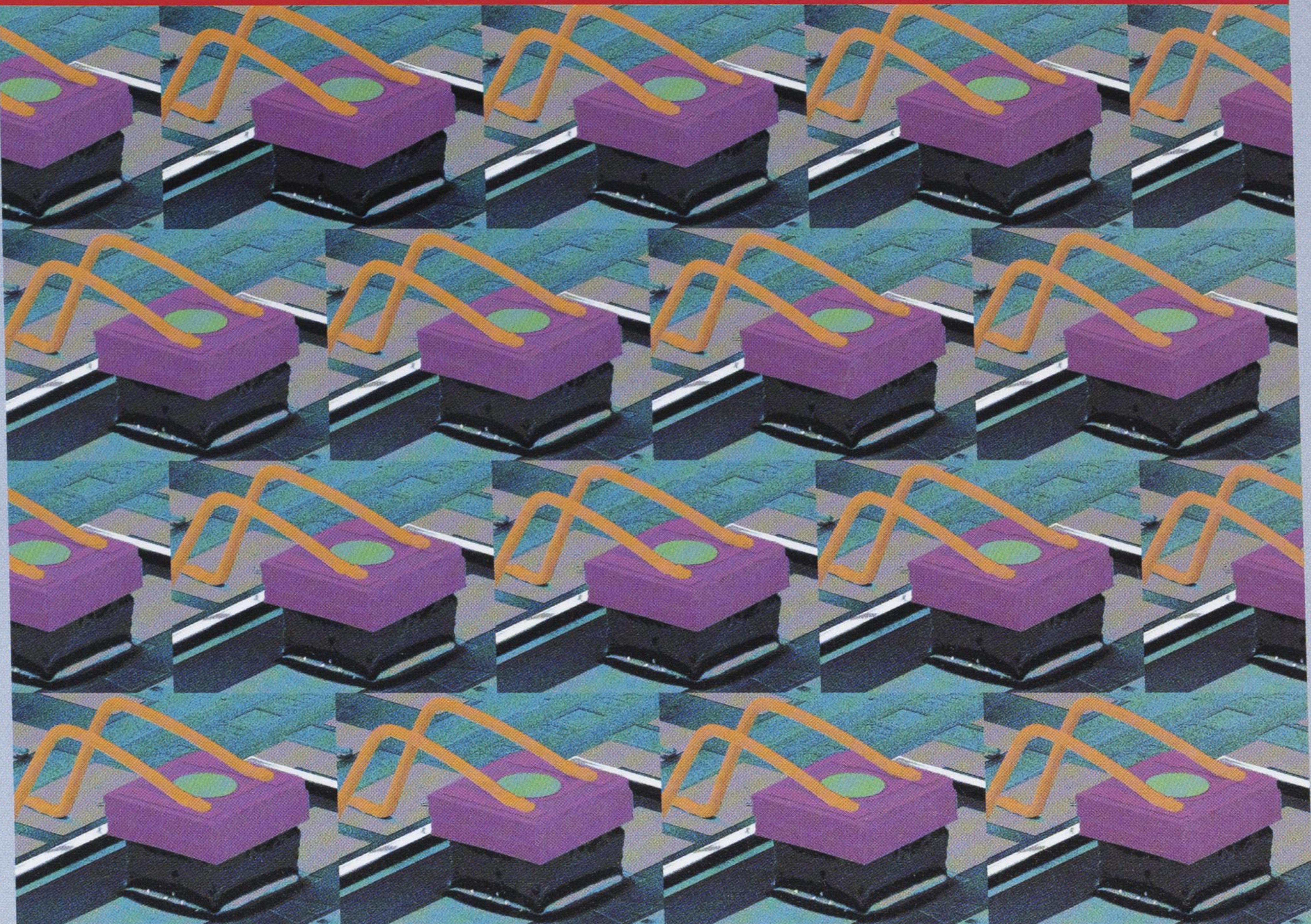


COMPOUND SEMICONDUCTOR

Three-Fives and Silicon Heterostructures

July 2005 Volume 11 Number 6



VCSELS

**Uncertain future looms for
dilute nitride lasers**

ALSO INSIDE

**Yokogawa builds
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**ZnO offers route to
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On the cover: Long-wavelength telecom lasers based on dilute-nitride structures face an uncertain commercial future, despite many advantages over InP-based devices (image courtesy of Infineon Technologies). See p23.

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What does Yokogawa know?



I've written about the trials and tribulations of the fiber-optic components industry in this column on more than one occasion over the past 18 months. While I apologize for returning to the subject, a recent announcement from Japanese company Yokogawa Electric Corporation does merit some serious attention.

Yokogawa is doing something virtually unheard of over the past few years: it is building a new fab to mass-manufacture photonic GaAs devices for use in optical-communications networks. And it sounds like a big one. Costing \$230 million, the fab will be five stories high, with its own R&D facility and, because it will be located near Tokyo, it will be earthquake-proof. With 200 staff expected on the roster, the annual production target is one million units.

The compound semiconductors that Yokogawa plans to make in its new fab from November 2006 onwards will end up in its 40 Gbit/s optical packet switches, IC testers and measurement equipment.

All of which begs the question: what does Yokogawa know that we don't? While it is true that NTT has a massive roll-out of communications infrastructure in the pipeline, exactly when that network overhaul is to be deployed, and the extent to which it will feature 40 Gbit/s optical technology, is unclear. What is clear, is that Yokogawa appears to be wasting no time with its fab construction, which will have a total floor space of 28,000 m² by the time production begins.

The last thing that this industry needs is another massively under-utilized fab, so we can only assume that Yokogawa does have some inside track on future deployments of optical networks in Japan. As countless companies that built factories to make photonics components in the last few years can testify, it is a very expensive decision to take, and one that can backfire quite spectacularly if the timing is wrong. Photonic fab usage is still way below the available capacity, with even market-leading companies like JDS Uniphase running at less than 25% of potential volumes.

