E-Beam Direct Writing with Photolithography

Ulf Weidenmueller
Leica Microsystems

Application of Si-Style Plasma Tools for Compound Semiconductor Processing

Andy Bavin
Trikon Technologies

Rapid and Controlled Processing of GaAs Wafers Using 170 KHz Ultrasonic Agitation

John Moore
General Chemical

Optimization of a Low Stress ECR Nitride Passivation Process for the Control of Breakdown Voltage Degeneration in GaAs Based PHEMT Devices

Kathy O'Donnell
NEXX Systems

**Session W1C
Optoelectronics II**

9:00 a.m. – 10:20 a.m.

Cost-Effective, Short Design Cycle Approach to Monolithically Integrated Photodiode Lenses

Susan Lindsay
JDS Uniphase

The Impact of GaAs Substrate Quality on Laser Diode Lifetime

David Forbes
Alfalight

Growth and Characterization of InAlAs Avalanche Photodiode Structures in a Multi-Wafer Production MOVPE Reactor

Joseph Boisvert
Spectrolab

Design and Simulation of Photonic Semiconductor Devices

Zhengyu Huang
RSoft Design Group

**Session W2A
Heterointegration**

10:40 a.m. – 12:00 p.m.

A Wafer-Scale Approach For Low Cost Optical Communication Component Integration

William Waters
Optogration

Compound Semiconductors on Silicon using Smart-Cut Technology

Fabrice Letertre
Soitec SA

Development of 200 mm Ge Substrates for Electronic and Opto-electronic Applications

Bendix De Meulemeester
Umicore

Wafer-bonded InGaAs-on-Si Avalanche Photodiode Devices

Steve Hummel
Nova Crystals

**Session W2B
LEDs III**

10:40 a.m. – 12:00 p.m.

Multiple Composite Inter-layers Grown in Si-Doped Gallium Nitride Layer for Crack Reduction and LED Device Improvement

Chunhui Yan
AXT Optoelectronics

Ammonia And Hydrogen For Blue LEDs, from Supply to Abatement

Joe Van Gompel
BOC Edwards

UV Laser Micro-Dicing on Ultra Hard LED Wafers

Patrick Sercel
JPSA

**Session W2C
Starting Materials II**

10:40 a.m. – 12:00 p.m.

Correlation of TMA Purity with AlAs/AlGaAs Layer Quality

Simon Rushworth
Epichem

6 inch Semi-insulating InP Single Crystals Grown by Hot Wall LEC Method

Takayuki Sato
Showa Denko KK

High Purity Trimethylindium and The Properties of Epitaxial InP Grown by MOVPE

Deo Shenai
Shipley Metalorganics

**Session W3A
Characterization II**

1:30 p.m. – 2:50 p.m.

Ex-Situ Characterization of InGaAsP

Alexana Roshko
NIST

Raman Imaging of Local Structure in Compound Semiconductors

David Tuschel
Chemicon

Improved Characterization Of Diffusion in Ohmic Contacts Using Backside SIMS

Patrick Van Lierde
Charles Evans & Associates

Topographic Electrical Characterization of Semi-Insulating GaAs, InP and SiC Substrates

Wolfgang Jantz
Fraunhofer IAF

**Session W3B
Wide Bandgap Materials II**

1:30 p.m. – 2:50 p.m.

Large Area Production of AlGaIn/GaN FETs

Ronald Birkhahn
Emcore

Innovative Low COO Solution for Safely Abating of GaN Exhaust

Vikrant Chidgopkar
BOC Edwards

FTIR Reflectance Metrology of GaN-Based Films

Victor Yakovlev
MKS Instruments

Performance of a 19 × 2 GaN-based MOCVD System

A R Boyd
Thomas Swan Scientific Equipment

**Session W3C
Front-End Processing**

1:30 p.m. – 2:50 p.m.

Reactive Ion Beam Etching of InP

Kurt Williams
Veeco Instruments

ICPECVD Low Temperature Deposition of SiO_x, SiO_xN_y, and SiN_x Films

Bernd Gruska
Sentech Instruments GmbH

Automated Rapid Thermal Processing for the Compound Semiconductor Industry

Hin Yiu Anthony Chung
Mattson Thermal Products

The Production, Measurement, and Control of Ultra-thin Films

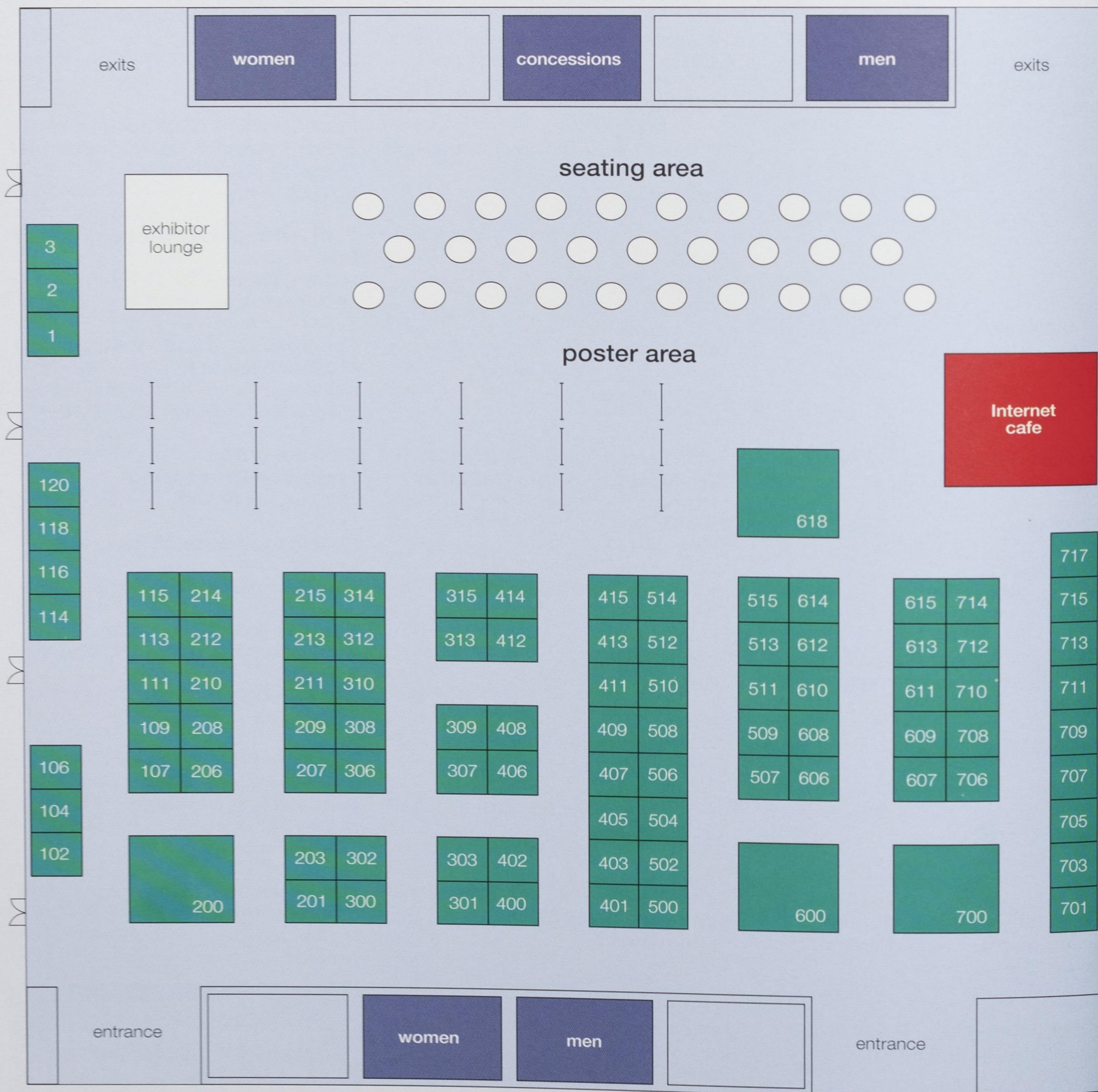
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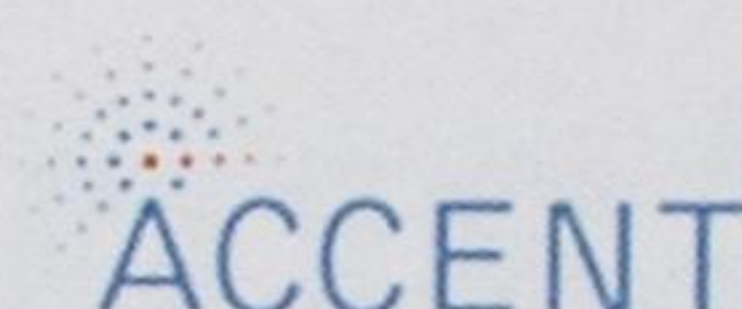


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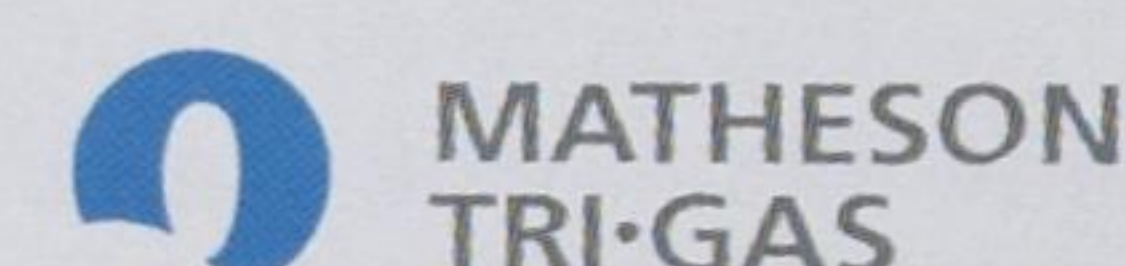
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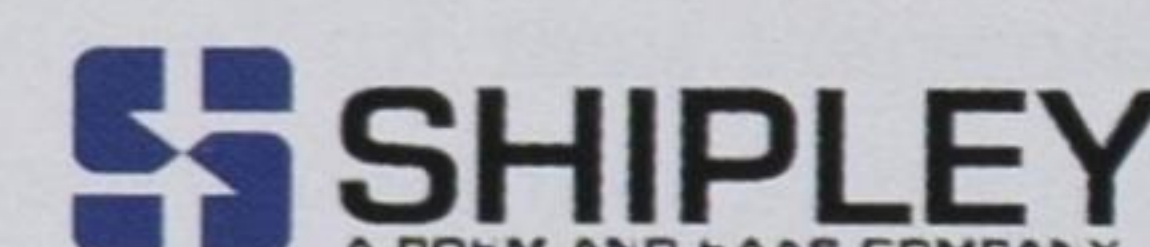
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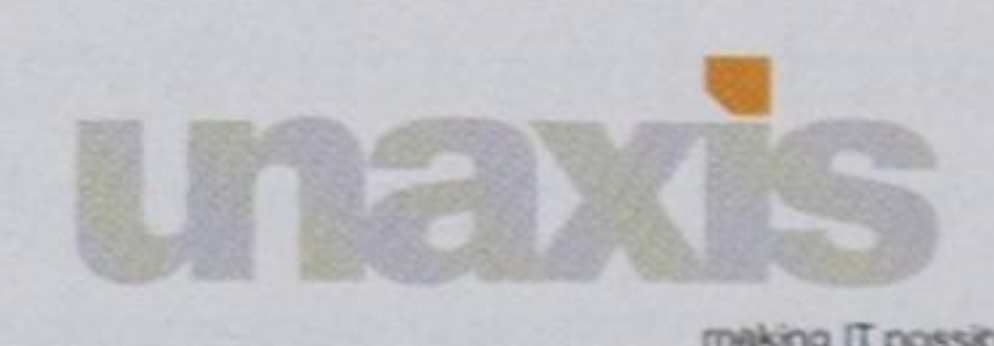










Cameras and color displays promise an end-of-year boost

Handset manufacturers are hoping that a host of new models featuring cameras, color screens and multimedia messaging capabilities will result in strong shipment numbers towards the end of 2002. But if they're wrong, it may spell a new disaster for the supply chain, writes **Tim Whitaker**.

Mobile handset sales could be in for a major boost as the holiday season approaches, as manufacturers start to introduce models with attractive features such as full-color screens, built-in cameras and multimedia messaging service (MMS) capabilities. Now that the industry's supply chain has stabilized, these increased sales figures should boost the demand for components such as GaAs switches and power amplifier modules and high-brightness blue and white LEDs. At present, full-color screens in handsets are liquid-crystal displays (LCDs) with white LED backlights, although organic LED displays are expected to supersede LCDs in the next few years.

Recent figures from Gartner Dataquest show that worldwide mobile phone sales totaled 98.7 million units in the second quarter of 2002. This represents a 5% increase on the 93.7 million units sold in the first quarter of the year. Most significantly, Gartner currently estimates that total handset sales will reach a record-breaking 420 million units in 2002, compared with 399.6 million in 2001 and 413 million in 2000.

As shown in the graph on page 38, these figures indicate that handset shipments will grow by around 18% from 192.4 million in the first half of 2002 to 227.6 million in the second – a healthy rate by anyone's standards. Most of this growth will come in the fourth quarter as shoppers gear up for the holiday season. However, as shown in the table, other sources have quoted lower numbers.

Overall, Gartner says that expectations remain high for strong fourth-quarter sales worldwide, driven in part by the introduction of numerous new, low-cost terminals from leading manufacturers. The outlook is particularly bright in Western Europe. "The frenzy of marketing activity around new services such as picture and photo messaging by mobile network operators in Western Europe



Nokia's new 7650 features a built-in camera with VGA resolution of 640 x 480 pixels, together with a 35 x 41 mm color display.

is likely to fuel replacement demand for color mobile phones in the second half of 2002," said Ben Wood, senior analyst for Gartner Dataquest in Europe.

New technologies and services

The replacement market is set to drive growth towards the end of 2002. Mobile phone manufacturers are preparing to introduce a whole range of new products to embrace color displays and other data-enabling technologies. Meanwhile carriers are increasingly focused on commercializing new applications and services such as MMS. These are expected to boost operator revenue across a mature subscriber base, while acting as a catalyst for replacement sales. Such 2.5G products are filling the gap left by the delay in the introduction of 3G services.

With more than a billion handsets in use throughout the world, the prospects for a very strong market for replacement models are excellent – provided that consumers want the new features on offer. This seems to be the

case in Nokia's home country Finland, where June shipments increased 32% year-on-year to 111,000 units, driven by replacement sales as newer models reached retail channels.

"The replacement market is very important, especially in the saturated markets in Western Europe," said Carolina Milanesi, an analyst at Gartner Dataquest in Europe. "In the second half of this year we expect that new product introductions will encourage buyers to exchange their boring old phones for more exciting handsets with new features."

These include technologies such as full-color displays, built-in cameras and polyphonic ring tones, as well as services such as multimedia messaging. "MMS is now being introduced in Western Europe, although it won't really take off until next year," said Milanesi. "Essentially, MMS is the evolution of text messaging, allowing the user to send messages with pictures and sound attached."

One of the new generation of handsets is Nokia's 7650, which features an integrated digital camera, MMS, a color display and GPRS (see picture). Similarly, Sony Ericsson is about to launch its T300, an inexpensive color-screen phone capable of playing and downloading high-speed games, which also incorporates MMS and many other multimedia features. If this phone and other new handsets are successful, Sony Ericsson plans to push for the number-one spot in the market for multimedia phones.

At present, Nokia continues to dominate worldwide mobile phone sales. During the second quarter of 2002, Gartner estimates that Nokia sold just over 35 million handsets (a 35.6% market share), thanks to the continued competitiveness of its entry-level GSM portfolio. Motorola had 15.7%, while the manufacturer's top five was completed by Samsung (9.5%), Siemens (8.4%) and Sony Ericsson (5.4%). Samsung increased its sales by 46.4% compared with the second quarter of 2001.

Handset figures from different sources

	Gartner Dataquest	Strategy Analytics	Nokia
Q2 2002 sales (\$m)	98.7	96.7	93.0
2002 sales (\$m)	420.0	417.0	400.0
2001 sales (\$m)	399.6	393.0	380.0
Nokia's market share (%)	35.6	37.2	38.0

Big in Japan

Milanesi estimates that only about 5% of new phones in Europe and North America currently have full-color displays. The situation is very different in Japan, where full-color displays are found in almost all new phones (see p19). Furthermore, handsets with cameras accounted for around 30% of total unit shipments in the second quarter in Japan, and the penetration rate of this application is expected to continue to increase. In June, monthly handset shipments in Japan reportedly exceeded 4 million units for the first time in nine months.

Japanese mobile network operator J-Phone is to offer two new phones with Movie Shamail, a service that enables users to send video clips of up to five seconds with sound as email

attachments. The J-SH52 handset, manufactured by Sharp, can take pictures at VGA resolution (640 × 480 pixels) with its 310,000-pixel built-in CCD camera. Also, NTT DoCoMo plans to release a new handset with a built-in 0.17 megapixel digital camera and the ability to store 1670 images.

Sell-in and sell-through

Further optimism for the mobile phone market comes from the sell-in numbers. Gartner estimates that sell-in shipments reached 97.5 million units in the second quarter of 2002, up 8.2% from the same period last year.

Sell-in refers to shipments from the handset manufacturers to various distributors and other sales channels. The main numbers

quoted by Gartner (98.7 million units in the second quarter of 2002) are sell-through numbers, which refer to sales to the consumer. Obviously, the sell-in number is of most relevance to component suppliers such as makers of GaAs ICs and nitride LEDs.

However, if the sell-in and sell-through numbers are far apart, this indicates a build-up of inventory, which caused problems last year. "At the end of 2000, we had high sell-in figures," explained Milanesi. "However, due to the poor economy and a lack of interesting new phones, there was a low sell-through in 2001, and handset inventories built up in the sales channel." These factors combined to cause the drop in shipments of both handsets and components. However, Gartner's figures for the second quarter of 2002, which show a small discrepancy between sell-in and sell-through numbers, are evidence that the relationship between global supply and demand is being well managed in 2002.

"We are definitely seeing improvement in channel stocks and how these are being handled," said Milanesi. "Distributors need to keep



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stocks low to be ready to take new phones as they appear during the second half of the year.”