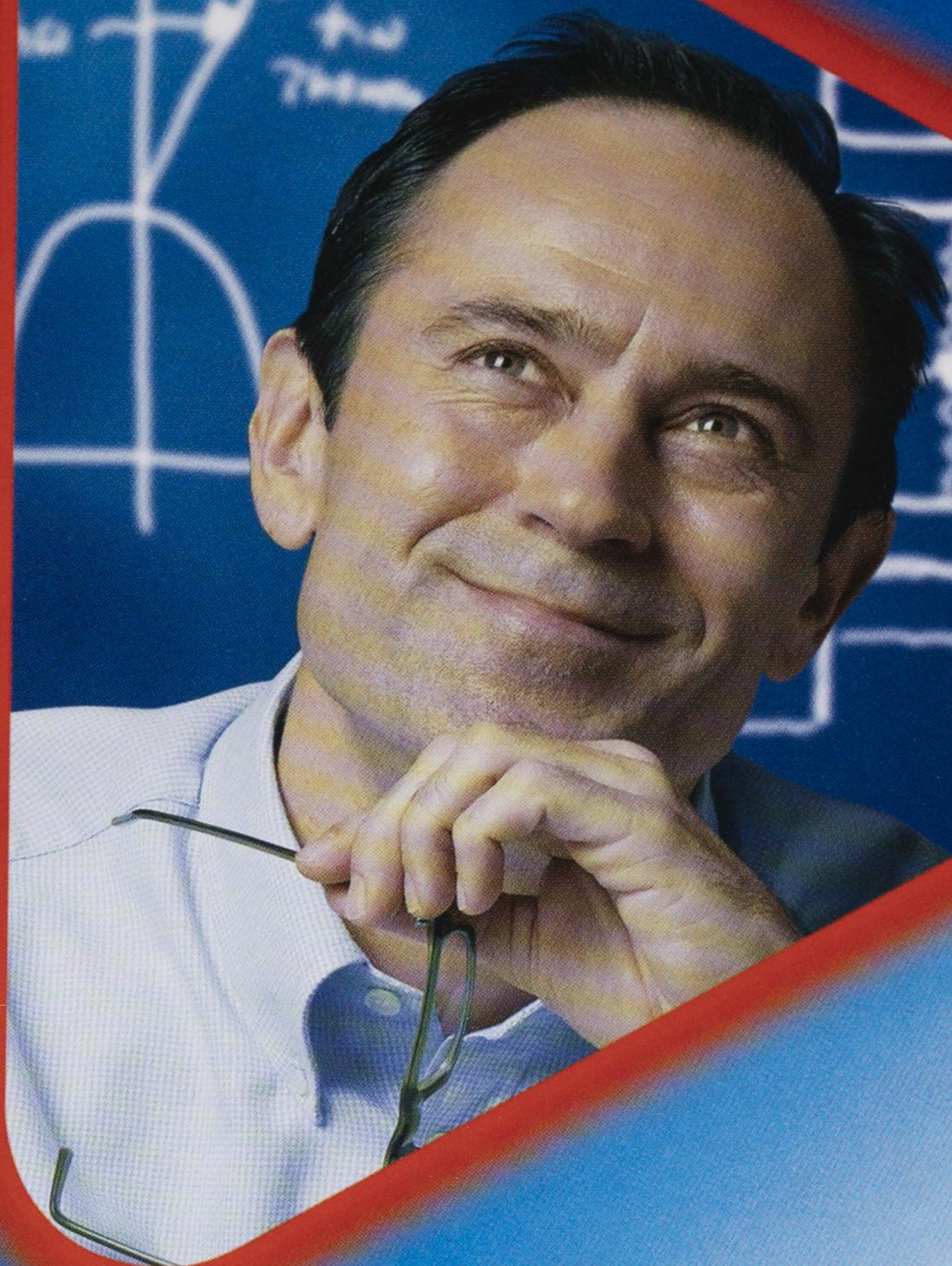
Let's hope that Yokogawa has got its timing right.

Michael Hatcher

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Yokogawa to build \$230 m chip facility

Yokogawa Electric is to invest ¥25 billion (\$230 million) in a large compound semiconductor chip fabrication facility near Tokyo.

The industrial giant, which specializes in automation and control systems, digital sensors, and test and measurement equipment, says that it has developed an optical packet switch for next-generation communications networks that operates at 40 Gb/s.

Yokogawa's all-optical switch technology is based around a GaAs chip that can route signals without the need for electronic conversion. The device can switch in less than 2 ns, which Yokogawa says makes it the world's fastest current-injected optical switch.

"In January this year, Yokogawa carried out the first ever practical demonstration of image data transmission over an optical packet network," said the company in a statement.

The five-storey earthquake-proof fab,

which will be built in Sagami-hara, Kanagawa Prefecture, will employ 200 staff across its 28,000 m² floor space. Production of compound semiconductor chips is set to begin in November 2006.

Yokogawa says that it expects to see large-scale investment in the optical communications equipment market as service providers switch from electronic to photonic links.

In November last year, the Japanese communications giant Nippon Telephone and Telegraph, better known as NTT, announced its intention to build extensive optical networks as part of its planned \$47 billion overhaul of communications infrastructure.

Yokogawa reckons that it can cash in on the upgrade cycle and estimates that its optical communications equipment business will generate annual sales of ¥100 billion (\$919 million) by 2010.

The 40 Gbit/s optical packet switch is based on more than 20 years of research into III-V devices, says Yokogawa. It describes the packet switch as a combination of a high-speed optical device that can switch between packet signals without the need for temporary electronic conversion, and an optical label recognition circuit.

Details of the packet switch were revealed at last year's Optical Fiber Communications Conference. GaAs-based double heterostructure ridge waveguides are the key semiconductor components in the device, which has a minimum switching time of 1.2 ns at 1550 nm. The waveguides were made on a 4 inch GaAs wafer that featured more than 800 switch chips. At the time, Yokogawa acknowledged that the optical communications market was not ready for such a product. Now, it seems, that thinking has changed.

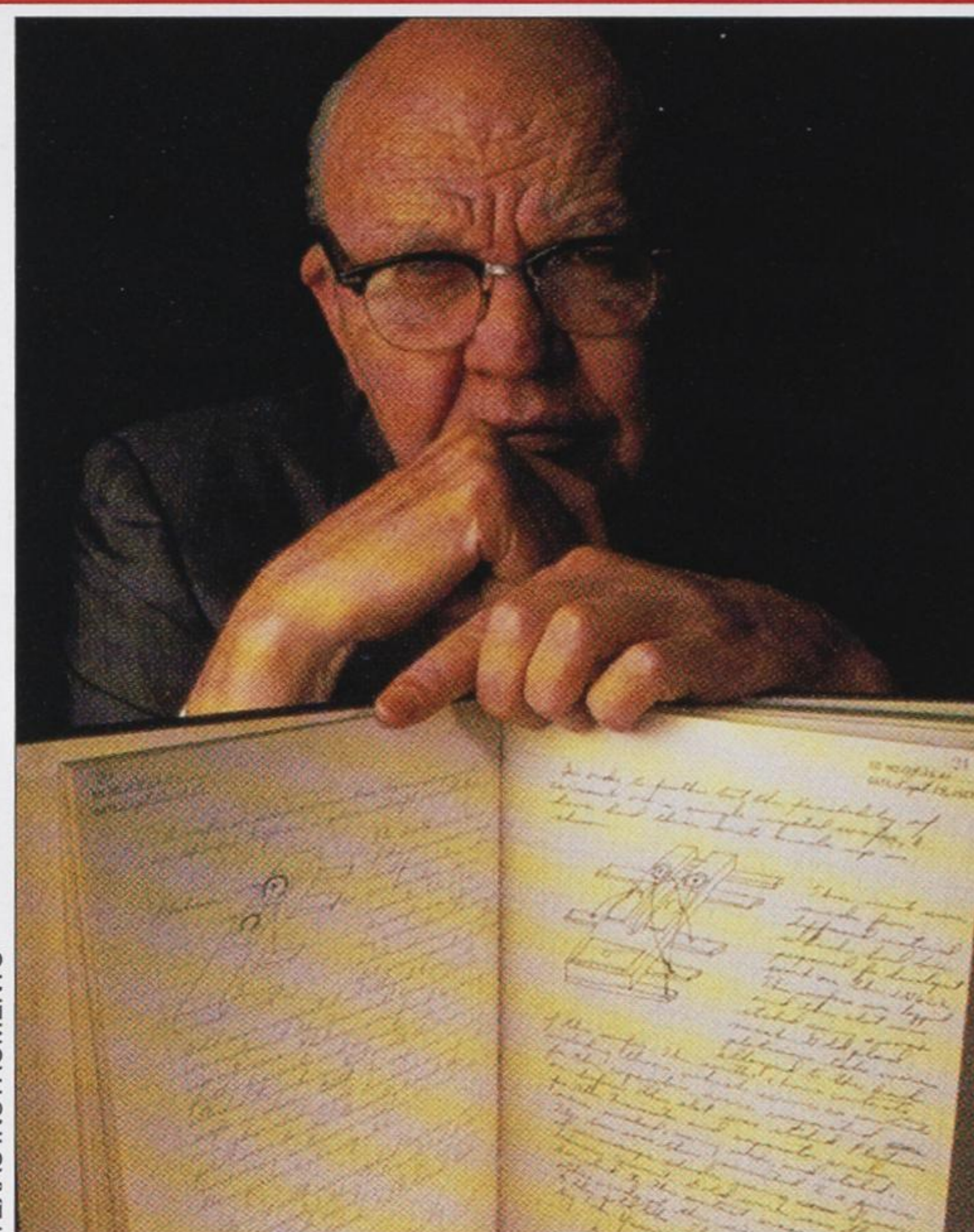
IC inventor Jack Kilby dies aged 81

Jack Kilby, the inventor of the monolithic integrated circuit, has died. Kilby, who was 81, is credited with transforming the modern world with his 1958 invention, for which he received the Nobel Prize for Physics 42 years later.

Although Kilby's work focused on the development of silicon-based ICs, his key invention had a profound effect on the entire semiconductor industry, including GaAs-based transistors and ICs.

Kilby spent much of his career at Texas Instruments (TI), and more recently he also served on the board of the III-V chip manufacturer Bookham.

"Jack was one of the true pioneers of the semiconductor industry," said Rich Templeton, the CEO of TI. "Every engineer, myself included, owes no small part of their livelihood to the work Jack Kilby did here at TI."



Jack Kilby, with the notebook in which he recorded the work that led to the development of the integrated circuit.

Gartner ups phone forecast despite European slowdown

Strong first-quarter growth in all major cell-phone handset markets has prompted market-research firm Gartner to raise its forecast on total sales for 2005 to 750 million units. That is despite other reports of a shrinking cell-phone market in western Europe and a marked slowdown in North America.

Gartner said that the mobile handset industry had a record first quarter, with worldwide sales of 181 million units, up 17% on last year. Meanwhile, Strategy Analytics said that 8% fewer cell phones were sold in western Europe than in the same period last year, and that handset growth in north America had slowed to 3%.

Cell-phone handsets represent the biggest single application area for both GaAs-based RFICs and high-brightness LEDs, where the technologies are widely used in power amplifiers and phone backlights.

The record sales volume for the time of year convinced Gartner to revise its prediction up from the previous forecast of 720 million units. If correct, the new figure would represent a 13% increase on 2004 – itself a record-breaking year for the technology. Both Nokia and Skyworks Solutions have made similar predictions for total 2005 sales after reporting a strong start to the year.

Agilent silent about semiconductor rumors

III-V chip manufacturer Agilent Technologies is refusing to comment on rumors that it may be planning to sell off its semiconductor products group.

According to the *Wall Street Journal*, the Palo Alto, CA, firm, which makes LEDs, GaAs ICs and laser chips, no longer sees the business unit as a core part of its corporate strategy and

has enlisted Goldman Sachs to handle a possible sell-off. But when contacted by *Compound Semiconductor*, Agilent declined to comment.

If Agilent was to sell the division it would affect Lumileds, the high-brightness LED chip manufacturer that it set up as a joint venture with global electronics and lighting giant Philips. Both firms hold a 50% stake in Lumileds.

Taiwan's BenQ to buy Siemens' mobile phone business in global expansion bid

Taiwan-based BenQ is set to acquire the cell-phone business unit belonging to Siemens. The Germany-based industrial giant has been looking at options to divest the unit for some time, and has seen its market share fall sharply as a result of the uncertainty.

BenQ sees the deal as a key part of its expansion strategy as it seeks to become one of the top global suppliers of wireless handsets. The Taiwanese firm had a global market share of only 0.3% in the first quarter of 2005, compared with Siemens' 5.4%, according to the latest market analysis by Gartner.

If the acquisition, which is subject to approval by BenQ shareholders and regulatory bodies, goes ahead, BenQ will take on the 6000 employees working in the Siemens unit. Under the terms of the agreement, BenQ will be allowed to use the Siemens brand for five years.

The Taiwanese company already has a strong handset presence in Asia and it also sells a range of consumer electronics products, including LCD screens, cameras and scanners. BenQ believes that the Siemens mobile-phone division will give it access to



Many consumers associate the Siemens brand with style and advanced features. However, the company has struggled to make its phone division profitable.

the European and Latin American markets that it has struggled to penetrate.