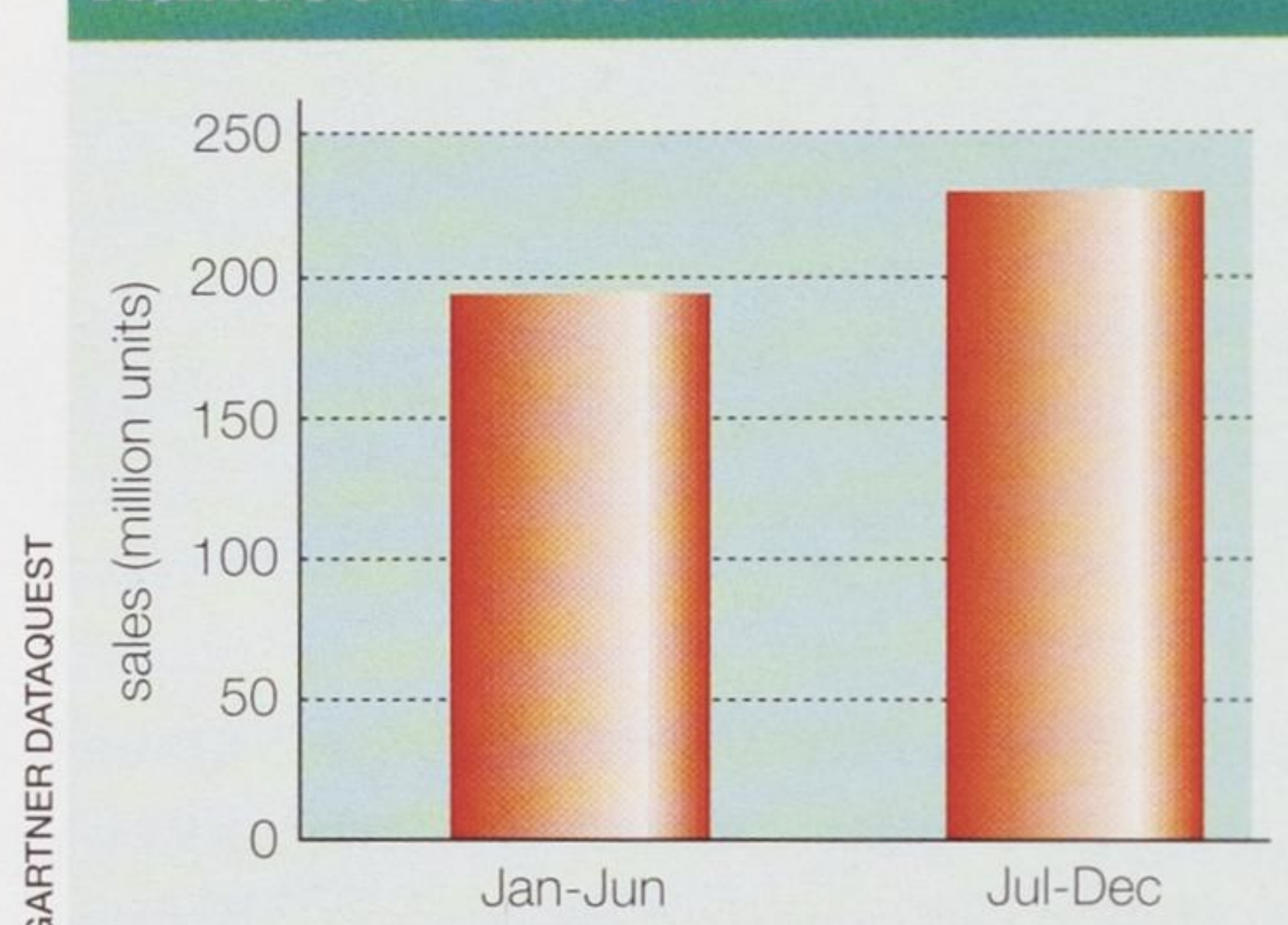
At the component level, GaAs IC makers such as RFMD are confident that the surge in handset sales will boost their own figures in the short term. RFMD, which had record revenues of \$103.9 m in the June 2002 quarter, expects a further 5–10% increase during the September quarter. In August, RFMD shrugged off rumors that it was losing business to its competitors or seeing order delays from Nokia, which accounts for about half of RFMD's shipments.

Another factor that could boost the market is that operators may seek to increase their subscriber bases by offering low-priced prepaid packages at the end of the year, driven by some manufacturers' extremely aggressive pricing of entry-level phones. Operators are also subsidizing phones that provide revenue-generating services, such as MMS and GPRS handsets.

Seasonal variation

Although the handset market is definitely showing signs of stability, the 18% growth figure for the second half of 2002 is not sustainable. Different regions are behaving dif-

Handset sales in 2002



GARTNER DATAQUEST

The handset market is expected to show 18% growth in the second half of 2002, due to demand for replacement phones with attractive features such as color screens, cameras and multimedia messaging.

ferently; Asia-Pacific is booming, Western Europe is highly saturated and looking towards a strong replacement market, while areas like Central America are not living up to their great potential because of the general economic situation. Overall, growth is expected to be cyclical, with a peak at the end of 2002 coinciding with the holiday season, fol-

lowed by a sequential decline in early 2003. However, year-on-year figures should show steady single-digit growth.

“We are not going to see the huge and sustained growth that happened in 1999 and 2000,” added Milanesi. “However, we don't expect to see a big drop at the start of next year like the one in 2001.”

A lot is riding on the success of the new phones. At the end of August, Ericsson's chief executive, Kurt Hellstroem, warned that his company would not continue to pour money into the Sony Ericsson joint venture unless its performance improves and consumers accept its new products. Investors in Nokia are likely to react badly if the company is forced to issue another downgrade for its 2002 handset estimates (at the start of the year, Nokia forecast global handset sales of 420–440 million during 2002; that was then reduced in stages to 400 million). Clearly, if the manufacturers fail to sell enough handsets towards the end of this year, inventory problems will return to the supply chain, which could spell bad news for the component vendors just when some optimism is starting to return. ●

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GaN growers model their way to higher quality materials

Computer modeling of fluid dynamics has brought great benefits to those designing semiconductor equipment and processes. **Jon Newey** looks at an example of how modeling is being applied to the understanding of what happens during GaN epitaxy and how this relates to material quality.

Understanding the flow patterns of gases and liquids is of vital importance to activities as diverse as weather forecasting or designing aircraft. Any process that involves the flow of gases or liquids is generally extremely complicated. Minor perturbations at one point in a fluid system can yield huge changes elsewhere. Semiconductor manufacturing relies on a whole range of gases and liquids at almost every process step, and while for some of these processes detailed knowledge of what is happening to the fluids is of little importance, in others it is vital.

One process where this knowledge can yield great benefits is MOCVD. How will a new reactor design affect the way the precursors and carrier gases flow in the growth chamber? What are the best growth parameters to start with when developing a new epitaxial structure? These are difficult questions to answer, but equipment manufacturers and growers are making increasing use of computer modeling to gain some insights.

The use of such computational techniques has been helped in no small way by the advent of powerful number-crunching desktop computers. Computational fluid dynamics (CFD) is no longer synonymous only with custom-written software and room-sized supercomputers. Today's top of the range personal computers are sufficiently powerful to model the internal workings of an MOCVD reactor and modeling software is commercially available, bringing CFD to a wider audience.

Saving time and money

The use of modeling techniques helps to reduce development time and cost by removing some of the guess work and getting as near as possible to the right answer first time. "At the present level [of reactor design and complexity] it is impossible to design new systems without modeling. The trial and error approach is too expensive," said Alex

The Asian Office of Aerospace Research and Development

The Asian Office of Aerospace Research and Development (AOARD) was established by the US Air Force Office of Scientific Research (AFOSR) as one of two foreign satellite offices. The other is the European Office of Aerospace Research and Development (EOARD) based in London. Located in Tokyo to work closely with the Asian science and technology community, AOARD manages the US Air Force basic research investment in Asia and the Pacific Rim. Like its counterpart in London, AOARD is colocated with equivalent organizations representing the Office of Naval Research and the Army Research Office.

The remit of the foreign satellite offices is to support the R&D efforts of the US armed forces and other governmental agencies by facilitating technical interactions and providing liaison between US scientists and engineers and their counterparts in Asia and the Pacific Rim. AOARD does this in several ways. Program managers identify prominent scientists and cutting-edge technology by visiting research institutes and attending technical meetings. Secondly, a program called Window on Science funds visits of prominent researchers to enhance Air Force programs and encourage research collaborations. A third way is through a

conference support program that provides financial backing to workshops and symposia that convene in Asia and the Pacific Rim on topics of interest to the Air Force research community.

Finally, AOARD accepts research proposals on behalf of AFOSR in five categories. One of these is Physics and Electronics, through which the GaN growth modeling work at Tokyo University of Science is funded. Across the five areas, AOARD funds 20–30 new contracts each year. AOARD publishes a quarterly newsletter to inform the research community of its activities in Asia and the Pacific Rim (see www.nmjc.org/aoard/Asia_Sci_Ltr_Dir.html).

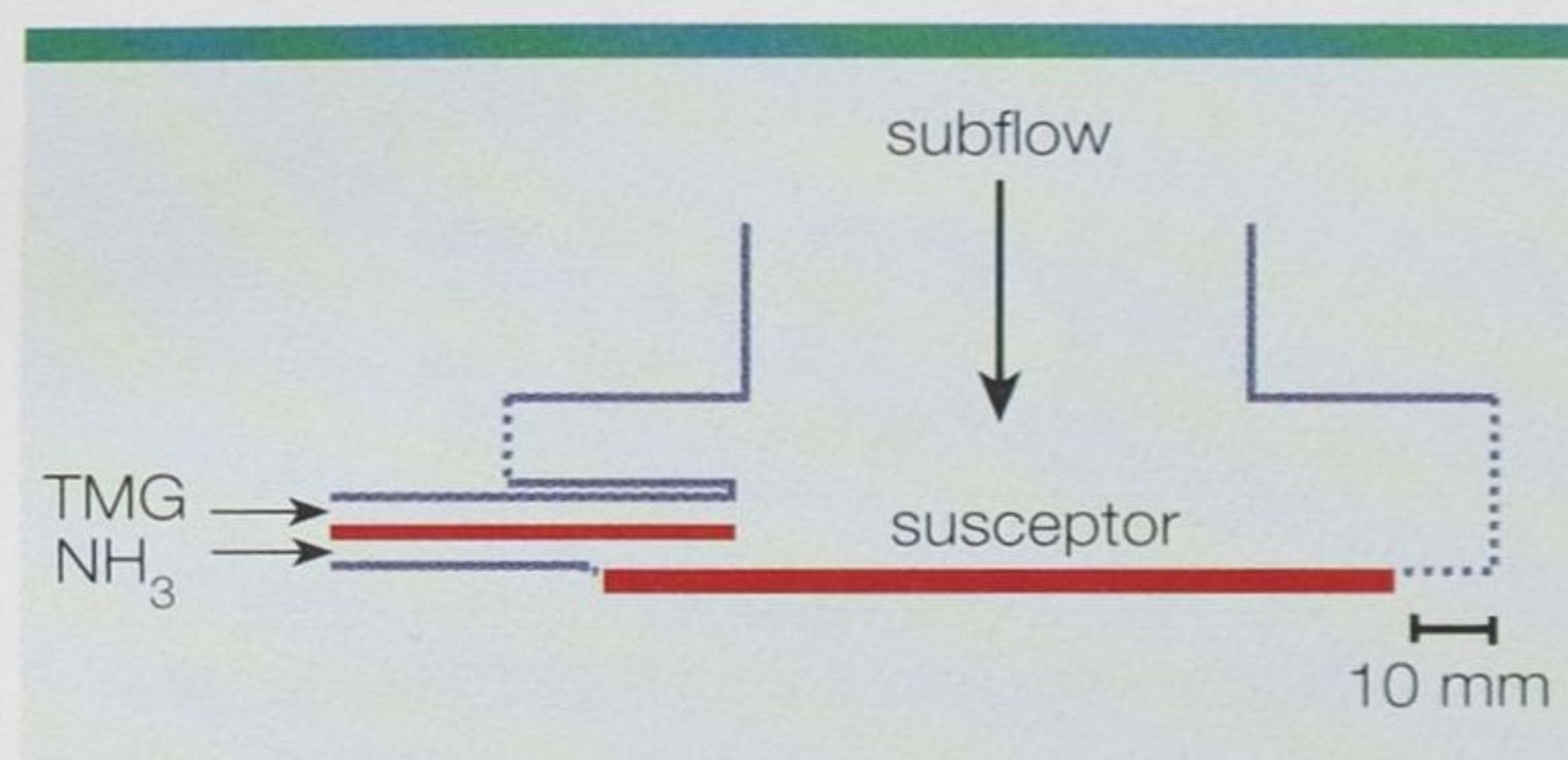


Fig. 1. A cross-sectional view of the three-flow MOCVD reactor configuration.

Gurary, head of the MOCVD reactor development group at Emcore.

If an accurate model for a particular reactor configuration can be made, then for a given

set of process conditions, such as temperature and pressure, it becomes possible to model the fluid dynamics of the system. This will indicate if laminar flow over the substrate is maintained or if undesirable effects such as gas recirculation are more likely.

The accuracy of the output from a computer modeling exercise depends on the quality of information input into the model. Understanding the chemistry of the system is particularly important in MOCVD, where the reactions between different metalorganic chemicals and the reaction by-products affect the fluid dynamics and therefore the epitaxial quality. For established compound semi-

conductors such as GaAs the chemistry is well understood, allowing the modeling of processes with considerable accuracy.

"For GaAs we can predict parameters like growth rate and uniformity [for a given set of reactor conditions] and use them for process development," said Gurary. "For other materials the chemistry is less well understood. This is particularly true for GaN, where different adducts are formed in the reaction stage that can change the situation dramatically, especially for AlGaN and InGaN. At present everyone is at the stage of trying to understand the chemistry of GaN and its alloys and learning how to model the process."

Modeling to avoid turbulence

Kazuhiro Ohkawa and colleagues at the Tokyo University of Science are one of the groups of researchers involved in this learning process. Ohkawa's group has received funding through the Asian Office of Aerospace Research and Development (see AOARD box, page 39) to model the MOCVD growth of GaN. Ohkawa's recent work provides a good

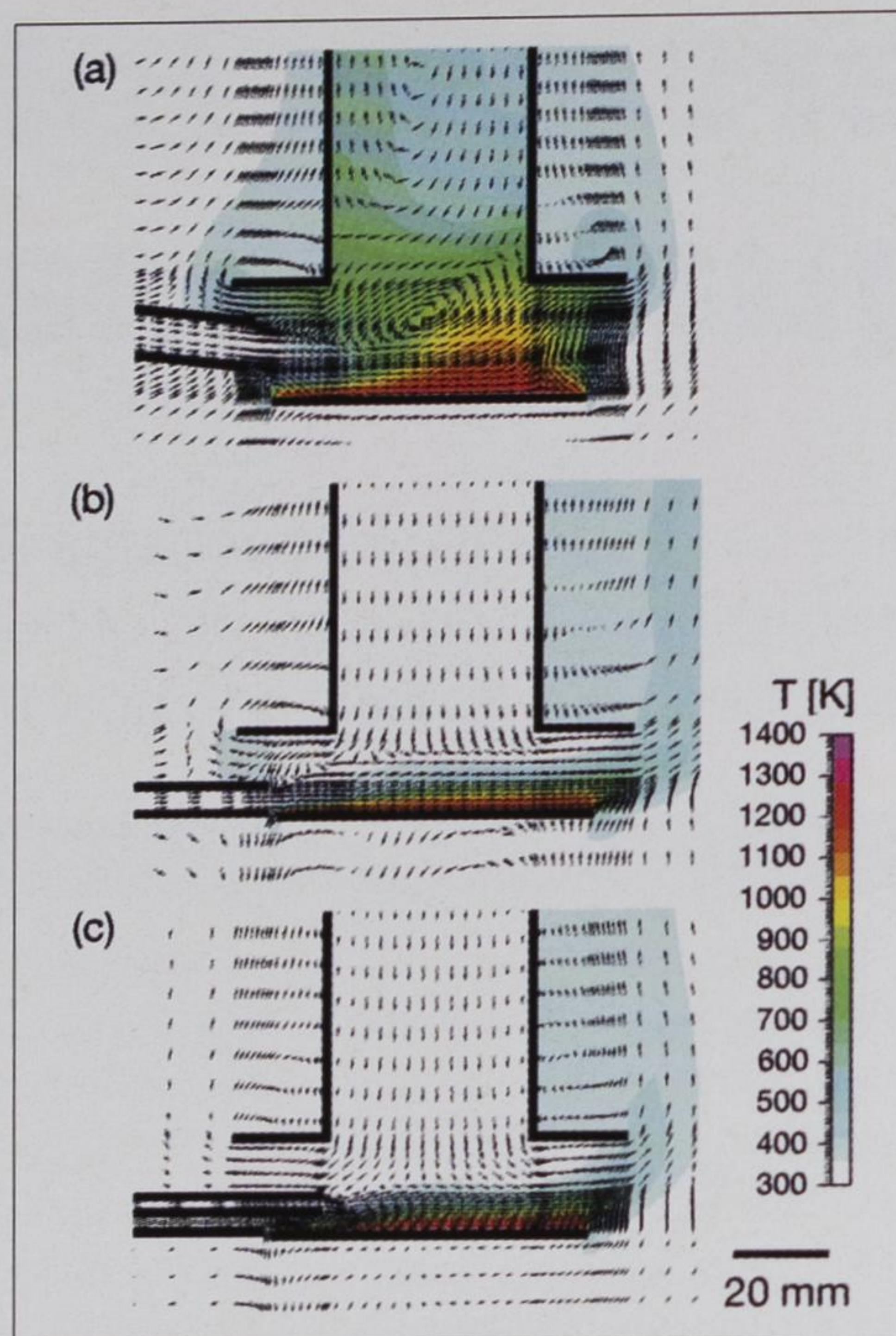


Fig. 2. CFD simulations of the gas flows for the one-flow (a), two-flow (b) and three-flow (c) reactor inlet configurations.

example of what can be done using computer simulations. The group is using a commercially available CFD code to look in three dimensions at a Nippon Sanso reactor during GaN growth under different reactor configurations and growth conditions. The group is able to correlate the modeled conditions in the reactor with the actual properties of GaN grown on sapphire when the conditions used in the model are applied to real growth situations.

The reactor is designed to give three possible gas-flow configurations (figure 1). In the one-flow setup, all of the gases, trimethyl gallium (TMG), ammonia and hydrogen, are fed in at 7° to the horizontal plane of the susceptor, with no gas flow from the subflow nozzle. In the two-flow configuration, the TMG and ammonia are fed in horizontally, while the reactor subflow carries hydrogen or nitrogen in vertically to suppress thermal convection from the hot susceptor. In the three-flow method, the horizontal main feed is split into two channels that feed the TMG and ammonia into the chamber separately.