Siemens was ranked as the fourth-largest global cell-phone supplier in 2003 with a market share of 8.4%, according to Gartner. However, since then its market share has fallen behind that of Korea's LG, and the uncertainty over the future of the firm's mobile division was seen as an important factor in this.

According to the most recent figures published by Gartner, Siemens looks set to drop behind SonyEricsson and into sixth place overall. Both companies registered a global market share of 5.4% in the first quarter, but Siemens was alone among the leading cell-phone suppliers to sell fewer units in early 2005 than it did in the previous year.

If the deal is approved, BenQ will acquire all of Siemens' development and manufacturing sites, which are located in Brazil, Germany and China. Siemens is set to receive new BenQ shares to the value of €50 million (\$60.7 million) and says that it will treat BenQ as a preferred partner for its remaining mobile-communications activities.

Freescall shrinks RF chipset with SiGe and GaAs

Freescall Semiconductor says that its latest RF subsystem will usher in a new breed of high-end cell-phone designs compatible with both W-CDMA and GSM/EDGE protocols.

The Austin, TX, company, which was spun out of its parent firm, Motorola, last year, claims to have reduced the number of individual components required from more than 100 to around 35. The multimode subsystem also takes up 70% less board space than previous solutions, the company says.

In all, the subsystem comprises four key elements: a triband W-CDMA transceiver; a W-CDMA integrated power-amplifier (PA) module with power detection; a quadband GSM/EDGE transceiver; and a GSM/EDGE PA module with power control.

Freescall told *Compound Semiconductor* that the GSM/EDGE PA module uses multiple processes on separate ICs. "We are using SiGe in the drivers and GaAs for the final PAs," said the company.

It adds that its customers are already planning to implement the new chipset in their high-end phones, which feature music players, GPS and digital cameras. Volume production of the subsystem is expected to begin in the third quarter.

Will Strauss from market research company Forward Concepts expects the W-CDMA/EDGE multimode handset market to grow 168% this year, with unit sales of nearly 50 million.

Mimix Broadband acquires Celeritek and raises \$8.5 m

Shareholders in Celeritek have approved plans to liquidate the designer and manufacturer of GaAs-based RFICs.

Most of Celeritek's assets have been sold to Mimix Broadband of Houston, TX. Mimix

paid \$2.8 million in cash for the Santa Clara company, and took on \$6 million in liabilities.

Celeritek's board of directors says that a cash dividend worth \$8.4 million will now be distributed to shareholders in the company. Any remaining cash will be similarly shared out under the plan for complete liquidation.

Mimix, which says that the acquisition of Celeritek gives it an immediate platform to expand its existing product portfolio and enter new markets in the telecom, satellite and

defense sectors, has raised an additional \$8.5 million in investment.

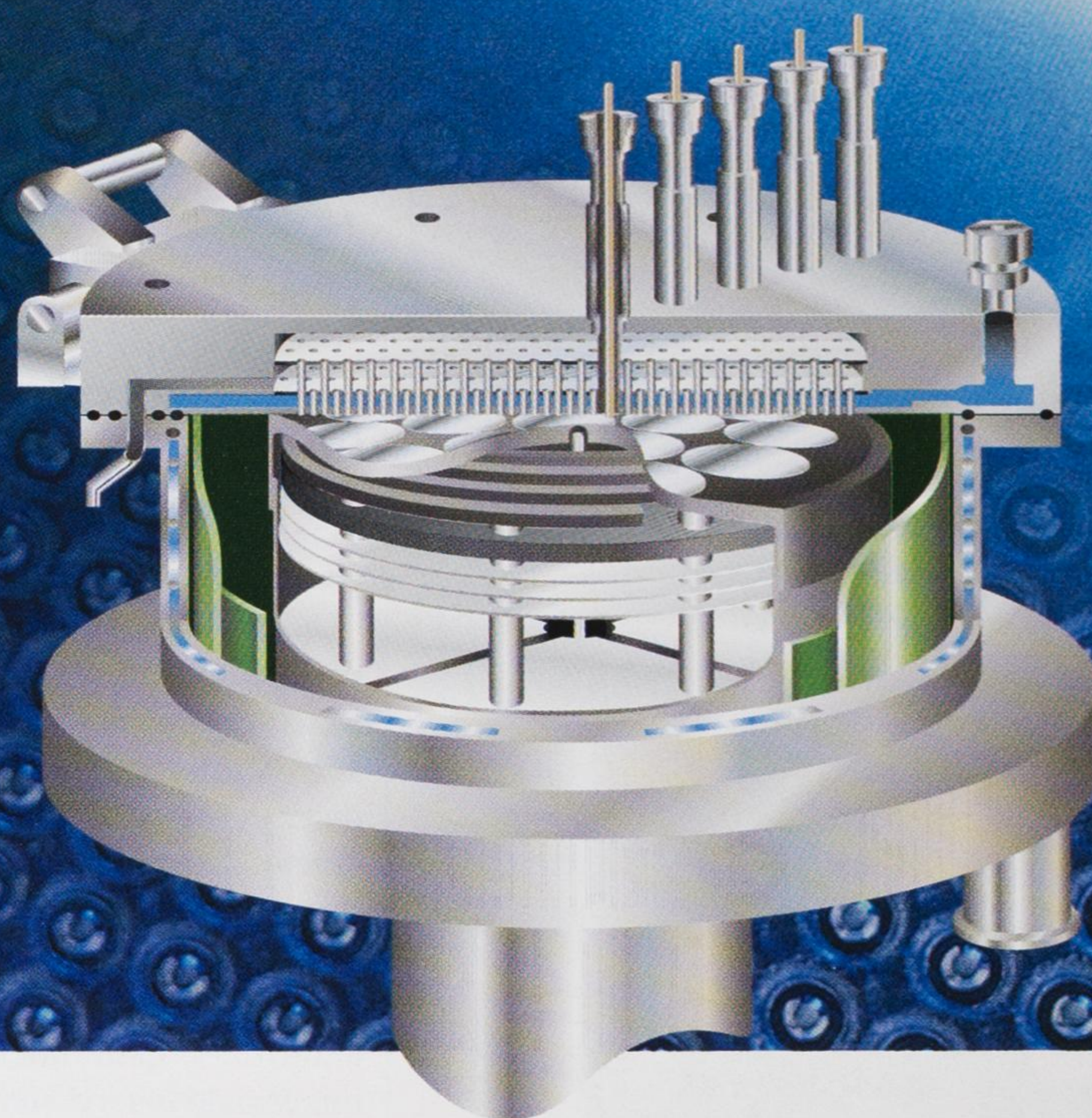
Financing in the latest round came from 3i, First Capital Group of Texas, and Gefinor Ventures, as well as from private investors.

Mimix chief executive officer Rick Montgomery says that the acquisition of Celeritek will "generate innovative technology and supply superior customer support, building the very best platform in the microwave and millimeter-wave semiconductor industry".

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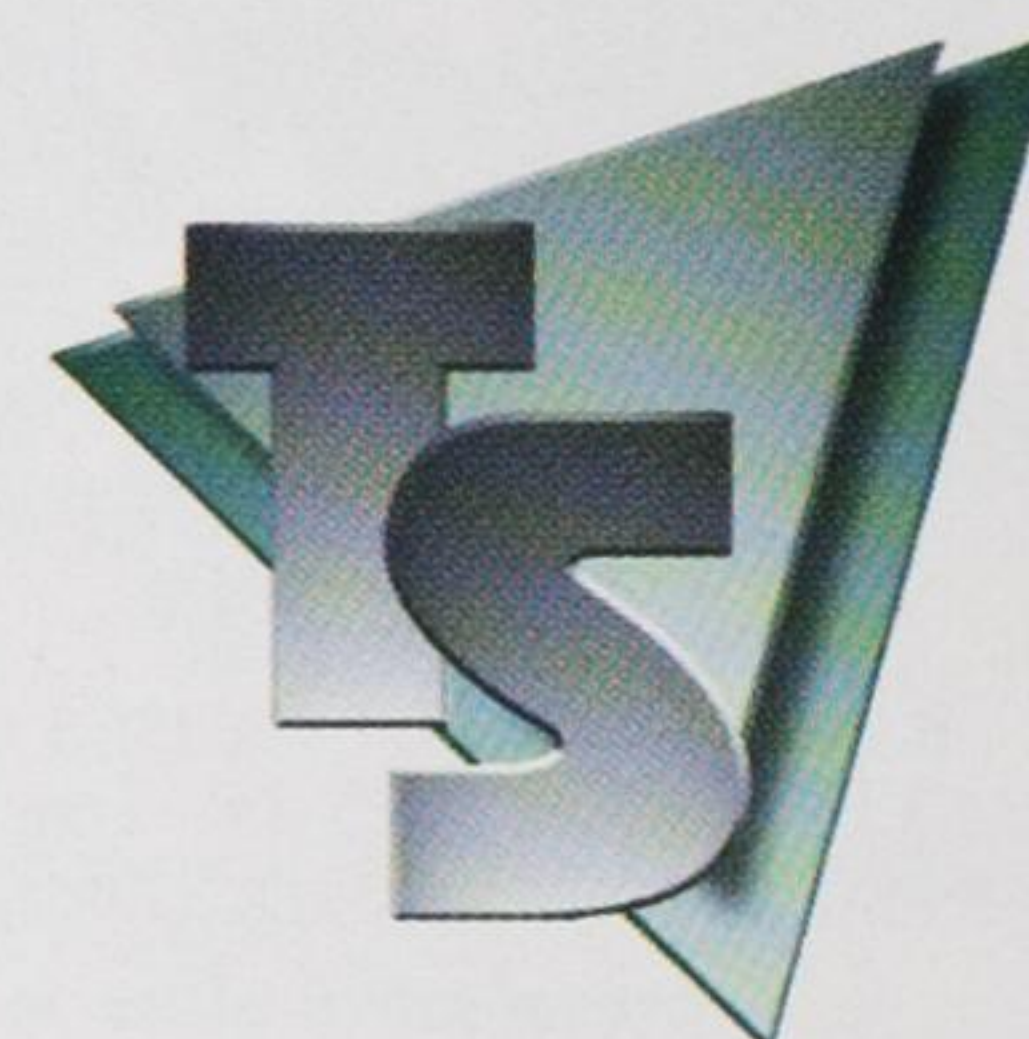


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Broadband access takes the lead at IMS 2005

The International Microwave Symposium in June saw a raft of new products from chip manufacturers targeting the emerging broadband wireless access (BWA) sector.

RF chip manufacturers TriQuint Semiconductor and Toshiba America Electronic Components (TAEC) both released new GaAs products aimed at WiMAX and other BWA protocols at the Long Beach, CA, event, while Cree said that it is now sampling a 10 W SiC MESFET for similar applications.

TriQuint revealed two new power amplifiers (PAs), manufactured using its 0.5 μm gate-length HFET process, that operate in the 3–4 GHz range. One is rated at 10 W and the other at 5.6 W.

According to Dan Green, TriQuint's marketing director for broadband products, the PAs are competitively priced, and a simple layout means that only two external components are needed to produce a 200 MHz bandwidth. Green added that TriQuint would also release MMIC PAs and drivers to complement the existing product range in the 2.5 GHz, 3.5 GHz and 5.8 GHz bands.

Meanwhile, TAEC showed off its GaAs FETs designed for fixed wireless access applications operating at 3.5 GHz and 5 GHz. Three of TAEC's new transistors operate in the 5.3–5.9 GHz frequency range.

"Recent progress in standardization of broadband wireless is expected to spur significant interest and growth in this market," said Toshi Nakamura, TAEC's business development manager for microwave devices.

"Support for WiMAX and unlicensed National Information Infrastructure fixed wireless access systems in leading PC and network chipset solutions is likely to help expand the market – particularly in regions without widespread availability of DSL or cable."

Cree's SiC MESFET is also designed for broadband PA applications. But the Durham, NC, company claims that the wide-bandgap properties of SiC permit twice the normal operating voltage and a fourfold increase in bandwidth compared with either GaAs-based or silicon technologies.

Volume production of the transistor is slated for later this year.

GCS process targets millimeter wave

Global Communication Semiconductors (GCS), the pure-play compound semiconductor foundry based in Torrance, CA, has extended its proprietary 0.25 μm PHEMT process to cover millimeter-wave frequencies.

"Our low-cost 0.25 μm PHEMT process was developed specifically for transceiver MMIC components," said GCS's new CEO, Jerry Curtis. "The device features high frequency characteristics, with a cut-off frequency greater than 60 GHz, a maximum oscillation frequency greater than 150 GHz, and a G_{max} of more than 15 dB at 30 GHz."