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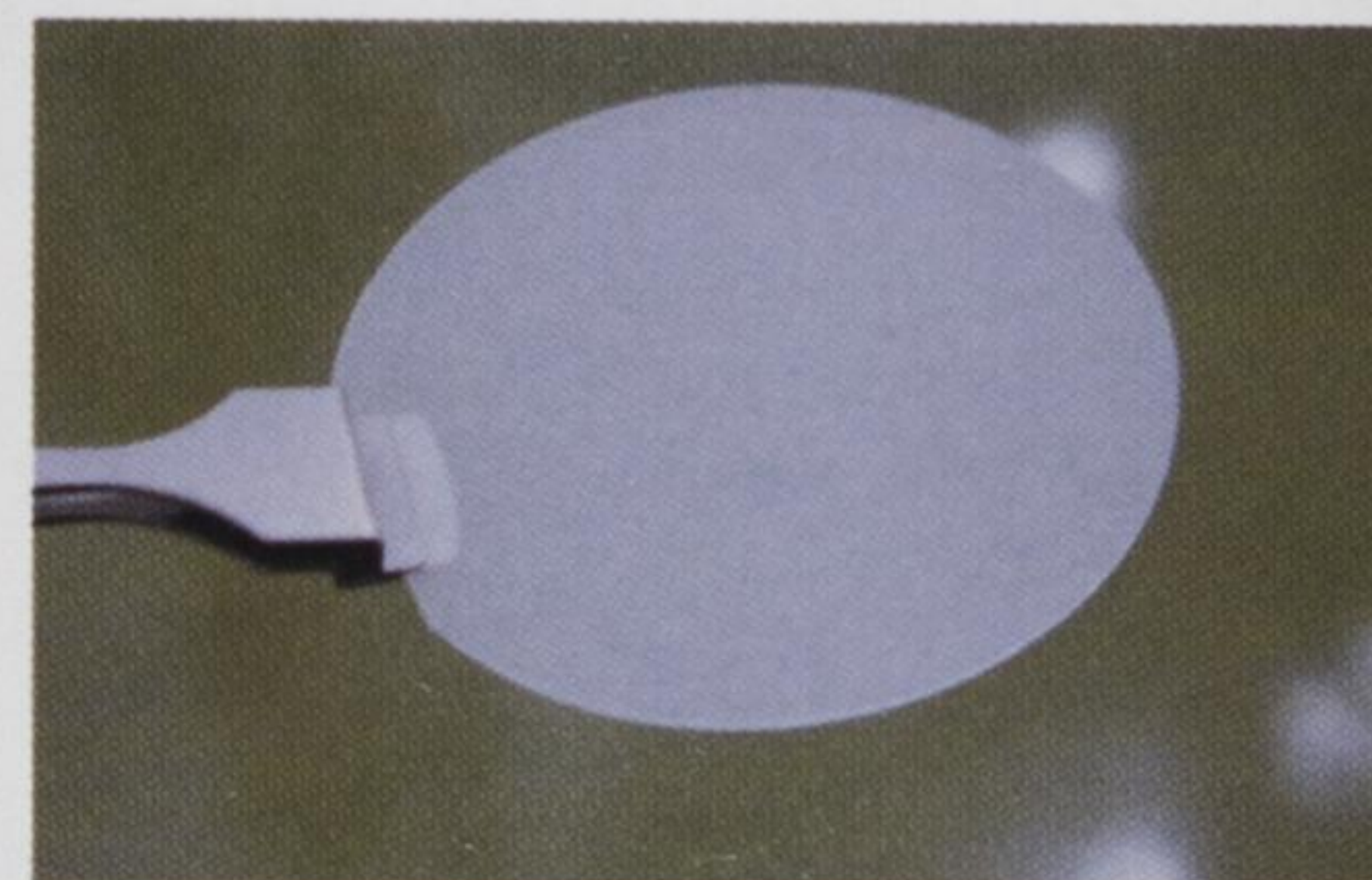
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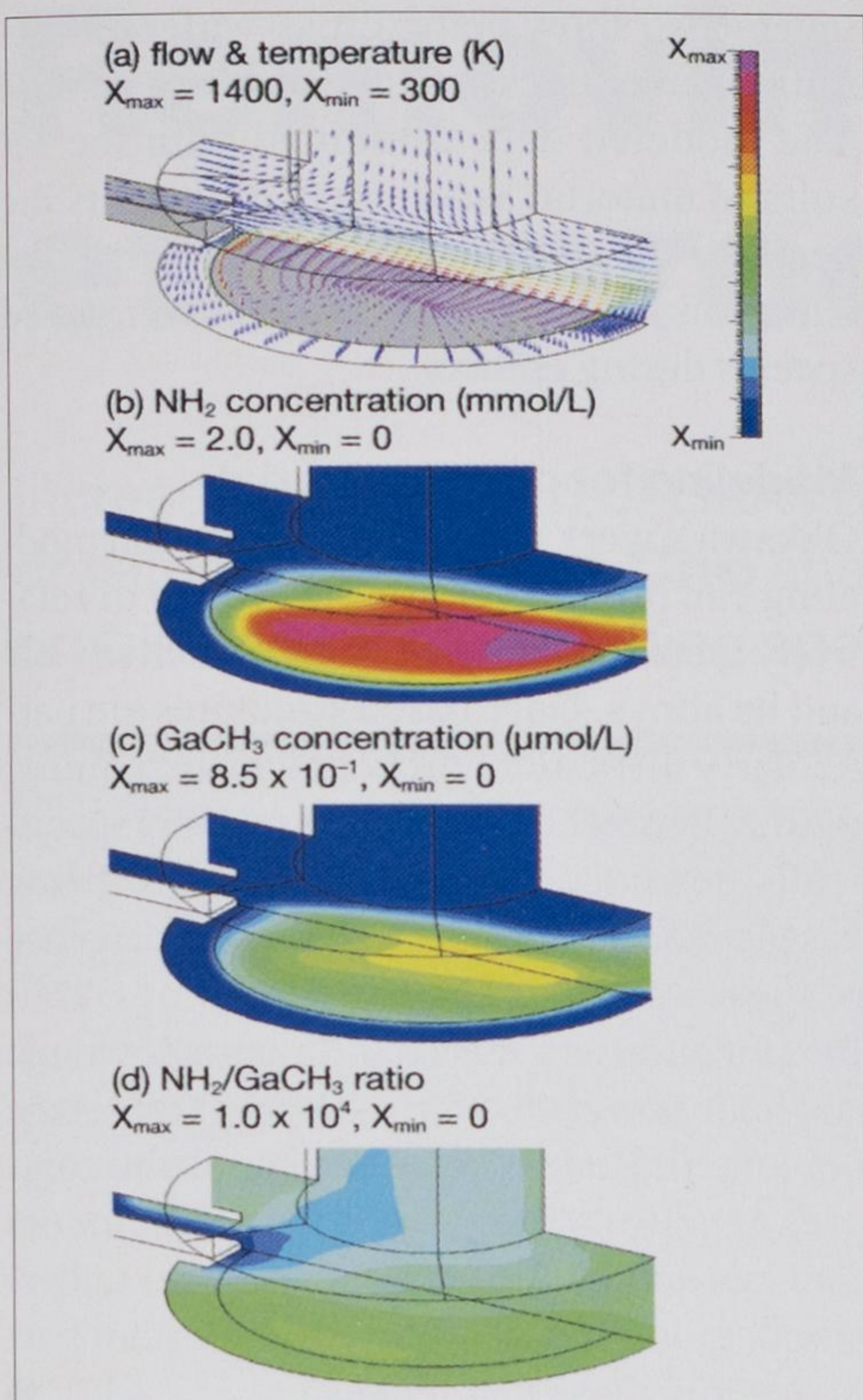


Fig. 3. MOVPE simulations for the two-flow growth of GaN with a mobility of $360 \text{ cm}^2/\text{Vs}$. The initial ammonia/TMG ratio is 5800.

The group performed growth under various conditions of temperature and V/III ratio. The reactor pressure was kept to 100 kPa and growth time was one hour for all experiments. GaN was deposited directly onto 2 inch sapphire wafers without substrate rotation. Growing without a low-temperature buffer layer removes the buffer layer's influence on the quality of the GaN subsequently deposited, enabling a direct correlation between the growth conditions, the modeled gas flows, the layer quality of GaN and its electrical properties. As a result, all the GaN layers had the hexagonal pyramid morphology characteristic of GaN grown onto sapphire without a buffer layer.

Figure 2 shows the output from a CFD simulation for the gas flows in the three configurations described above. For the one-flow case, a region of turbulence is seen above the susceptor. This is as a result of the gases becoming hot due to thermal convection from the heated susceptor. The gases decompose and react in the space above and not on the substrate surface. These reacting gases can be directly observed as smoke in the reactor. The growth rate in this case is very low at only about $1 \mu\text{m}/\text{h}$ and the resulting layers take the form of GaN islands.

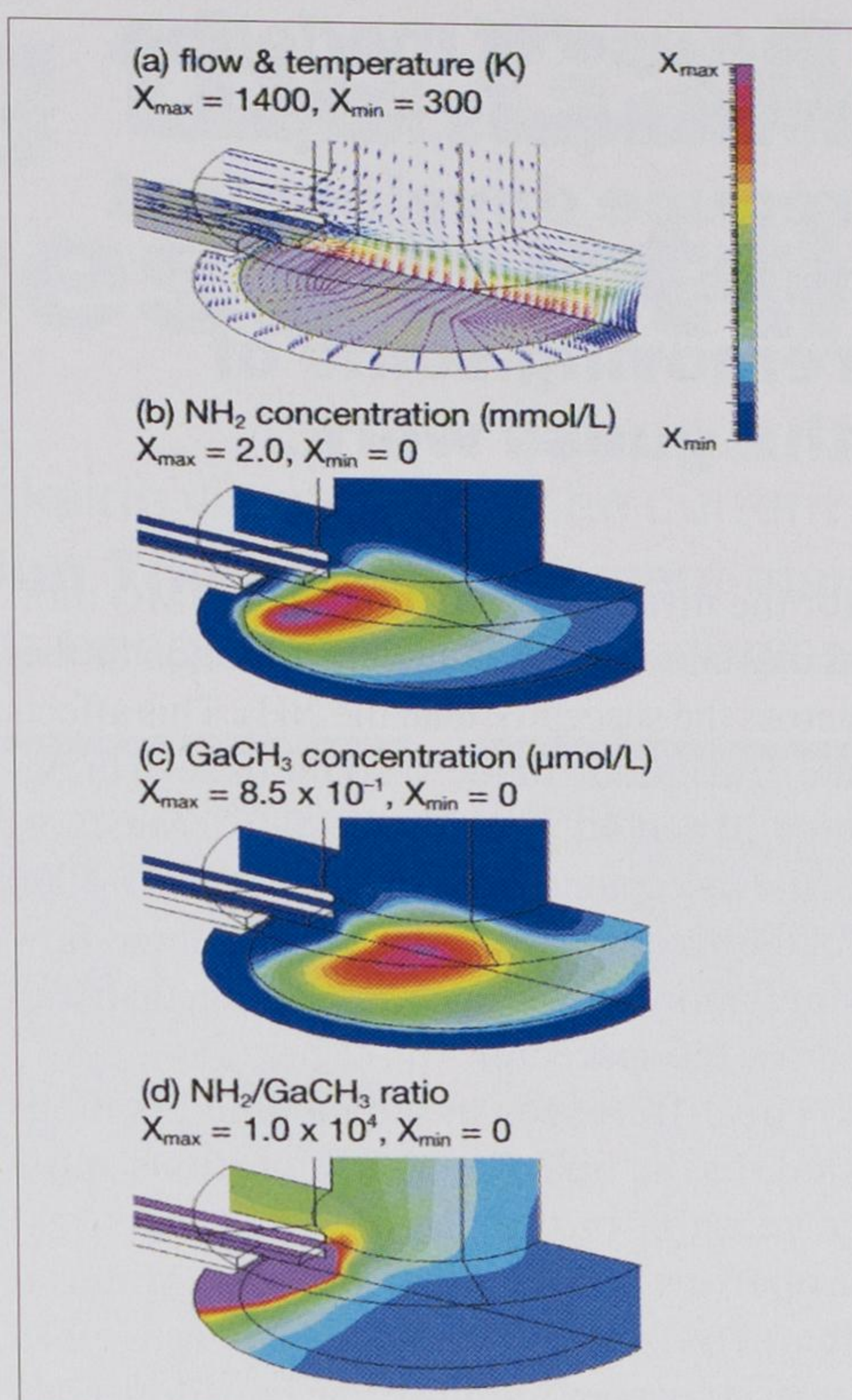


Fig. 4. MOVPE simulations for the three-flow growth of GaN with a mobility of $230 \text{ cm}^2/\text{Vs}$. The initial ammonia/TMG ratio is 5000.

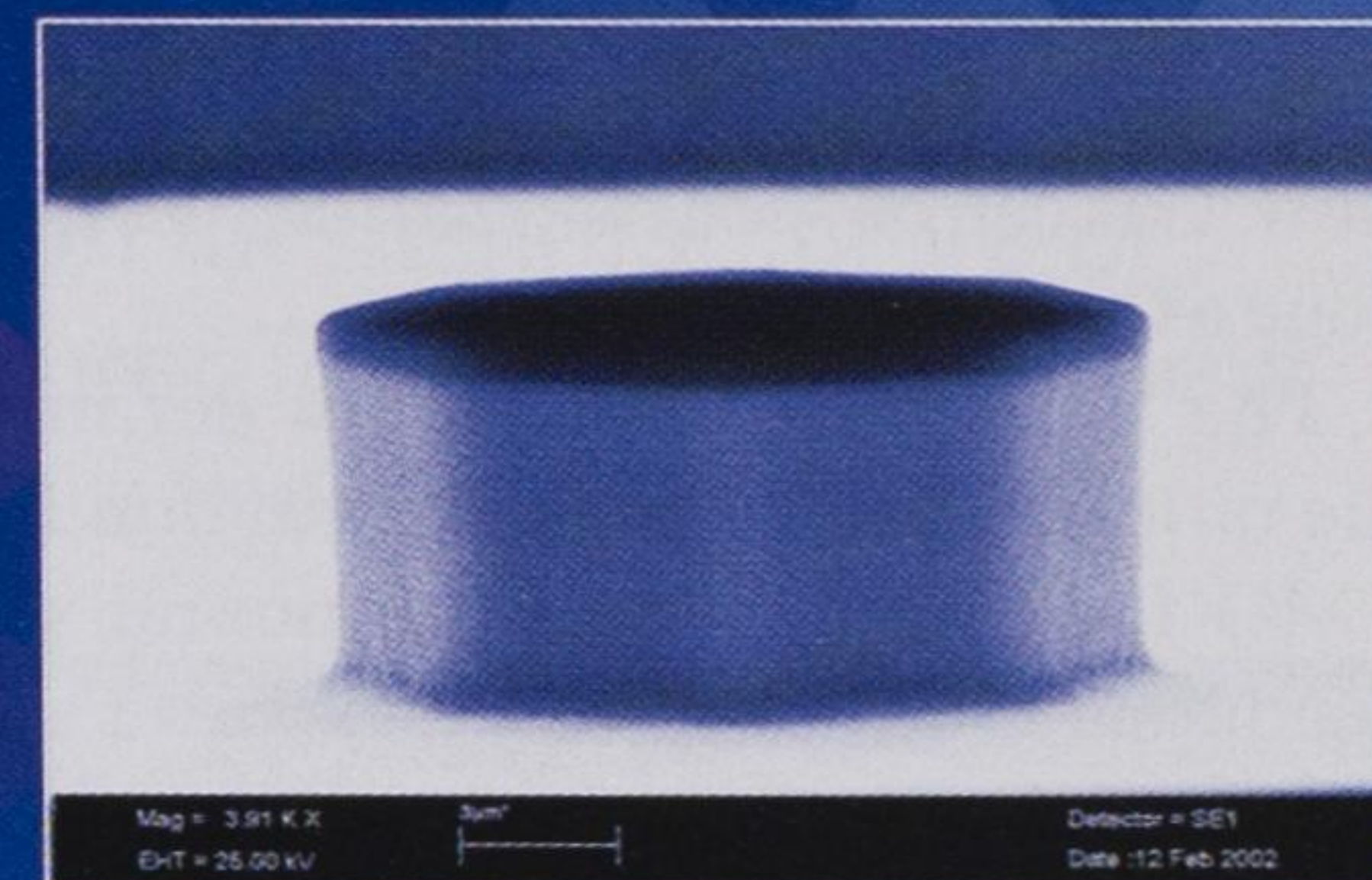
Introducing the subflow suppresses the thermal convection (figure 2b) producing smoother gas-flow patterns in the CFD simulations for the two- and three-flow methods. The simulation in figure 2c reveals that some recirculation is occurring in the three-flow configuration. Precise gas control is needed to maintain laminar flow over the substrate, and the operating window for this flow condition under three-flow growth is very narrow.

CFD and real material

Hall mobility measurements showed that the GaN which was grown using a two-flow setup has a higher carrier mobility of up to $360 \text{ cm}^2/\text{Vs}$, compared with $230 \text{ cm}^2/\text{Vs}$ for three-flow growth. Layer thicknesses were 4.6 and $8.4 \mu\text{m}$ for two- and three-flow growth, respectively.

Figure 3 shows the simulations for the growth of the material with a mobility of $360 \text{ cm}^2/\text{Vs}$. Figure 3a shows the modeled gas flow and temperature, while figures 3b and 3c show the NH_2 and monomethyl gallium (MMG) concentrations, respectively. NH_2 and MMG are molecules that are formed by the decomposition of ammonia and TMG, respectively. The NH_2/MMG ratio is

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shown in figure 3d. Figure 4 shows the same set of modeled parameters for the three-flow growth of the GaN showing a mobility of $230 \text{ cm}^2/\text{Vs}$.

Figures 3a and 4a show arrows representing gas velocity vectors, with the arrow color corresponding to temperature. The main gas flow is spread over the susceptor by the sub-flow. Gas can be seen rising at the susceptor's edge as a result of convection.

The V/III ratio is generally defined as the ratio of source materials (ammonia and TMG for GaN) used in compound semiconductor growth. However, Ohkawa's simulations use the decomposed species ratio (NH_2/MMG) as this has more influence on growth at the microscopic scale. The NH_2 concentration has a dense and wide distribution in the two-flow regime compared with the three-flow case. In the three-flow case the lower ammonia flow is being influenced by the upper TMG flow.

The MMG concentration distributions for both flow types follow a similar pattern to their respective NH_2 distributions. However,

The use of modeling techniques helps to reduce development time and cost by removing some of the guess work.

for the three-flow condition the MMG molecules show a peak in their distribution further across the susceptor than the NH_2 . This affects the distribution of the V/III ratios seen in figures 3d and 4d. For the two-flow case, most of the susceptor area has a value of 3000–5000 for the decomposed V/III ratio. The three-flow simulation shows an abrupt change halfway across the susceptor.

The differences in the parameters modeled for the different configurations show correlation to the physical and electrical properties of the grown material. Material characterization has shown that as well as superior carrier mobility, the two-flow GaN

layers also show better cross-wafer uniformity of layer thickness and material quality. The modeled data combined with the results of material assessment highlights the need for the overlapping and uniform distribution of precursors and decomposed species during epitaxy.

Modeling for better material

Ohkawa's work shows the benefits that modeling can bring, even for the growth of relatively immature material systems such as GaN and its alloys. GaN-based structures are particularly difficult to grow and have required the development of MOCVD reactors specifically designed for GaN growth. Modeling has played an important role in the emergence of these systems. The realization of GaN's full potential as a material for optoelectronic and high-power electronic devices faces some big material-related challenges. As the complex reaction chemistry of the precursors for GaN and its alloys becomes better understood, modeling will play an important part in meeting those challenges.



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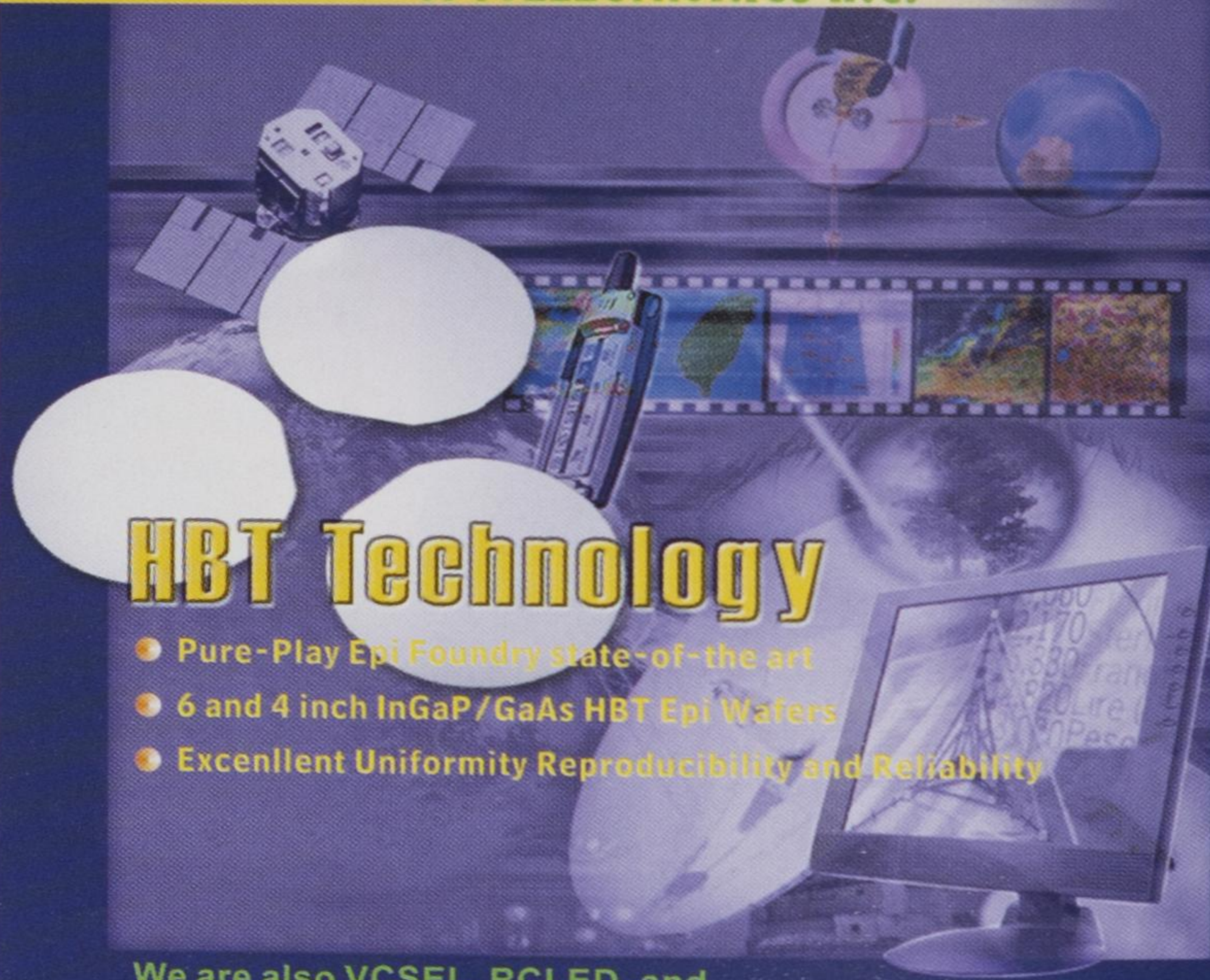
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Removing the GaAs via hole etch process bottleneck

Increasing the speed of GaAs backside via etching is the current mission for manufacturers of dry etch tools. **Young Cho** and **Jim Thomas** of equipment manufacturer Tegal explore the new problems that high etching speeds bring, and suggest strategies for how they can be solved.

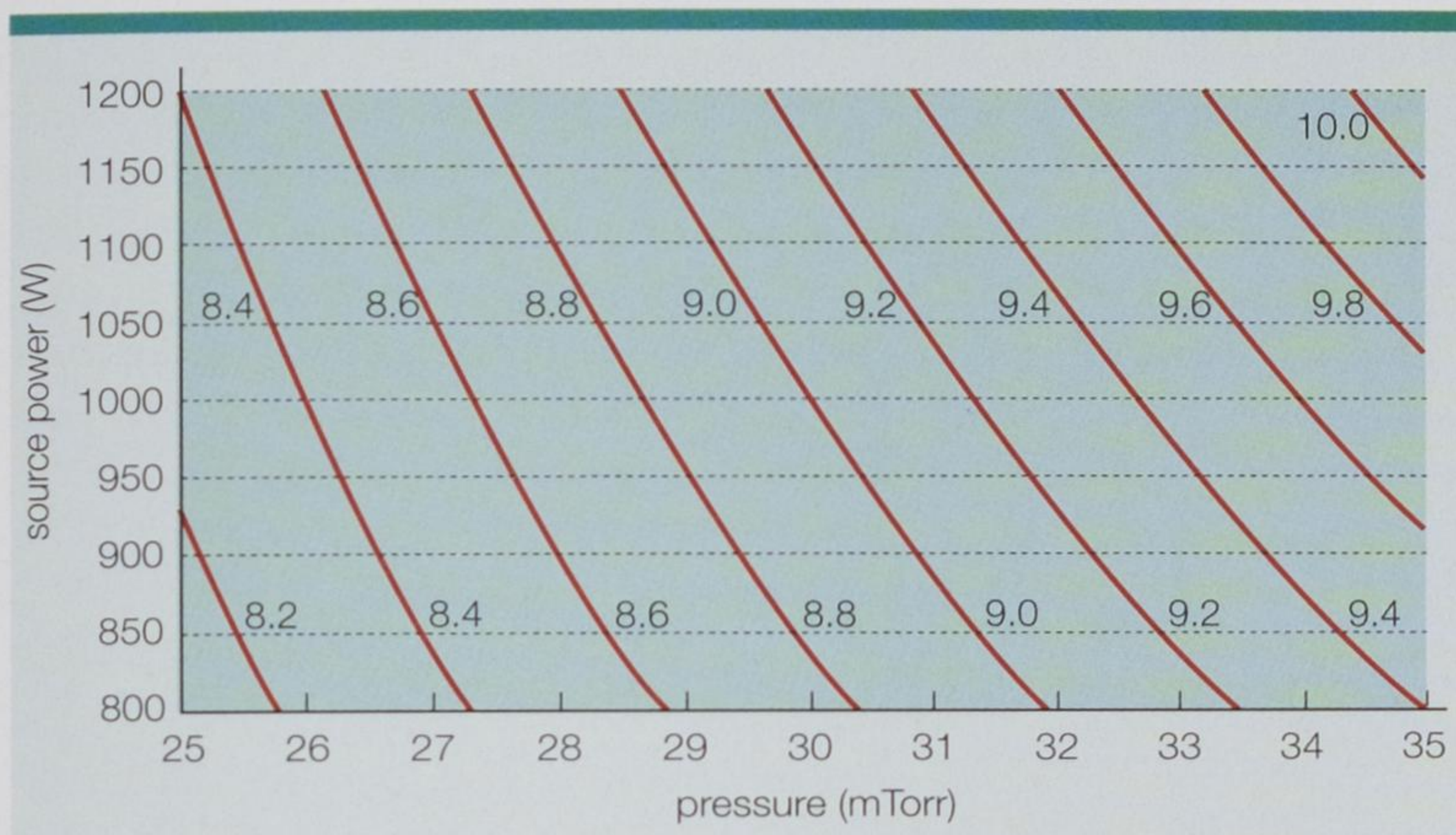


Fig. 1. Increasing the pressure boosts the etch rate in $\mu\text{m}/\text{min}$ much more effectively than increasing the source power.

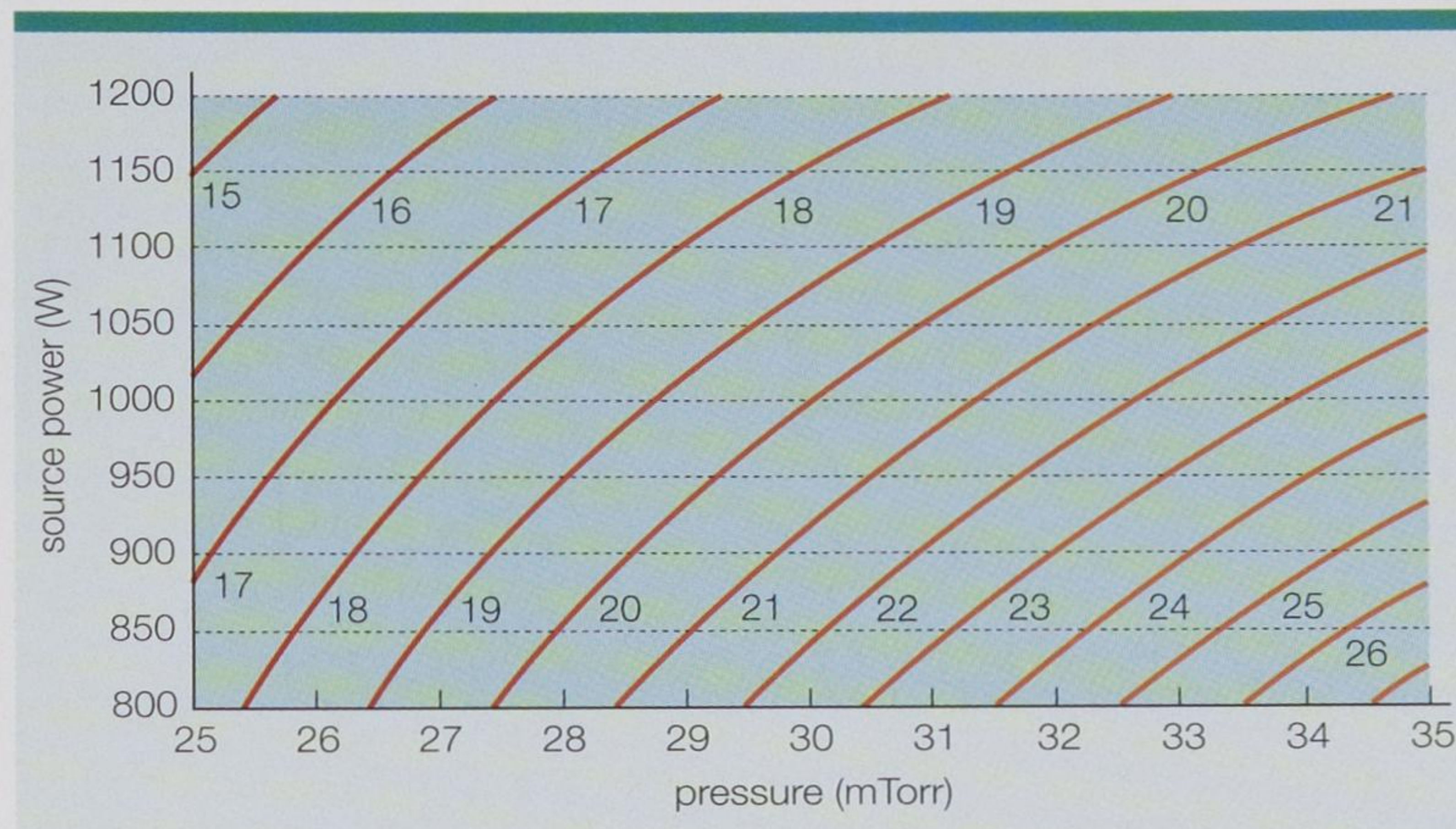


Fig. 2. The chamber pressure exerts a strong influence on etch selectivity. As pressure rises the GaAs etch rate increases.

GaAs backside via etching is one of the most critical processes in the manufacture of GaAs MMICS. Contacts through via holes provide low inductance grounds that are critical to the performance of FETs and MMICs (Williams). Since the process was initially developed, much effort has been invested in increasing the etch rate and therefore reducing both the process time and the manufacturing costs.

GaAs backside via etching has a reputation as a bottleneck process in MMIC manufacturing. The drive to eliminate this bottleneck has stimulated great competition between dry-etch equipment manufacturers to increase the etch rates of their tools.

However, the strong demand for a high-rate backside via etch has not yet been fully satisfied in the GaAs device industry. GaAs provides a number of performance advantages for high-speed devices, but the complicated material properties of compound semiconductors require comprehensive work on process development.

At Tegal we have carried out a project to develop a high-rate GaAs via etch, exploring how process parameters such as chamber pressure and wafer temperature affect the

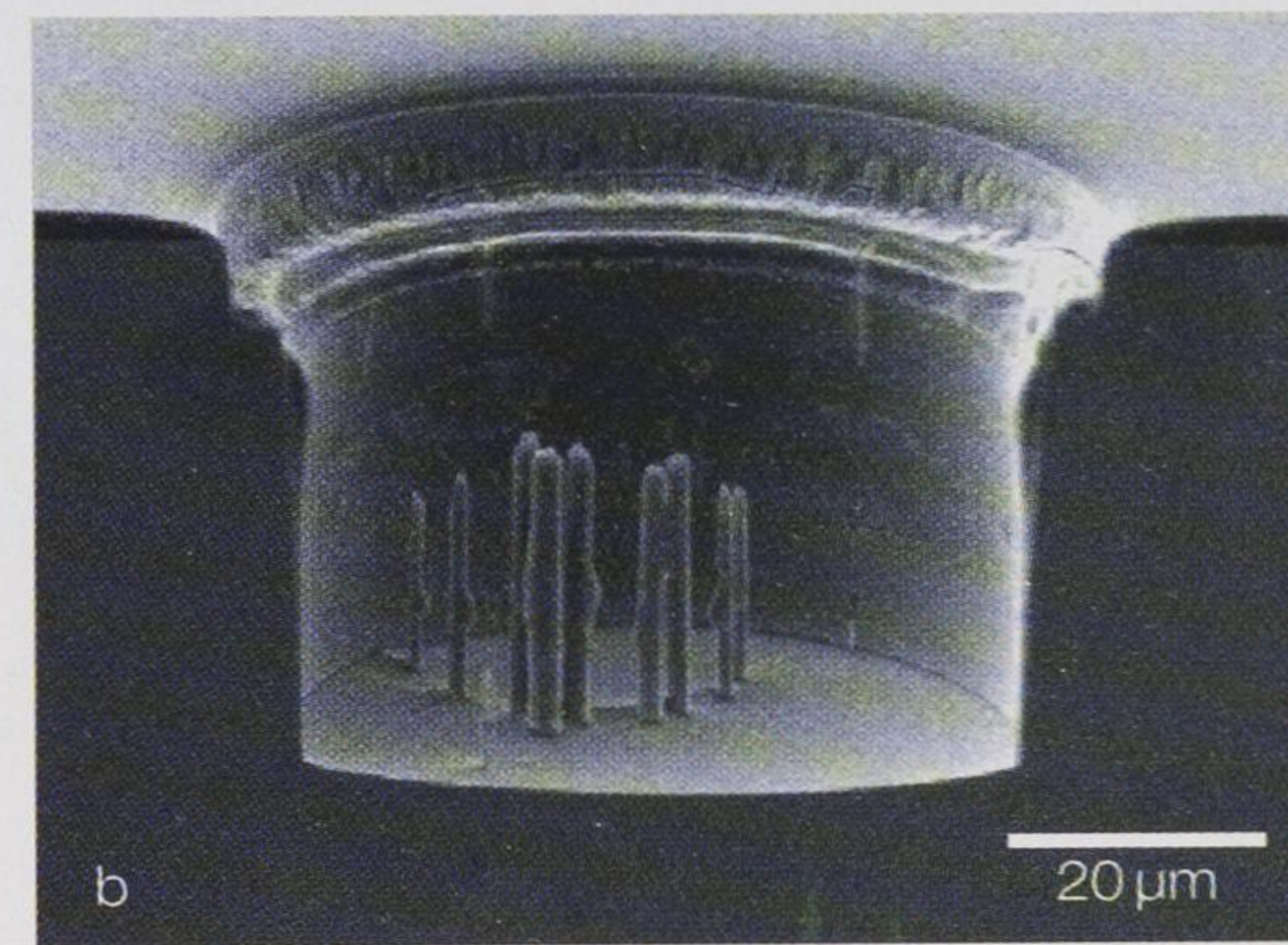
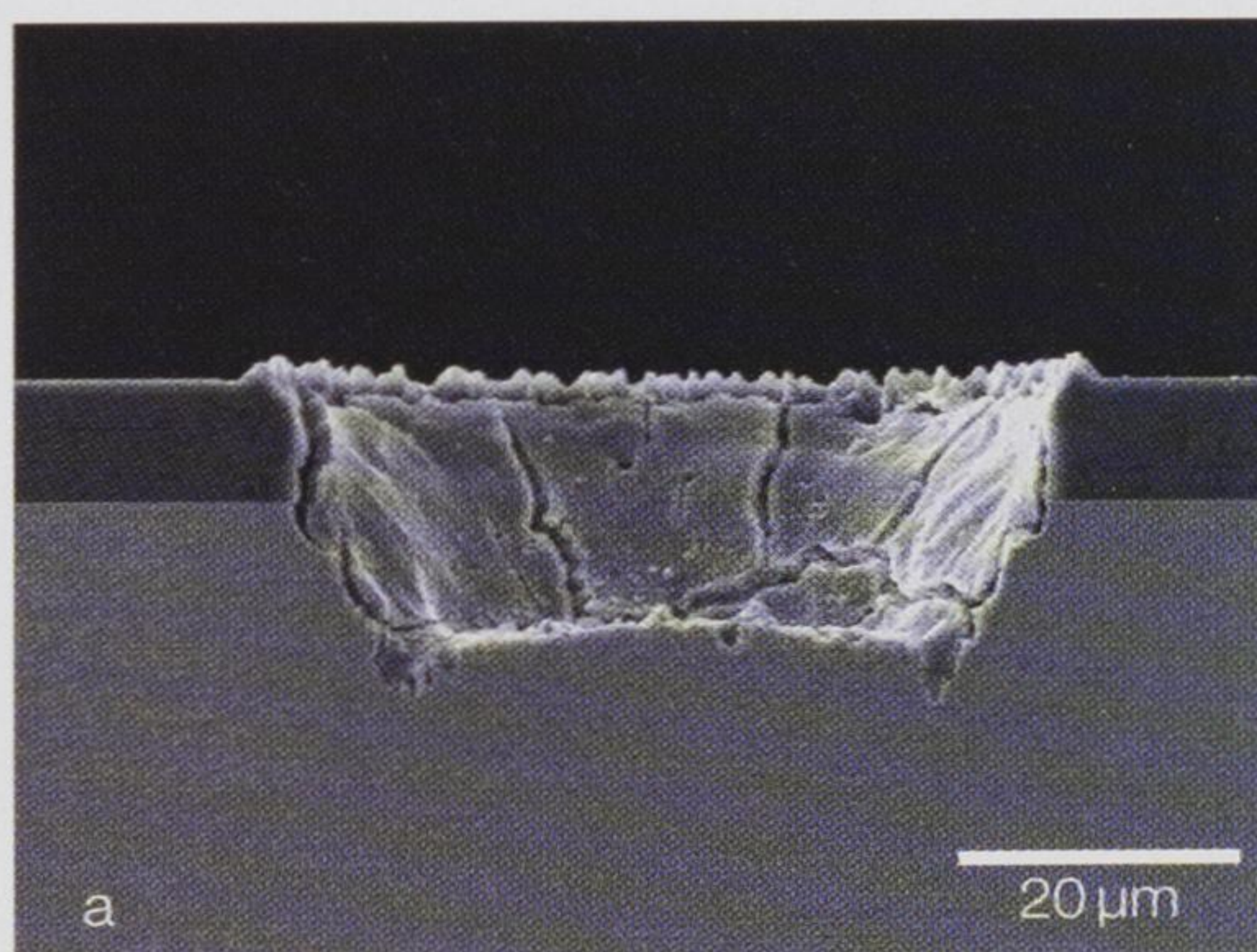


Fig. 3. Etch defects observed at backside via holes. Fig. 3a shows an etch stop caused by polymer deposition, while fig. 3b shows pillar formation occurring in the via holes.

etch rate and the factors that need to be considered in order to ensure defect-free vias.