Curtis continued: "It is ideal for power amplifiers, gain blocks, LNAs, switches, mixers and other discrete or MMIC components with operations through Ka-Band (or up to 40 GHz) frequencies."

According to the new CEO, the unique feature of the GCS process is that it uses optical gate lithography, which enables low-cost manufacturing and a short cycle time.

Cree to cease silicon chip manufacturing

Cree is to focus on wide-bandgap technologies for RF and microwave applications after deciding to stop making silicon chips. The Durham, NC, company will close its Sunnyvale-based silicon fab by the end of 2005.

Cree Microwave will take orders for silicon LDMOS products until the end of July, but expects to wind down the business by the end of the calendar year. Closing the Sunnyvale facility will cost the company \$13 million – 15 million, a total that includes just under \$2 million in severance payments to staff, and around \$4.7 million in facility lease obligations.

Cree had been looking for some time to dispose of the silicon RF business, which cost the parent company \$9.2 million in pre-tax operating loss for the nine months ended March 27.

Manufacture of Cree's Schottky diode product line, which was recently qualified in Sunnyvale, will now be consolidated at the company's Durham, NC, headquarters.

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Sumitomo signs \$200 m purchase deal with Cree

Sumitomo Corporation has agreed to buy \$200 million worth of Cree's LED products during the fiscal year ending June 2006. This deal follows purchase agreements of \$100 million and \$160 million made by Sumitomo for Cree's LED chips during the fiscal years 2004 and 2005.

Sumitomo, which has a distributorship deal with Cree that extends to June 2007, sells the chips to Japanese packaging companies.

Cree and Sumitomo anticipate that the purchases, which are subject to end-customer demand, will be made across Cree's full line of LED chip products and will include MegaBright, XBright, and XThin LEDs.

With Cree's revenue now in the region of \$100 million per quarter, the Sumitomo deal

will probably account for around half of Cree's sales in the fiscal year 2006.

"The renewal of our agreement and increased purchase commitments reflects the growth we are forecasting in Japan, and highlights the strength of our partnership with Sumitomo and our Japanese customers," said Cree's chief executive officer Chuck Swoboda.

- Cree has launched two new energy-efficient LED chips. The MegaBright 290 Gen 2, which is designed for camera phone flash and LCD backlighting applications, is said to be 30% brighter and to use 8% less power than the chip it replaces. The RazerThin 230 is designed for keypad backlights and also consumes 8% less power than the previous generation of devices, says Cree.

Osram unveils giant television backlight

Osram Opto Semiconductors says that it has made an LED backlight unit that can illuminate an 82 inch LCD display. According to the company, the backlight, which is the size of a door and only 40 mm thick, is the largest such system ever built.

The backlight is based on Osram's Golden Dragon LEDs. A total of 1120 chips are used, arranged in clusters of four. Each cluster contains one red chip emitting at 625 nm, one blue chip emitting at 458 nm, and two green chips

that peak at 527 nm. These emission wavelengths have been slightly shifted from the regular Golden Dragon output to improve the so-called "color gamut", or fidelity, of color reproduction on screen.

Osram's massive light engine comes at a high energy cost, however. It consumes 1 kW of power. The German firm's rival manufacturers Cree and Lumileds are also targeting large-scale LCD backlights as a critical new application for their high-brightness LEDs.

In brief

- **Lamina Ceramics**, which develops and sells arrays of high-brightness LEDs, has raised \$9 million in Series C financing. Granite Global Ventures led the round, and Yi Pin Ng from the investment firm now joins the Lamina board. Other investors in the latest round of financing included Morgenthaler Ventures and SpaceVest.

In February Lamina claimed to have developed a white-LED array capable of emitting 28 klm.

- **Lumileds**, a maker of high-brightness LED chips and modules, won a silver medal for its LCD television-backlight product at the recent Display of the Year awards. The award was made at the Society for Information Display event held in Boston.

- Taiwan-based LED maker **Genesis Photonics** has bought a large-scale Thomas Swan MOCVD reactor as it looks to ramp up its GaN device production. The close-coupled showerhead reactor has a capacity of 19 two-inch wafers.

- **Agilent Technologies** has introduced two side-firing, tricolor, surface-mount LEDs that it says allow handset and PDA designers to mix separate red, green and blue light sources in any combination.

The LED is mounted vertically, with the light emitted through a lens on the side rather than the top of the package. According to Agilent, this simplifies the coupling of emitted light to a light pipe for backlighting keypads and LCD screens.

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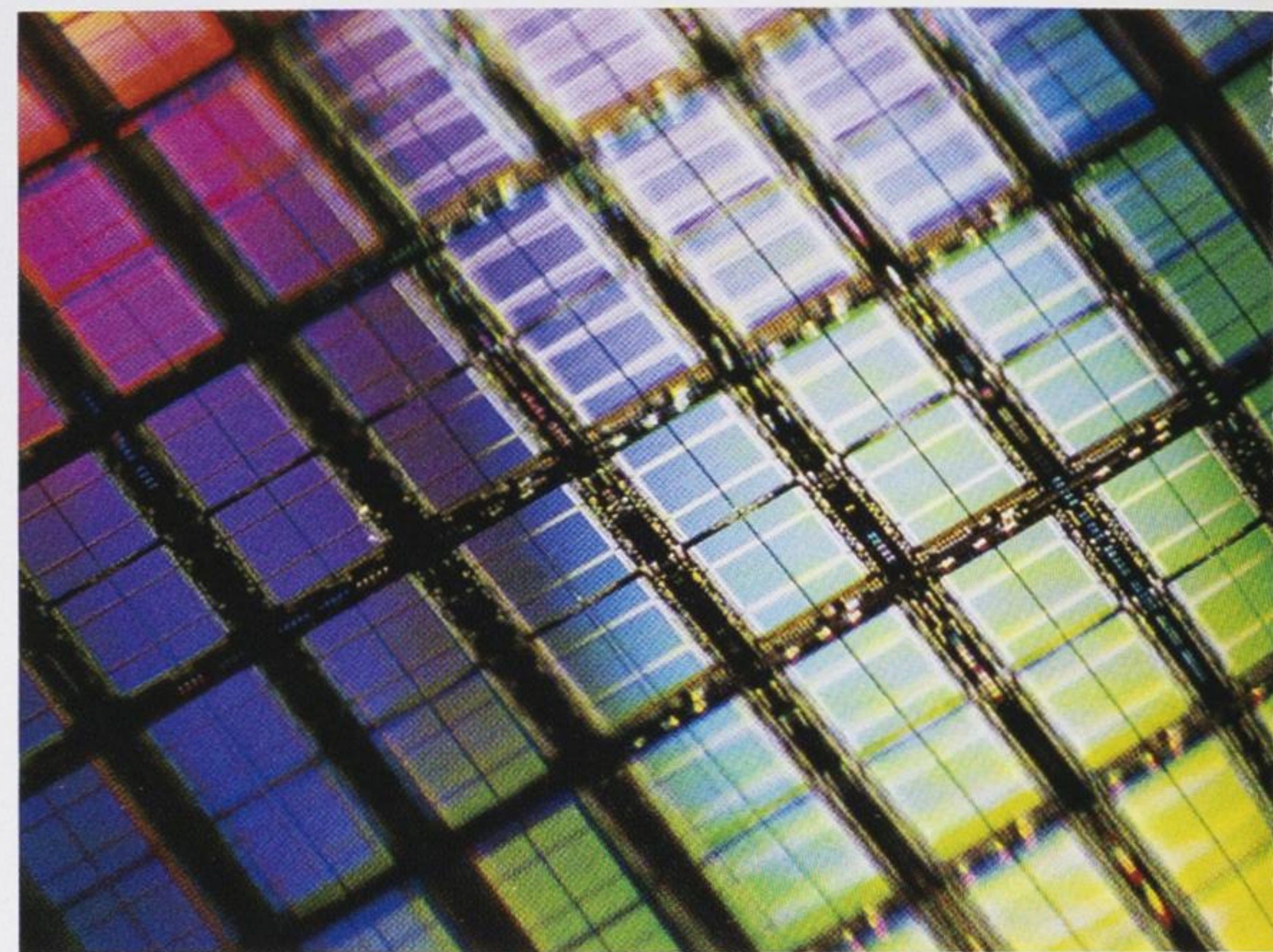