A new process window

The etching experiments described below were carried out on 4 inch GaAs wafers using Tegal's HRe (high-density reflected electron) plasma-etch tool. The plasma-etch process involves introducing a gas containing an element, in this case chlorine, that is reactive with the material to be etched. A plasma is struck in the Cl gas mixture, forming charged Cl radicals that are accelerated towards the substrate

by the application of a DC bias. These radicals react with the GaAs, forming volatile gaseous AsCl_3 and GaCl_3 species which are pumped away. Using a DC bias means that the etchant radicals are accelerated vertically down onto the substrate, so features with high aspect ratios such as via holes can be etched.

Maintaining the plasma density and uniformity at high pressure is very important for achieving a high etch rate. A high pressure means that there is an abundance of the reactive species available. Energetic free electrons within the plasma impact with the heavier Cl-

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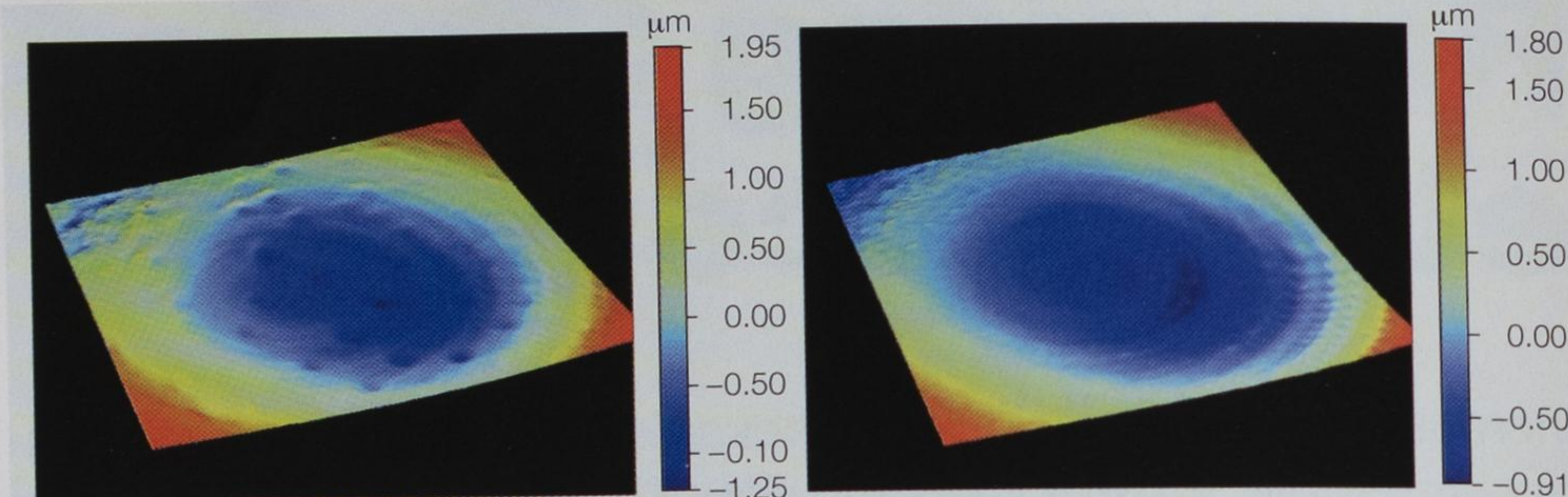


Fig. 4. Optical surface profiles (area $26 \times 28 \mu\text{m}$) of wafers etched at (left) 0°C , $R_a = 504.8 \text{ nm}$ and (right) -20°C , $R_a = 403.6 \text{ nm}$. Etching at a low temperature reduces surface roughness.

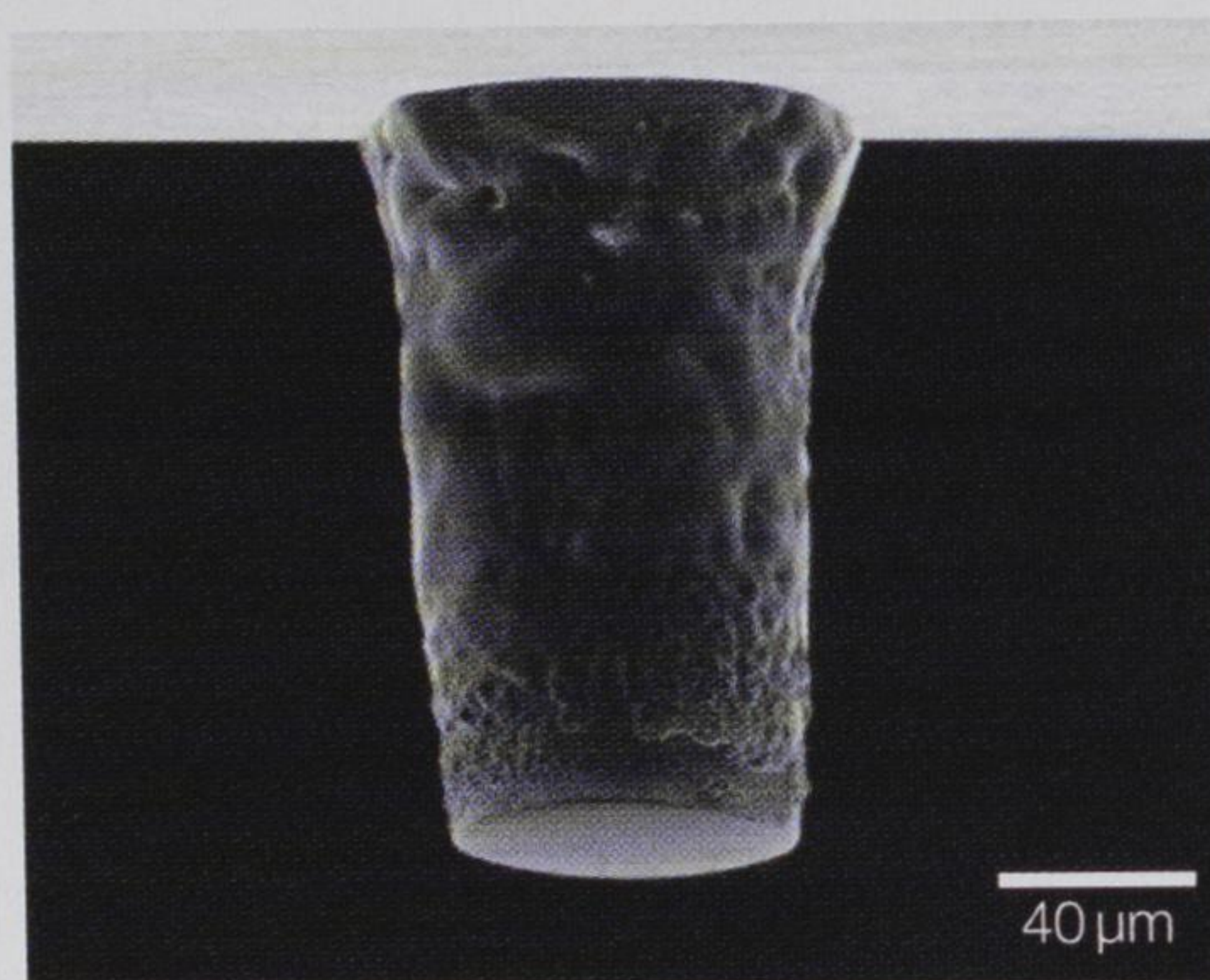


Fig. 5. A defect-free $150 \mu\text{m}$ deep via hole that has been etched at $10 \mu\text{m}/\text{min}$.

The effects of wafer temperature have also been investigated in Tegal's development laboratory and found to have a major impact on pillar formation.

containing molecules, breaking the chemical bonds and thereby releasing charged Cl radicals for etching.

It is well known that conventional reactive ion etch and inductively coupled plasma tools have difficulty sustaining a high-density plasma at chamber pressures over 20 mTorr, because the mean free path of electrons reduces as the pressure rises. In the HRe, permanent magnets at the top of the chamber and at its sidewalls reflect free electrons back into the plasma, making it possible to maintain a high plasma density at high chamber pressure. This provides a new window of process parameters to explore.

For the development of a high etch rate process in the HRe, a 13.56 MHz generator was used for plasma generation, and 450 kHz

was chosen as the bias power frequency. The GaAs wafers were coated with an AZ4620 photoresist etch mask and patterned with $50 \mu\text{m}$ diameter holes more than $100 \mu\text{m}$ apart. RS/1 data management and analysis software from BBN Corporation was used for designing the experiment and analyzing the results.

Performance under pressure

Figure 1 shows the GaAs etch rate as a function of the source power and chamber pressure. The results show that pressure has a much stronger influence on GaAs etch rate than the source power. The etch rate also shows a linear increase with increasing pressure. This implies that the GaAs etch rate is limited by the amount of chlorine radicals present. Therefore the key to achieving a high etch rate is to provide sufficient reactant at a high chamber pressure. The highest etch rate achieved was more than $10 \mu\text{m}/\text{min}$ at a chamber pressure of 35 mTorr.

Figure 2 shows the etch selectivity to photoresist for the same process parameters as figure 1. A maximum selectivity of 27:1 was achieved at the highest chamber pressure. The etch rate of the photoresist is dominated by the DC bias and the energy of the etchant ions. The etch rate for GaAs is largely chemically dependent so it increases at higher pressures. The photoresist etch rate therefore remains more stable than that of GaAs as the pressure rises, improving the etch selectivity.

Etch stop and pillar formation

Within the process window for obtaining high etch rates, the elimination of defects such as pillar formation and the possibility of etch stop caused by polymer build-up become the critical issues. Many laboratories have already investigated the relationship between pillar formation and the wafer condition or the process parameters (Kiriakidis *et al.*, Nam *et al.*). Polymers of various types are formed

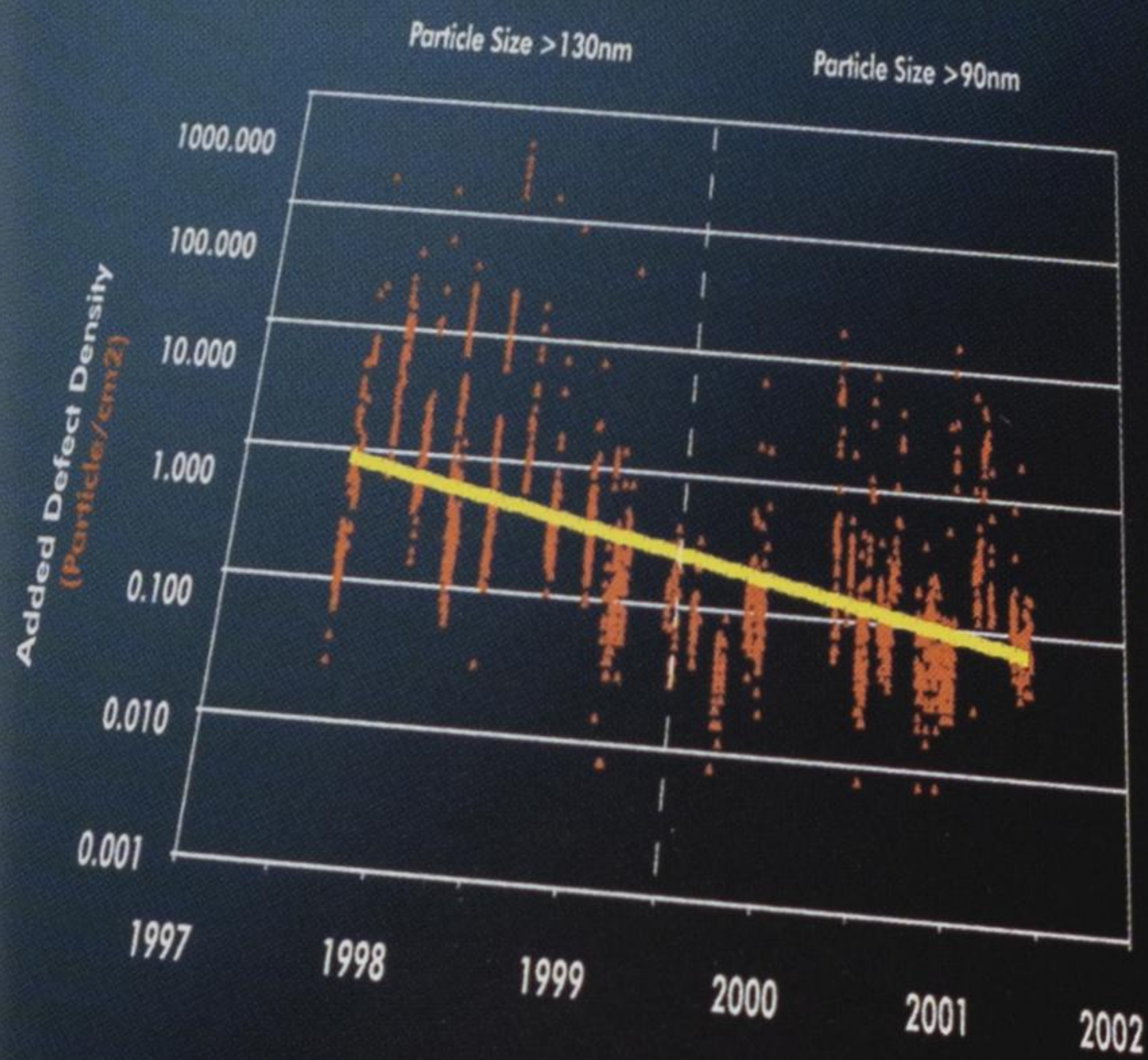
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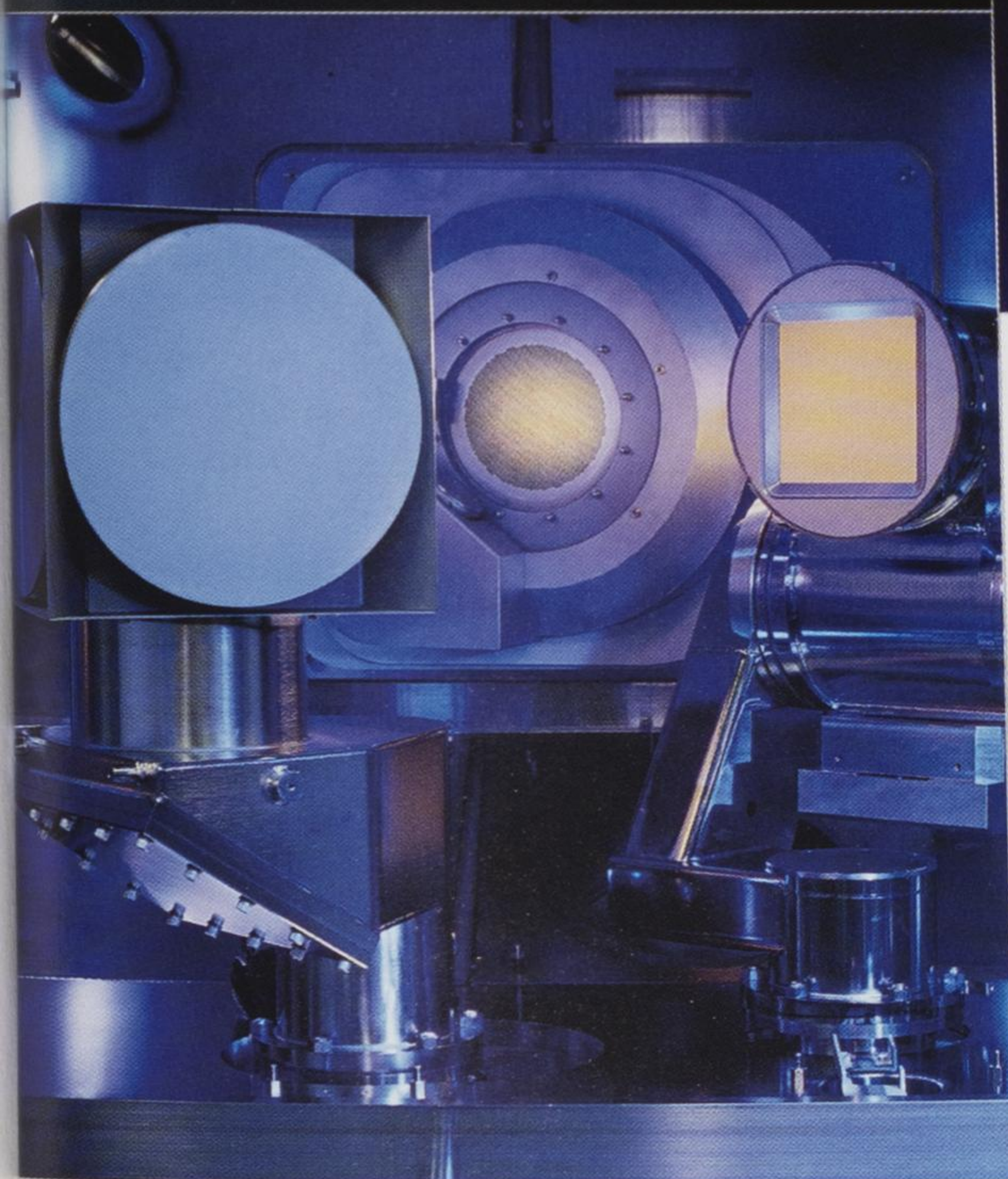
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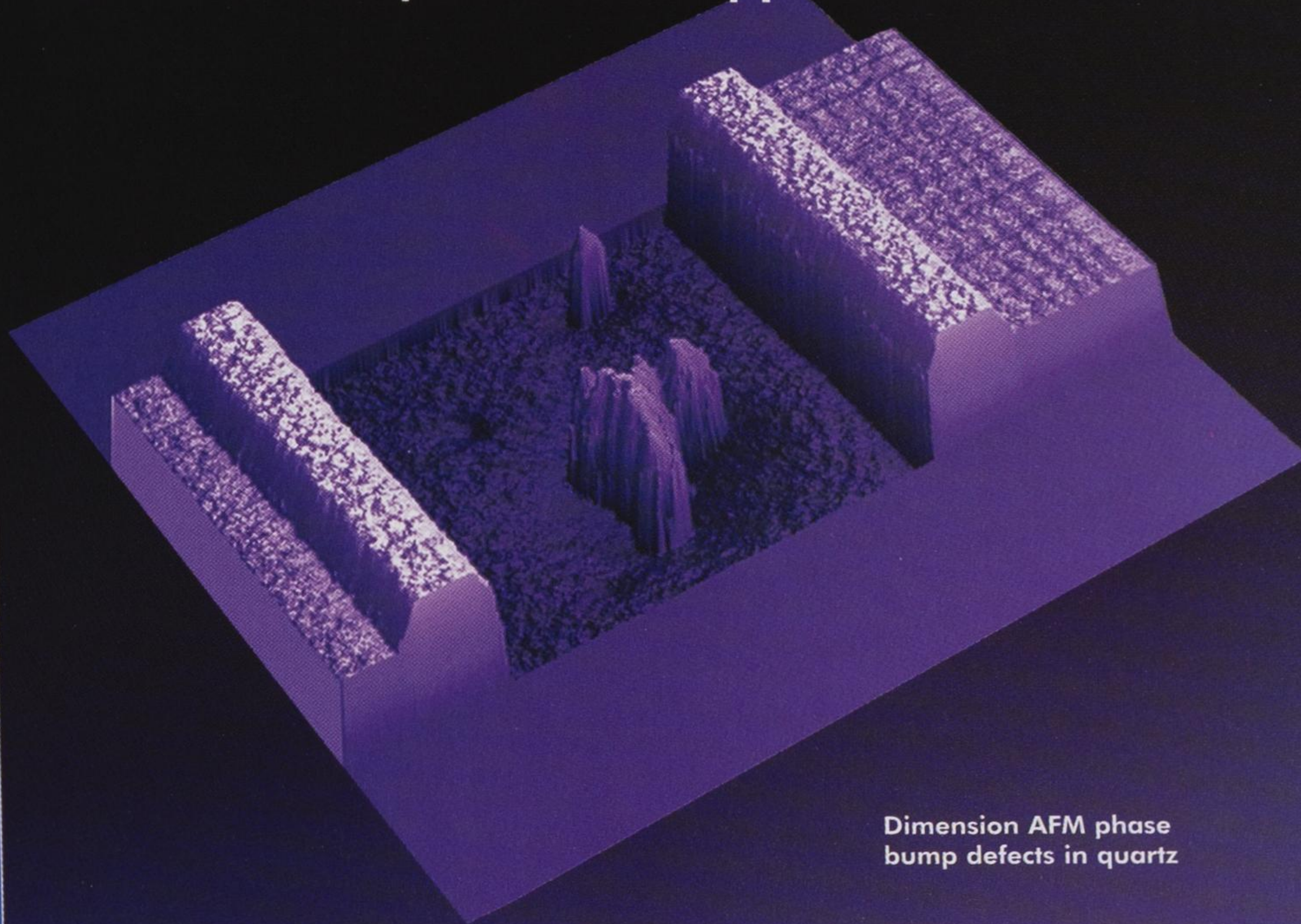
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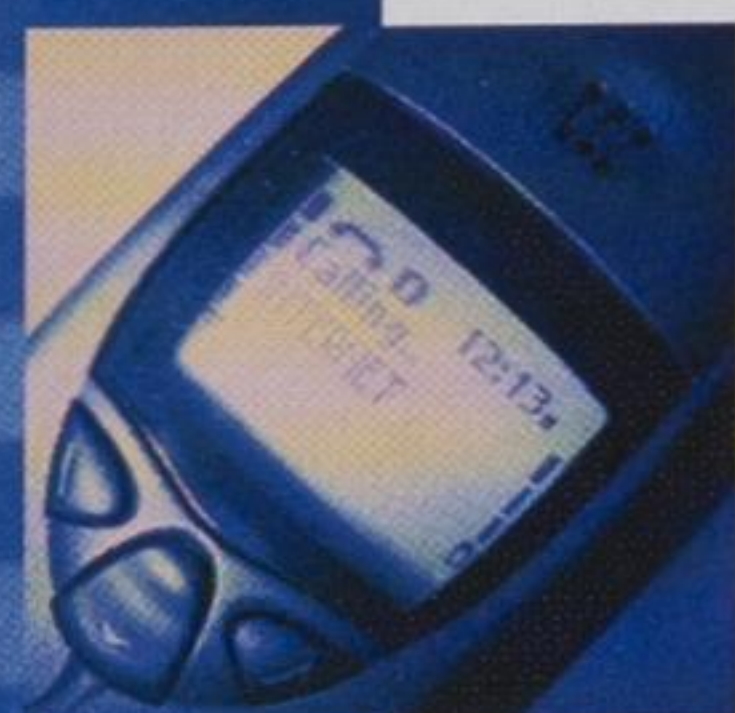
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during etching as a result of reactions between the chlorine-based etchant, gallium and the photoresist mask. The amount of polymer generated rises with etch rate, and excessive polymer generation can slow and eventually stop etching. Etch stop can be avoided by controlling the wafer temperature and optimizing the bias power. Heavy polymer deposition and pillar defects in GaAs via holes are shown in figures 3a and 3b.

Pillar formation is a well known phenomenon, but it is not fully understood and it is a difficult problem to solve. Carbon-rich impurities on the wafer surface or within the epitaxial layer can cause pillars to form, although improving the pre-etch wafer-processing steps makes it less likely. The incorrect combination of etch-process variables such as chamber pressure and DC bias can also result in pillar formation.

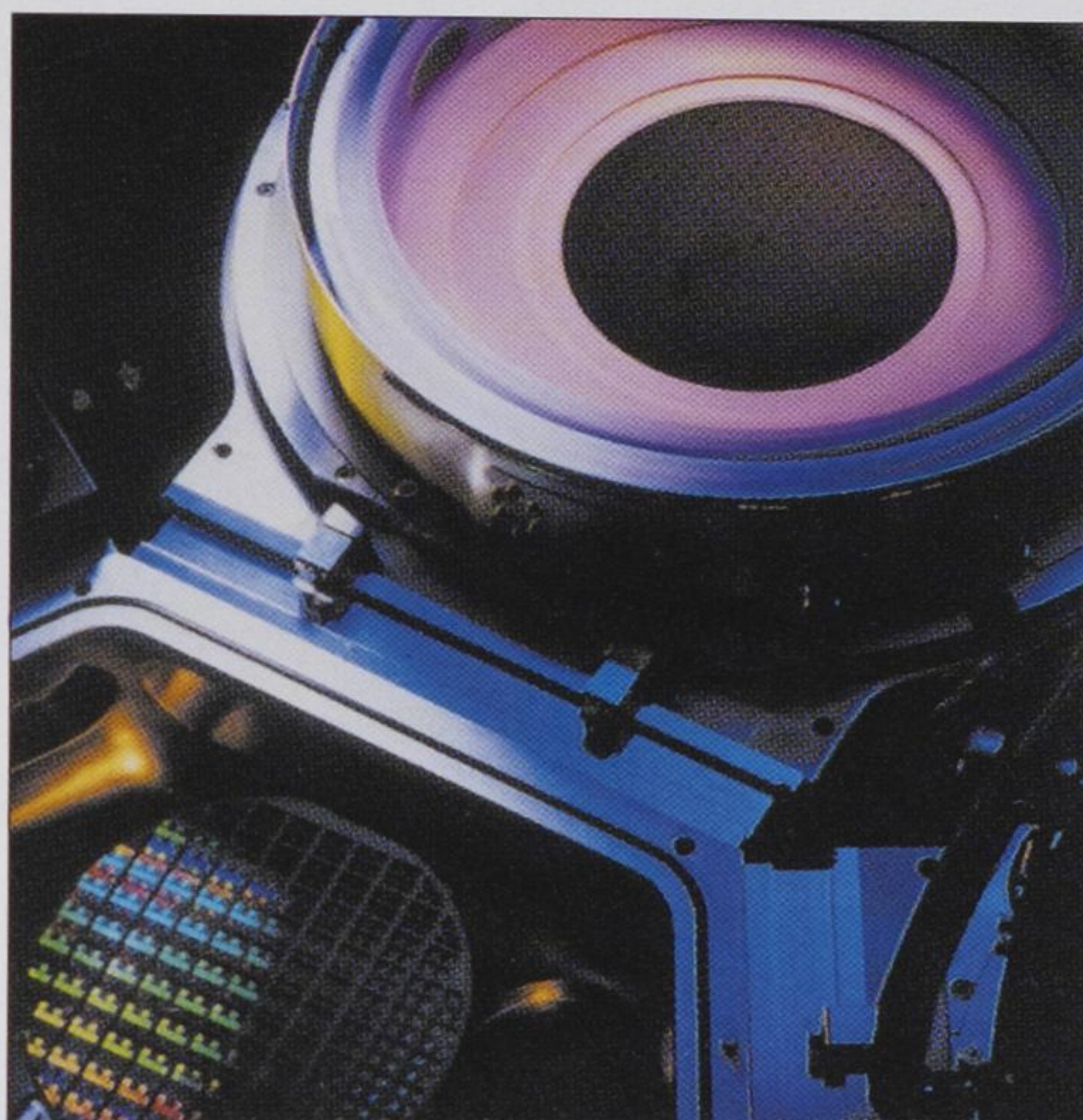
The effects of wafer temperature have also been investigated in Tegal's development laboratory and found to have a major impact on pillar formation. Figures 5a and 5b show the results of optical surface-profiler scans on two GaAs samples at different temperatures. The temperatures of the samples in 5a and 5b are 0 and -20°C respectively. The average surface roughness (Ra) is 504.8 nm for 5a and 403.6 nm for 5b.

The difference in Ra at the two temperatures stems from the different melting temperatures of the two major reaction products formed during etching. The melting point of GaCl_3 (77.9°C) is much higher than that of AsCl_3 (-16°C). As the temperature rises towards 77.9°C , the liquid AsCl_3 becomes increasingly volatile while the solid GaCl_3 remains more stable. The disparity in the materials' volatility causes roughening of the surface during etching, which can eventually induce the pillar-shaped defects.

Therefore the surface roughness can be minimized by reducing the difference in volatility between the by-products of the etching reaction. This can be achieved by etching at a low temperature or by changing the process in some way to improve the removal of GaCl_3 . Experiments have shown that as the wafer temperature decreases, pillar formation is eventually eliminated near -20°C .

Beyond $10\text{ }\mu\text{m/min}$

The pressure of the process chamber has turned out to be the most important process parameter for achieving high GaAs etch rates, with the etch rate showing a very proportional increase with chamber pressure. As the GaAs



Tegal's HRe 6520 high plasma density reactor, which is used for via etching.

etch rate increases, defect control becomes critical. A large amount of polymer byproducts can induce etch-stop problems and the high etch rate makes pillar formation more likely. The optimized GaAs etch results are shown in figure 5. An etch rate of more than $10\text{ }\mu\text{m/min}$ can be achieved without etch stop

or pillar formation. The test results also revealed the possibility of increasing GaAs backside via etch rates beyond $10\text{ }\mu\text{m/min}$.

Device pattern sizes are constantly reducing and even higher GaAs etch rates for smaller vias will be required in the future. This will ensure that the competition between dry-etch tool vendors for the higher GaAs etch rate process will continue as long as backside processes are necessary in MMIC manufacturing. GaAs etch rates have improved very rapidly and $20\text{ }\mu\text{m/min}$ can be expected in the near future.

Further reading

G Kiriakidis *et al.* 1986 *NATO ASI Series E* 112 297.

P Nam *et al.* 2000 *J. Vac. Sci. Tech. B* 18(6) 2780.

R Williams 1990 *Modern GaAs Processing Methods* 324.

Young Cho (ykcho@tegal.com) is the project leader of the R&D group and Jim Thomas (jthomas@tegal.com) is the manager of the Engineering group at Tegal, Petaluma, CA.

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SUVOS targets UV emitters for biosensors and communications

The US Department of Defense is funding a project called SUVOS that aims to develop UV lasers and LEDs for biological agent detection and secret communication systems, writes **Richard Dixon**.

The US Department of Defense views compact UV sources as critical to biological agent detection and non-line-of-sight (NLOS) covert communications, as well as water purification and the decontamination of equipment and personnel. To address these applications, the Semiconductor UV Optical Sources (SUVOS) project has been instigated by DARPA's Microsystems Technology Office, an agency that actively promotes core technologies in electronics, photonics and MEMS.

The SUVOS project is expected to run for up to four years and will foster R&D that speeds the introduction of compact high-power UV sources. The program specifically targets wide-bandgap semiconductors such as GaN and its various alloys for use as optical sources that can be integrated into modules and subsystems.

Detecting biopathogens

To address the detection of airborne biological agents, the new project aims to demonstrate novel UV LEDs and lasers that operate from 280 to 340 nm. Recent research has resulted in LEDs with wavelengths as short as 305 nm (*Compound Semiconductor* March 2002 p29), although these devices typically suffer from low output power and high series resistance.

DARPA is aiming to mitigate these problems and is targeting compact, low-power UV sources to perform tasks such as laser-induced fluorescence spectroscopy of the common constituents in biological agents (figure 1). These constituents include tryptophan, with a peak absorbance at 280 nm, and NADH at 340 nm. The primary focus of the program is to develop the properties of AlGaIn materials to provide inexpensive, low-power UV sources tailored to these wavelengths.

Covert communications

The US military also needs a secure means to send messages in the field using low-power communication systems – a requirement that

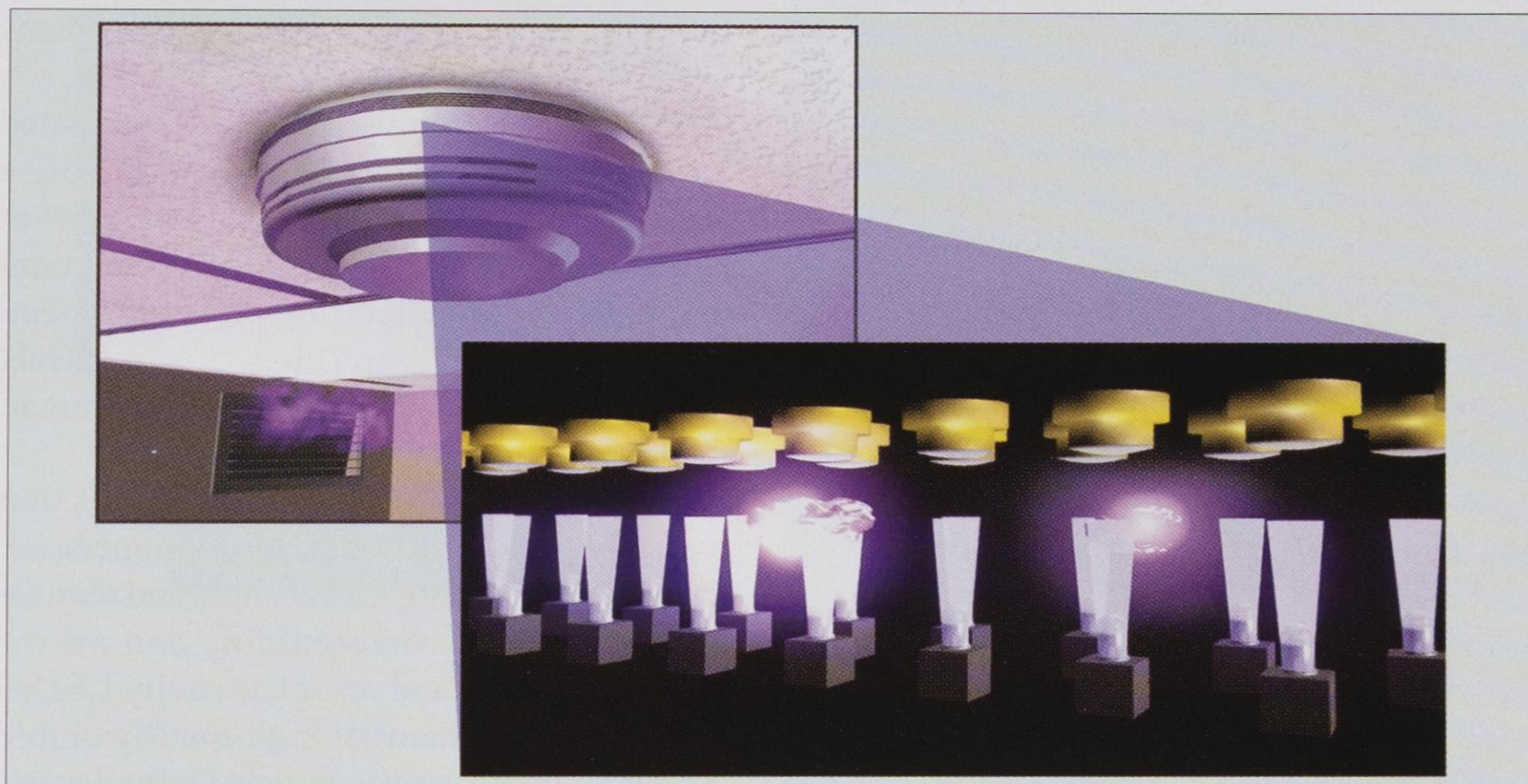


Fig. 1. Schematic diagram showing the arrangement of UV lasers and detectors in a compact sensor used to detect biopathogens. The UV laser light excites any biological agent present, causing photon emission. The wavelength of the emitted photons is characteristic of the bioagent and is collected by the detector elements in the sensor.

cannot be met with conventional RF radios. Covert communication is made possible by UV sources that exploit the solar blind region located at 280 nm and below. In this region of the spectrum, the terrestrial solar flux is essentially zero, and the very low background can be used for NLOS communications over distances up to 250 m. The strong extinction coefficient of the signal in the UV makes it difficult to detect these emissions from a distance, particularly in the forward direction. The success of such a portable UV frequency communicator unit depends on the availability of a compact, powerful and energy-efficient UV optical source.