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SURFACE TECHNOLOGY SYSTEMS

Sharp Laboratories Europe fabricates continuous-wave blue lasers with MBE

Engineers at Sharp's research laboratory in Oxford, UK, have fabricated the first continuous-wave InGaN-based laser diodes to be grown using an MBE process.

Commercial blue-violet laser diodes are now grown by MOCVD, but early last year Jon Heffernan and colleagues at Sharp Laboratories Europe produced violet diodes using MBE for the first time.

However, those first devices only worked in pulsed mode and had a high threshold current. To be used commercially, the lasers need to emit laser light continuously at a power output of around 90 mW to read data on optical discs.

"This latest result confirms that MBE is a viable growth method for nitride lasers," said Heffernan. "Sharp is now in the unique position of having both MBE and MOCVD technologies available."

At room temperature, the Sharp team's latest lasers emitted around 0.2 mW for three minutes before burning out. The continuous-wave threshold current was 125 mA, corresponding to a threshold current density of 5.7 kAcm^{-2} .

Heffernan and colleagues made the lasers on n-type GaN substrates supplied by Sumitomo Electric Industries. The active laser region included three undoped 3 nm-thick InGaN quantum wells with a 9:1 gallium-indium ratio.

The lasers operated in continuous-wave mode for around three minutes, and across the wafer there was a variation of some 6 nm about the crucial emission wavelength of 405 nm.



Fabricated by MBE, this 405 nm laser diode developed at Sharp Laboratories Europe operates in continuous-wave mode, which is a prerequisite for applications in next-generation DVD players and recorders. The laboratory's parent company is already a big player in red laser manufacturing for today's DVD applications, for which it also uses MBE.

The Sharp team has also produced blue-violet lasers on sapphire template substrates, where devices have shown similar threshold current densities.

Growing the lasers by MBE rather than by MOCVD promises to lower manufacturing costs by reducing the consumption of ammonia gas, which provides the nitrogen content in the devices.

However, Heffernan and colleagues still have much development work to do before the MBE method can be considered suitable for mass production. The team will concentrate on improving device operating characteristics by optimizing material growth conditions and p-type doping in the AlGaIn

cladding region. The aim is to reduce the operating voltage of the lasers, which should in turn increase the lifetime of the devices.

Increasing the laser output power has not been the major priority so far, but the team will now look at the facet coating and try to improve the efficiency of the quantum wells.

Significantly, the European laboratory's parent company already uses MBE in its mass production. At its Mihara fabrication facility in Hiroshima, Sharp manufactures a significant proportion of the world's red lasers that are used in DVD applications.

Sharp is also part of the Blu-ray Disc Association, along with blue laser manufacturers Nichia, Sony and Matsushita Electric.

Disc manufacturers prepare for new DVD

Japanese optical disc manufacturer TDK claims to have developed a prototype recordable Blu-ray Disc with a capacity of 100 GB.

Using four recording layers, the disc also has twice the recording speed of today's Blu-ray specification. And with double the capacity of previous dual-layer Blu-ray discs, the format could store around nine hours of high-definition video.

Consumer electronics firms are planning to introduce next-generation DVD technology in the next few months, and the move is

expected to kick-start the mass-manufacture of GaN-based blue-violet lasers, which are required to read data on the discs.

Meanwhile, four companies working under the rival high-definition DVD (HD-DVD) industrial group have developed a recordable disc that is compatible with DVD-R disc production lines.

The discs will be commercialized by Hitachi Maxell and Verbatim early next year, to coincide with the launch of HD-DVD recorders and drives by key hardware manufacturer Toshiba.

A new dye developed by the companies is said to be highly sensitive to blue light and compatible with the spin-coating process that is used by DVD-R disc manufacturers.

Comlase VP to drive reactor development

Comlase, the Swedish company that develops process technology for semiconductor laser production, has hired Olof Sahlén as its new vice-president of engineering.

Sahlén will direct development of the company's next-generation Nitrel process reactor. The reactor is said to increase manufacturing yield, performance and reliability of all kinds of diode lasers by eliminating device failures that result from facet oxidation.

Sahlén was previously at the Swedish photonics company Optillon.

Emcore buys JDSU cable-TV unit

III-V component-maker Emcore has acquired the analog cable-TV (CATV) and RF-over-fiber business units of JDS Uniphase (JDSU) for \$1.5 million.

In addition, Emcore has agreed to buy \$2.8 million–3.8 million worth of components from JDSU over the next two years. The Somerset, NJ, firm will also pay JDSU a royalty on licensed intellectual property.