"Semiconductor UV emitters offer the potential for compact, inexpensive systems with low power and high reliability, all of which are needed for the systems we require at the Department of Defense," said SUVOS program manager John Carrano. "Current research in the AlGaIn/GaN materials system is critical to this effort." By building on the commercial success of visible GaN-based

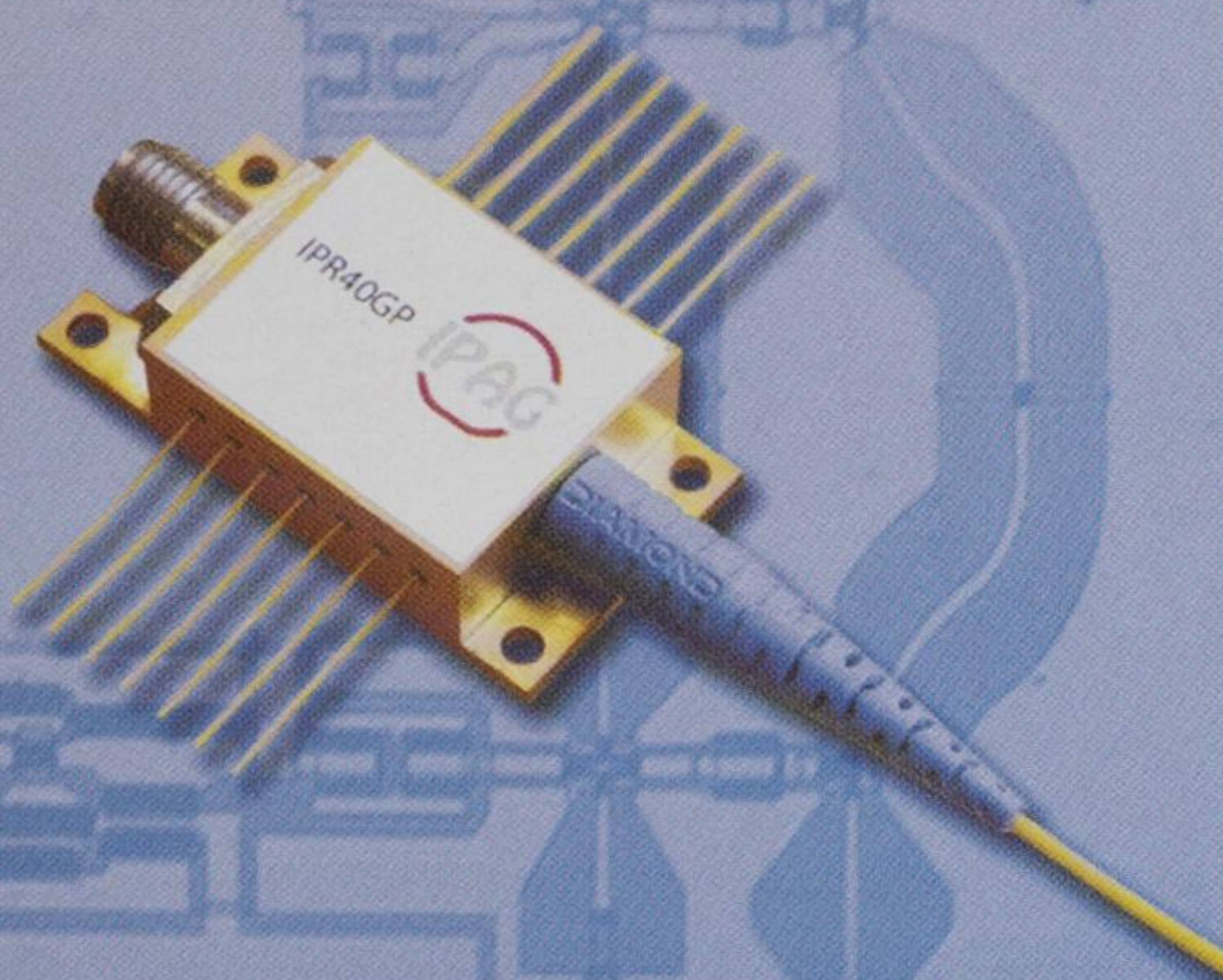
LEDs, DARPA has initiated a program to develop short-wave UV sources. "These sources could be used in a compact unit that includes early warning detection of biopathogens, and that also performs fluorescence spectroscopy with a laser to confirm the diagnosis of the first alert," said Carrano. "We would also like this unit to consume only low power and to be inexpensive so that we can use the units in as many platforms and environments as possible."

DARPA's wish list for UV LEDs and lasers includes high external quantum efficiency, an optical output power in the mW range, high reliability devices with 10,000 hours of life, and a modulation bandwidth of 10 MHz. UV devices should provide room-temperature operation in either pulsed or CW mode.

The SUVOS program recognizes a number of technical challenges that need to be overcome to achieve these goals. According to Carrano, one of the most important issues is attaining sufficient p-type conductivity in high-aluminum-content AlGaIn. A

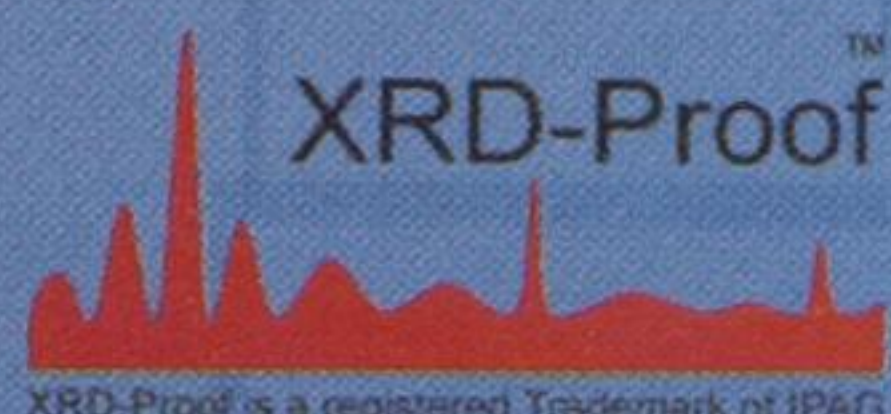
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doping level of around $5 \times 10^{17}/\text{cm}^3$ is needed to achieve sufficient hole injection in the AlGaIn active regions and to provide efficient radiative recombination.

"A high aluminum content in the active region is needed to achieve a sufficiently wide electronic bandgap for emission in the UV," explained Carrano. "During the growth of AlGaIn with higher concentrations of aluminum, it becomes more and more challenging to achieve p-type doping in the material." A related problem is the suppression of non-radiative recombination mechanisms in the active regions.

The large heterojunction offsets associated with the AlGaIn material system also pose a significant problem to carrier transport at heterointerfaces. "To achieve confinement using barrier and cladding layers, we need to control the quality and properties of AlGaIn materials with as much as 65% aluminum in the layers," added Carrano.

There are also the additional factors that typically face all LED and laser designers, i.e. the need to efficiently extract light and remove heat, as well as wave-guiding and mirror design for lasers and resonant-cavity LEDs.

"The development of high-quality ohmic contacts is particularly important for the devices envisioned in this program," said Carrano. "As high levels of current injection are needed to drive high-power sources, the design of innovative structures for both LEDs and laser diodes is crucial to meeting SUVOS objectives."

Program structure

The SUVOS program is structured to take place in two phases. Phase I will concentrate on the development of wide-bandgap semiconductor materials, and will also include the design, fabrication and characterization of innovative optoelectronic device structures with operating wavelengths at 340 nm.

In Phase II the emphasis will shift to the optimization of UV photonic materials and LEDs and lasers with operating wavelengths of 280 nm. In this phase UV optical sources will be integrated into testbeds for demonstrations of biological agent detection and NLOS communications.

Initially the main focus will be on materials development, in particular high aluminum content n-type and p-type material with device-level doping of around $10^{17}/\text{cm}^3$. Later efforts will focus on improving material uniformity. Devices such as lasers and LEDs operating at 340 nm will be developed first, and the final goal is emitters at 280 nm.

SUVOS finalizes funding round

All the funding for SUVOS has now been awarded. The commercial companies being supported over the next two years are Cree, Crystal Photonics and Lumileds Lighting, each of which will work exclusively on III-nitride LEDs and lasers. A number of universities are also involved with SUVOS at much lower levels of funding.

The SUVOS program consists of a two-year core effort, followed by an optional third and fourth year for research with the greatest potential. A total of around \$20 m has been allocated, and up to \$25 m is available for projects in the third and fourth years.

In March Cree was awarded the largest SUVOS contract – \$14.5 m – to develop UV LEDs and laser diodes for tactical communication systems and biological agent sensors, including anthrax detectors (*Compound Semiconductor* May 2002 p11). Cree is developing a proprietary technique for defect reduction in GaN materials. Carrano says the approach Cree is taking is also consistent with high-volume production.

"Cree is partnering with the University of California Santa Barbara to develop novel approaches to devices with quantum dots and resonant cavity-enhanced LEDs," said Carrano. "They have also succeeded in demonstrating efficient 340 nm LEDs that operate at room temperature with 1 mW of output power."

Lumileds, teamed with Brown University (Providence, RI), was chosen for its novel solutions to p-type doping and the thermal management of device packages. Lumileds is well known for its high-power package technology, which is designed to remove heat from its Luxeon range of high-flux LEDs (*Compound Semiconductor* January/February 2002 p37).

Crystal Photonics and Boston University form the final team, which shares around \$1 m in funding. Located in Sanford, FL, Crystal Photonics produces alternatives to SiC and sapphire substrates such as lithium gallate. Previous work by the company has been sponsored under a SBIR Phase I award, and involved using lattice-matched lithium gallate as templates for visible LEDs using high-quality GaN layers grown by HVPE (*Compound Semiconductor* June 2002 p9).

John Carrano can be contacted at +1 703 696 2252, jcarrano@darpa.mil. More information on the SUVOS project can be found at www.darpa.mil/mto/suvos.



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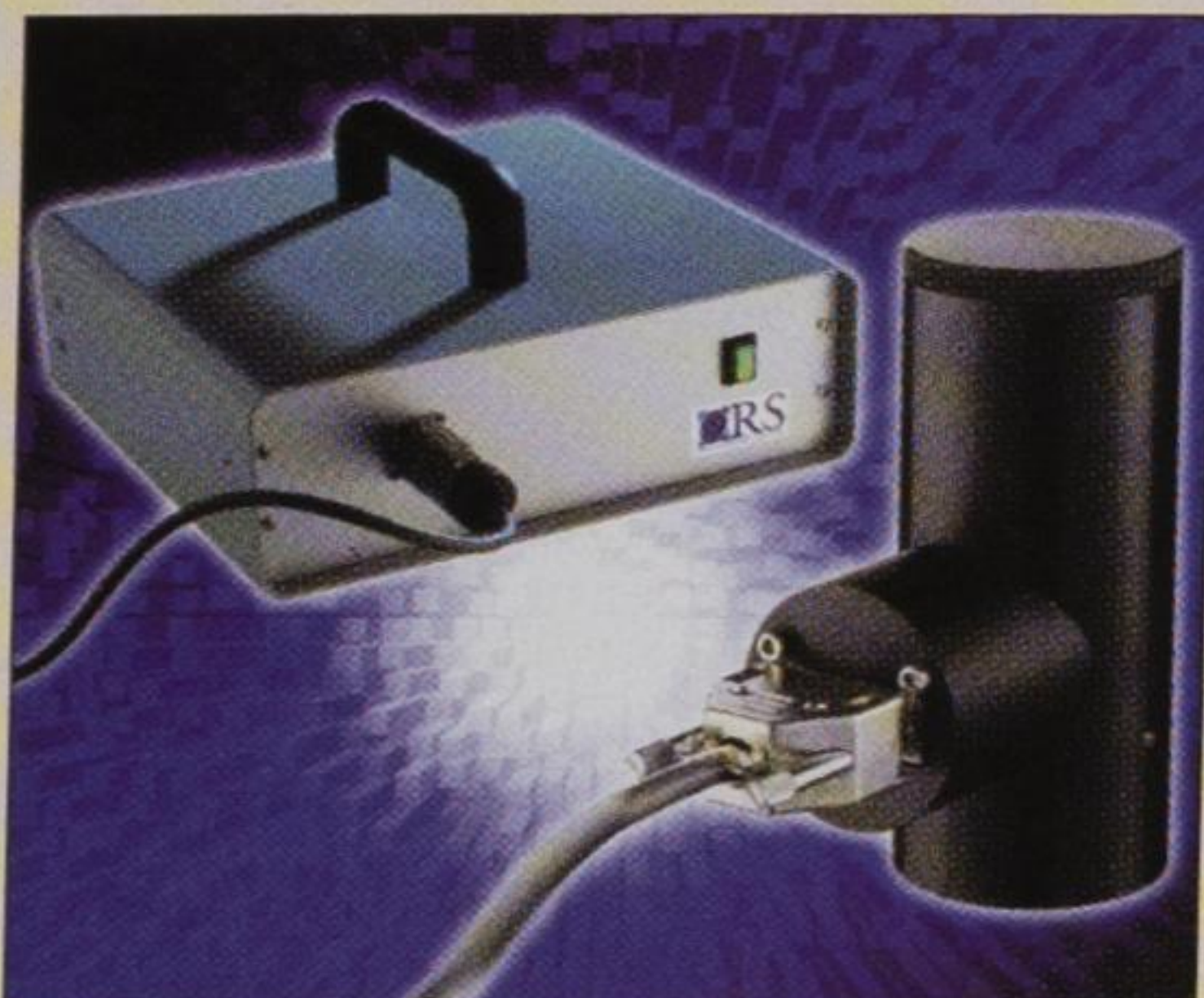
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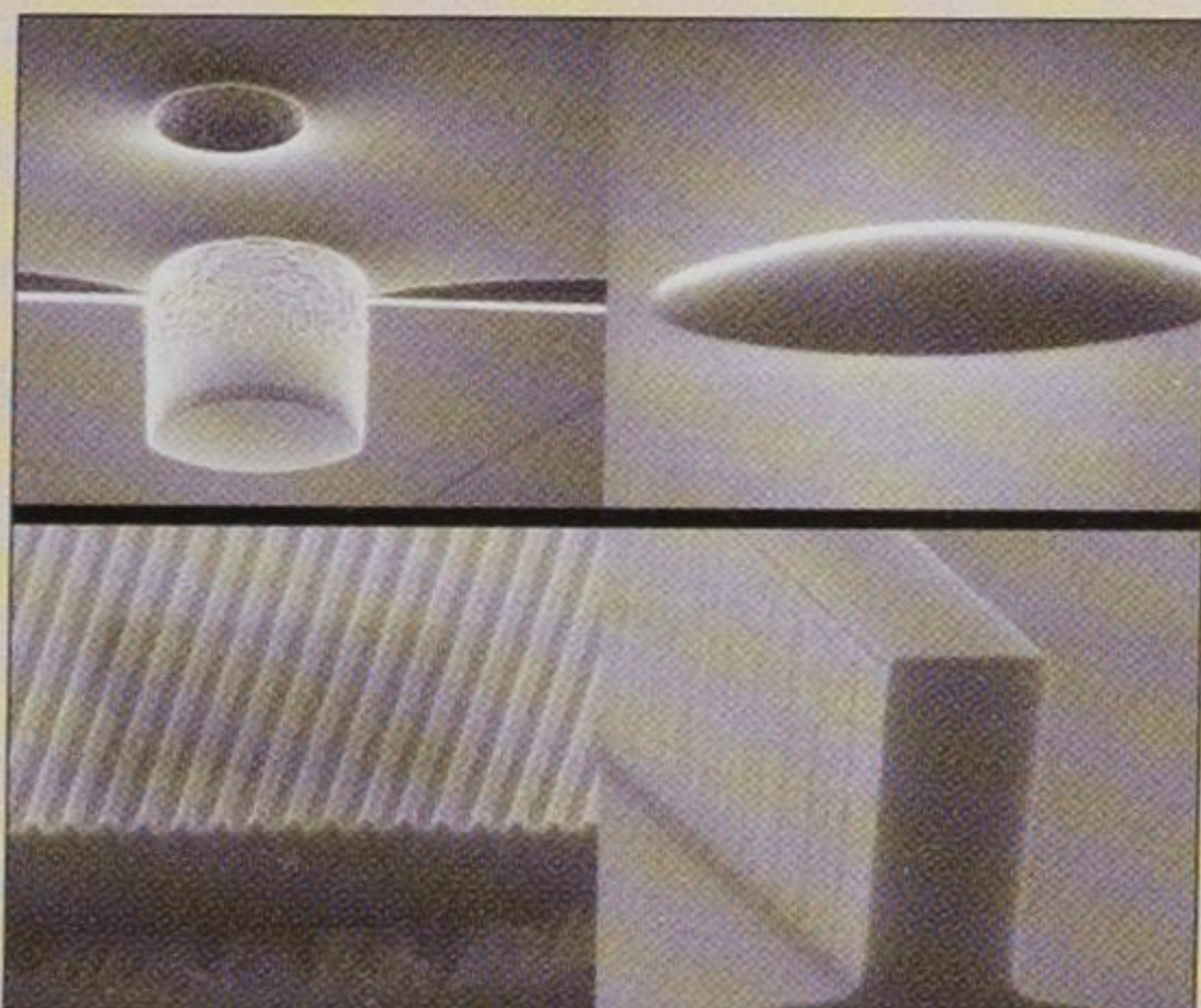
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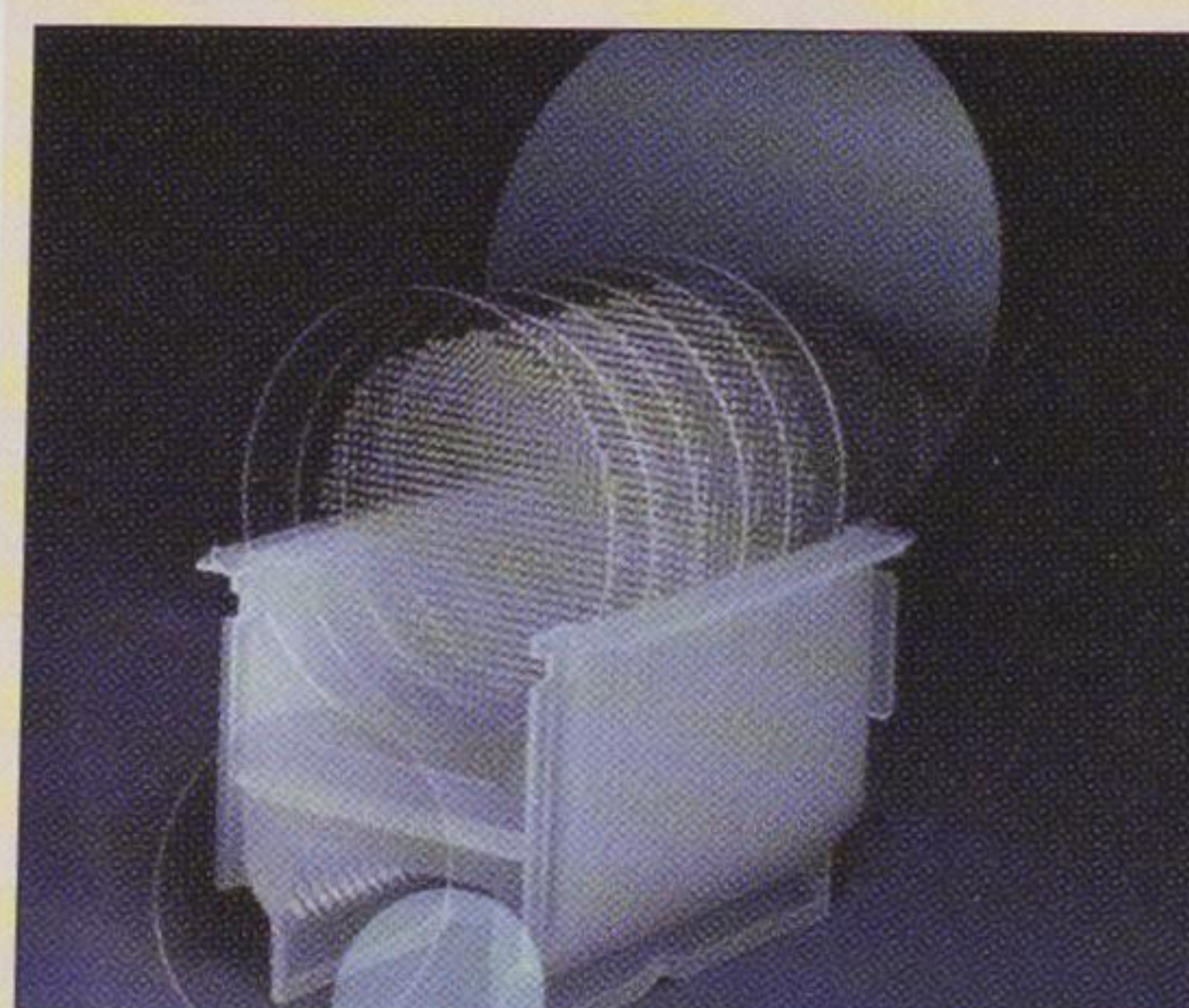
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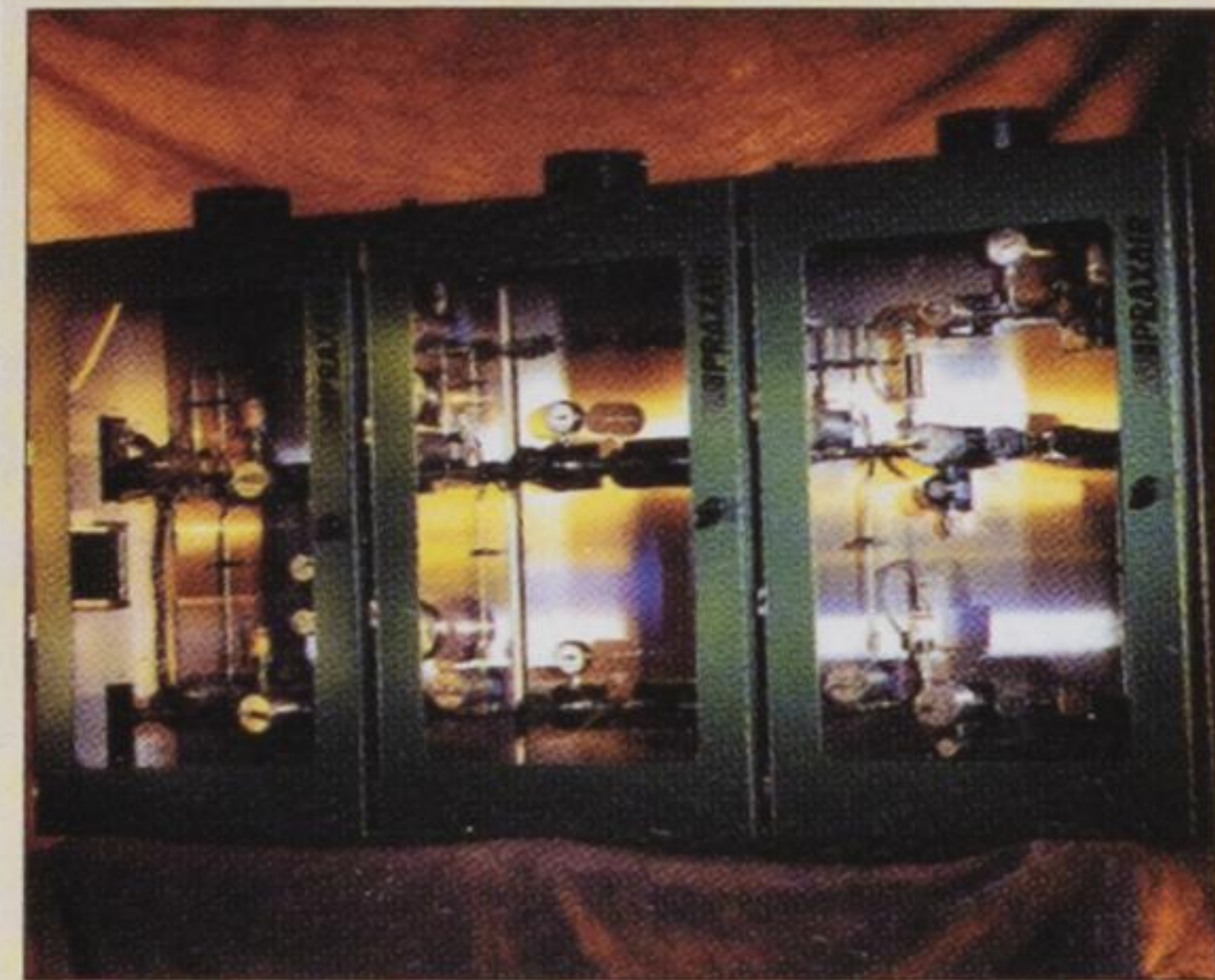
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Telecom components market must get worse to get better

As the telecom industry is advised to “assume the worst”, massive consolidation may be the only prescription that will return the troubled fiber-optic component sector back to good health.



Evidence is mounting that the oft-cited claim that Internet traffic doubles every 100 days is not true.

The Dutch tulip-bulb mania, the English South Seas bubble, the French Mississippi Company bubble, the US Great Crash of 1929, the Japanese real-estate bubble of the late 1980s, and the Dot-Com Disaster of a few years ago – what do all these things have in common with the current telecommunications component market?

According to James Jungjohann of CIBC World Markets, each is a crisis having three common precursors: financial liberalization, failed due diligence, and a significant expansion of capital markets. As a result, poorly conceptualized and inadequately researched new entrants were easily funded, and they piled into a market which could not hope to support all of them.

Jungjohann says that the time has come for what he calls “component Darwinism” – a shakeout of epic proportions that only the strongest will survive. He believes that more than 700 start-ups have entered the component sector, but estimates that maybe 10% can survive. He also predicts that the current top 25 component vendors will shrink to just four or five by 2006, through attrition and consolidation. For those who find the scale of this proposition too large to be credible, Jungjohann offers the example of the computer industry: in 1985 there were more than 500 manufacturers.

And indeed, the consolidation has already started. *Compound Semiconductor* has reported on several de-

velopments among the smaller players in recent months: the closure of Siros, the sell-off of Gore’s VCSEL business, the consolidation of Bookham and Marconi, and scaling back at nLight, Princeton Lightwave, Genoa and others. But the real bombshells have been delivered by the big companies, notably announcements from ADC and, most shockingly, Agere saying that it is exiting the fiber-optic component business entirely (*Compound Semiconductor* September 2002 p3).

Another shoe will likely drop this month, as Nortel is widely rumored to be on the verge of selling off its High Performance Optical Components business for the bargain-basement price of \$50 m. This is a staggering development if you think back to the summer of 2000, when Nortel was publicly musing about spinning off the division in a \$100 bn IPO. If that had happened, it would have been the largest IPO in history, exceeding the \$70 bn record set by AT&T Wireless in April 2000 by 40%. (The largest offering since the decline of the bull market was the June 2001 IPO for Kraft Foods, which valued the company at \$54 bn).

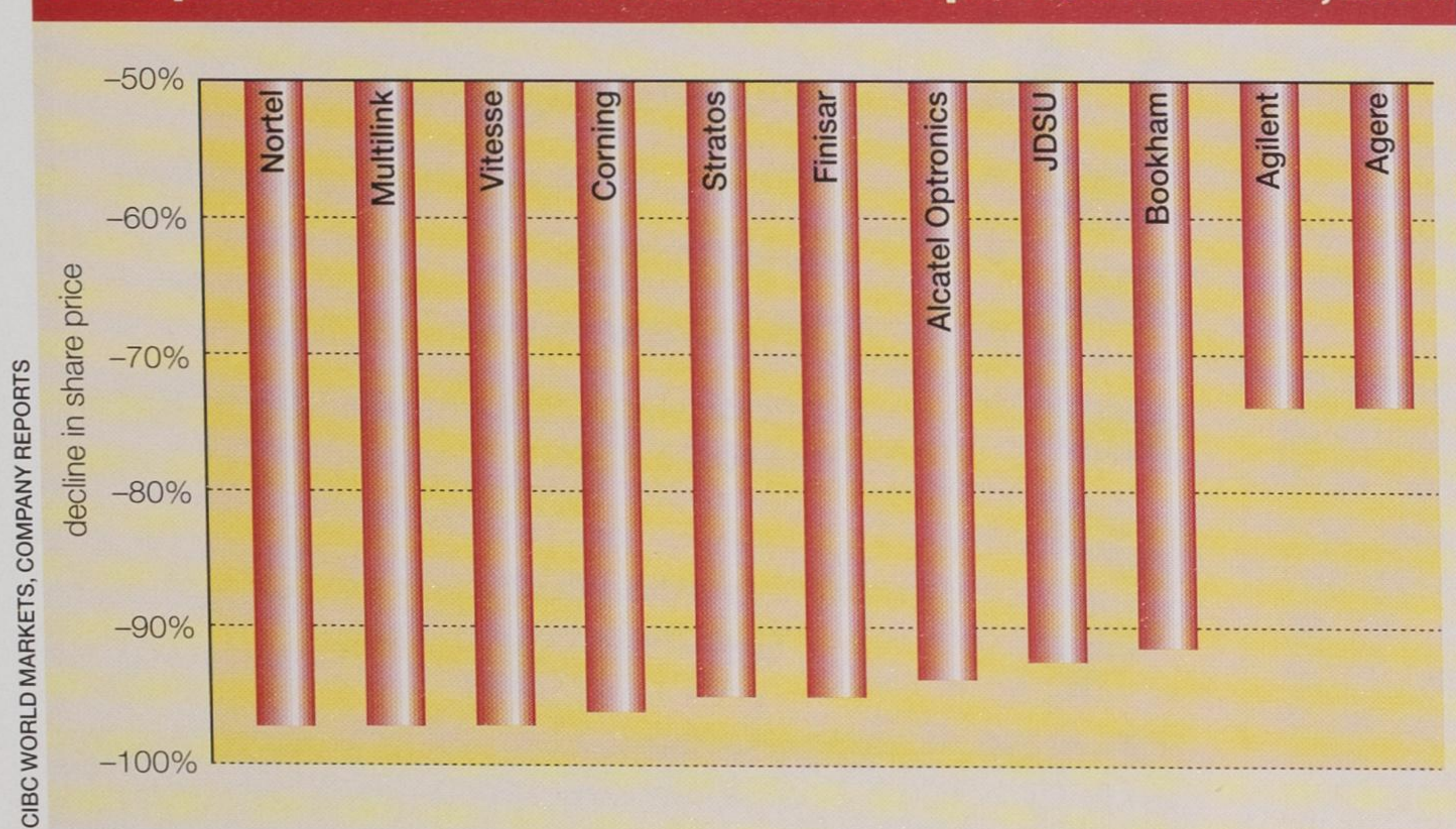
Banning the r-word

What lies ahead for the telecom industry will be vastly different from what we’ve left behind. “We don’t use the term ‘recovery’ any more because it instills a feeling that the telecom market will get back to historical levels again,” said Jungjohann. Instead, he advises CEOs to “assume the worst” and act now on the basis of current conditions, rather than wait for the service provider market to stabilize.

Jungjohann also advises companies to continue to assume that there is a glut of bandwidth. Remember the claims in the mid 1990s that the Internet was near to collapse under the weight of traffic growth? Evidence is mounting that the oft-cited claim that traffic doubles every 100 days was not true – or at best it was only true once at an early stage in the development of the Internet. To quote a recent article in *The Economist*: “The claim assumed unimpeachable status... unfortunately for the telecoms firms that rushed to build networks to carry the reported surge in traffic, it wasn’t true.”

So where did the claim come from? *The Economist* article reports that blame has been placed squarely on the shoulders of WorldCom. Efforts to trace the source of the statistic have repeatedly led back to WorldCom

Share price decline of selected telecom companies since Jan 1, 2001



“We don’t use the term ‘recovery’ any more because it instills a feeling that the telecom market will get back to historical levels again.”

Market overview

Company	Symbol	Closing price on September 13	52-week low-high	Market cap*	P/E ratio†
GaAs IC companies					
Anadigics	ANAD	3.01	2.31–21.05	92.1 m	N/A
Celeritek	CLTK	7.05	6.36–15.04	86.4 m	N/A
Endwave	ENWV	1.02	0.83–5.84	9.1 m	N/A
Multilink	MLTC	2.60	2.19–92.10	19.7 m	N/A
RF Micro Devices	RFMD	6.49	5.16–28.56	1.094 bn	115.83
Sirenza Microdevices	SMDI	1.72	1.13–8.49	51.4 m	N/A
Skyworks Solutions	SWKS	5.26	2.89–31.84	723.3 m	0.88
TriQuint	TQNT	4.60	4.51–21.00	607.4 m	N/A
Vitesse	VTSS	1.27	1.11–15.50	255.3 m	N/A
Opto companies					
Agilent	A	14.98	12.76–37.99	6.991 bn	N/A
Agere	AGRa	1.29	1.18–6.30	2.115 bn	N/A
Alcatel Optronics	ALAO	2.36	1.50–9.63	38.9 m	N/A
Coherent	COHR	20.62	19.70–36.39	598.3 m	N/A
Cree	CREE	13.45	10.35–33.32	978.2 m	N/A
JDS Uniphase	JDSU	2.56	2.06–12.44	3.879 bn	N/A
Stratos Lightwave	STLW	0.59	0.55–7.40	42.9 m	N/A
Uniroyal Technology	UTCI	0.10	0.07–6.47	3.1 m	N/A
Semiconductor materials and equipment companies					
ATMI	ATMI	15.51	14.50–37.10	475.2 m	N/A
AXT	AXTI	4.16	4.01–17.15	93.4 m	N/A
Emcore	EMKR	2.89	2.55–17.04	106.1 m	N/A
Kopin	KOPN	5.93	5.30–19.05	411.3 m	N/A
Tegal	TGAL	0.53	0.13–2.00	7.6 m	N/A
Trikon	TRKN	7.35	4.01–15.90	103.1 m	N/A
Veeco	VECO	13.55	11.65–40.12	394.8 m	N/A
European companies (currency data in €)					
Aixtron	AIXG.F	6.05	5.25–30.00	391.4 m	N/A
Bede	BED.L	1.62	1.59–3.33	46.9 m	N/A
Bookham	BHM.L	0.80	0.87–3.03	113.0 m	N/A
Filtronic	FTC.L	1.36	1.22–7.03	99.8 m	N/A
IQE	IQE.L	0.17	0.16–3.06	27.4 m	N/A
Picogiga	PGIG.LN	0.77	0.37–5.62	4.97 m	N/A
Riber	RIBE.LN	0.88	0.72–5.66	16.5 m	5.18
STS	SRTS.L	0.35	0.20–2.69	10.8 m	1.65

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

executives Bernie Ebbers or John Sidgmore, or executives at UUNET, WorldCom’s Internet subsidiary. “As the world’s largest carrier of Internet traffic, UUNET was assumed to know the numbers,” said *The Economist*. But of course we now all know that they may have had questionable motives.

It seems clear that after the initial frenzy of 1995 and 1996, when the Internet first went mainstream, the annual growth in traffic settled down at 70–150%. Nevertheless, WorldCom continued to advertise figures that varied between 700% and 1500% per year, and in 1997 they even claimed it was “almost doubling every quarter”. Unfortunately for everyone concerned, the only thing that ever approached that growth rate was the introduction of new network capacity – actual traffic lagged far, far behind, as we are all now learning to our cost. ●

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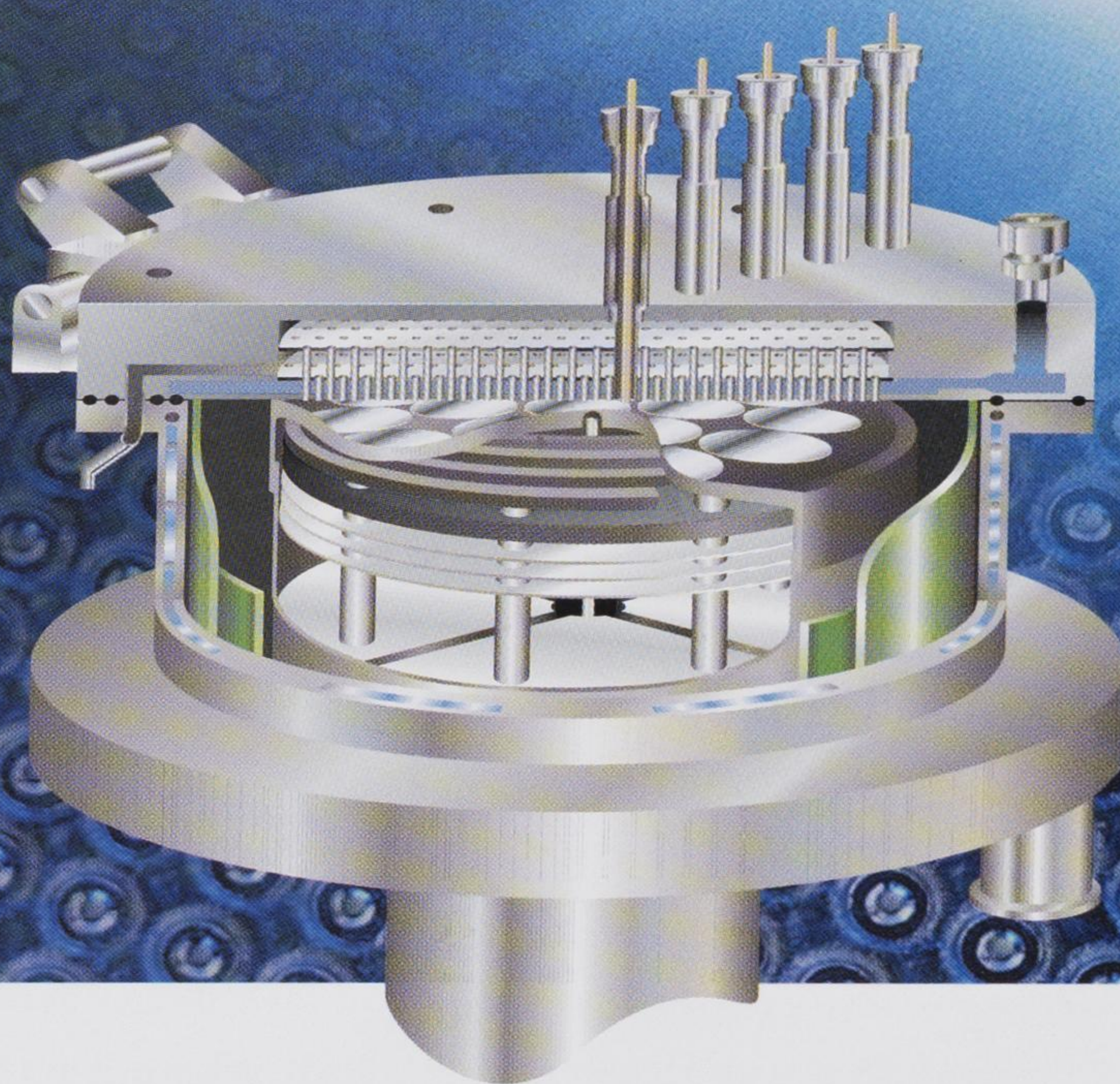
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