The CATV business brought in around \$20 million in revenue over the past year, and Emcore expects its own sales figures to be boosted by \$10 million–15 million this year as a result of the acquisition.

Product lines in the transaction include: 1550 nm broadcast transmitters, which link cable networks and hubs; 1310 nm transmitters linking cable hubs and nodes; 1550 nm dense wavelength division multiplexed transmitters; analog receivers; amplifiers for fiber-to-the-premises applications; and RF-over-fiber specialty products for defense and

satellite communications. Under the terms of the deal, the two companies have also agreed a preferred supplier arrangement for certain (undisclosed) optical components.

Emcore says that it will now set up a design center in northern Pennsylvania, close to CATV product customers. JDSU employees acquired through the transaction will continue in product design, marketing, sales and applications engineering functions.

Hong Hou, vice-president and general manager of Emcore's Ortel division, said: "Emcore now offers complete product solutions to OEMs in this market."

Continuing to focus down on its core business activities, JDSU has also completed the sale of three of its manufacturing sites to Thailand-based Fabrinet.

Fabrinet now owns the former JDSU sites in Mountain Lakes and Ewing, both in New Jersey, as well as the crystal-manufacturing operation in Fuzhou, China.



Yves LeMaitre is the new vice-president and general manager of Avanex's optical-components business unit. The newly formed unit, which was created as a result of the photonic chip-maker's recent restructuring, combines the former active and passive discrete-components group with the transmission-modules unit. LeMaitre was previously at Lightconnect, a California-based MEMS component maker.

Finisar loss mounts despite high revenue

Photonic chip and module-maker Finisar racked up a net loss of \$112.7 million in its full fiscal 2005 results.

The loss was almost unchanged from the previous year's figure of \$113.8 million, despite a 51% rise in overall sales that totalled a record \$280.8 million.

Reporting its results for the final quarter of fiscal 2005, Finisar says that if a number of one-time financial charges were excluded, the fiscal 2005 loss would have been a mere \$43.1 million.

At \$74.9 million, Finisar's fourth-quarter revenue was also a company record, and represented a 2% sequential increase. The quarterly net loss was \$36.5 million.

Finisar's latest balance sheet shows that the Sunnyvale, CA, firm, which in January acquired the optical transceiver business previously belonging to Germany-based Infineon Technologies, holds \$29.4 million in cash and cash equivalents. The company lists \$72.9 million in short-term investments.

Finisar also has a new member on its board of directors. David Fries represents the venture capital company VantagePoint Partners, which recently bought 34 million shares in Finisar from Infineon Technologies.

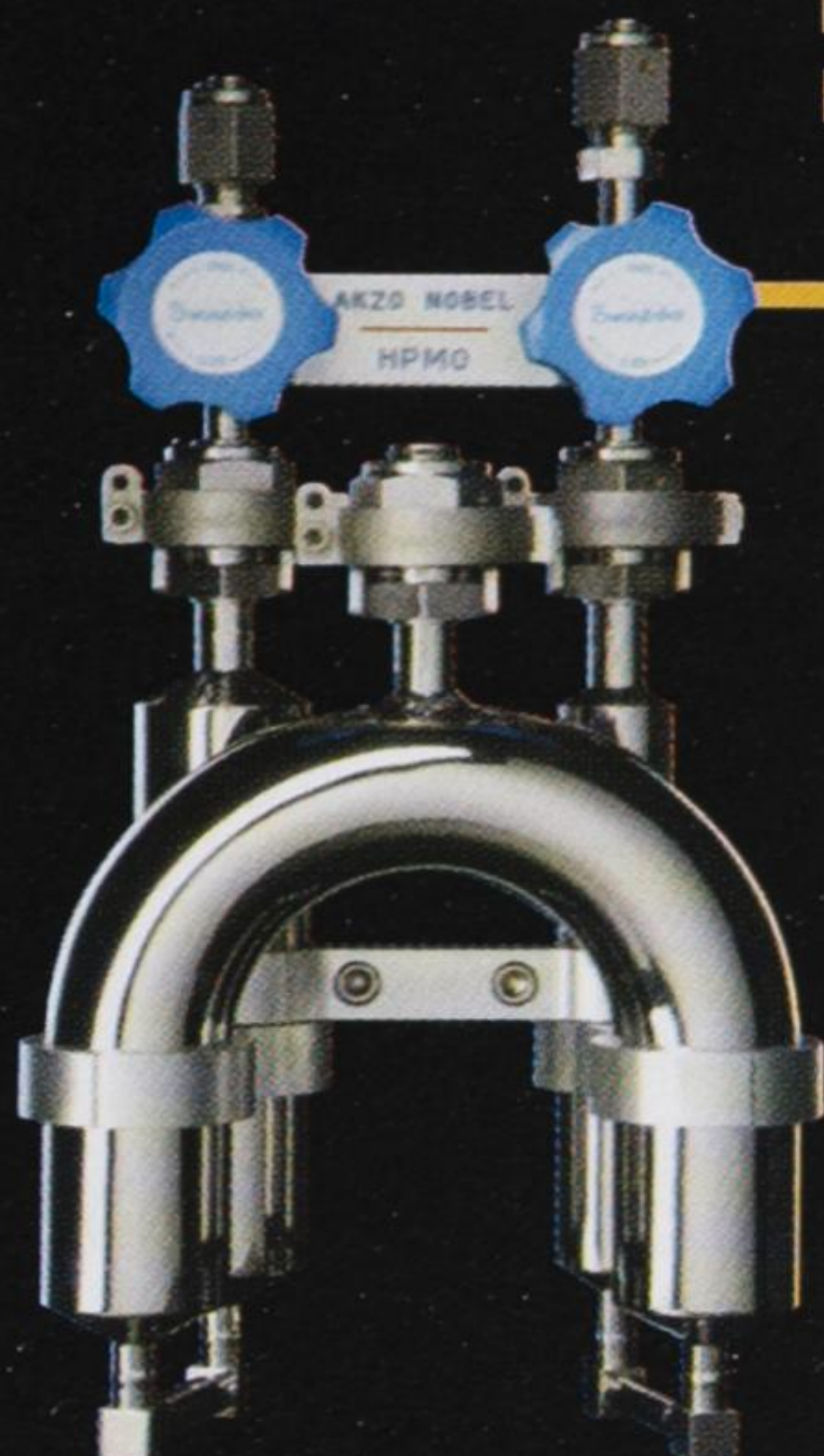


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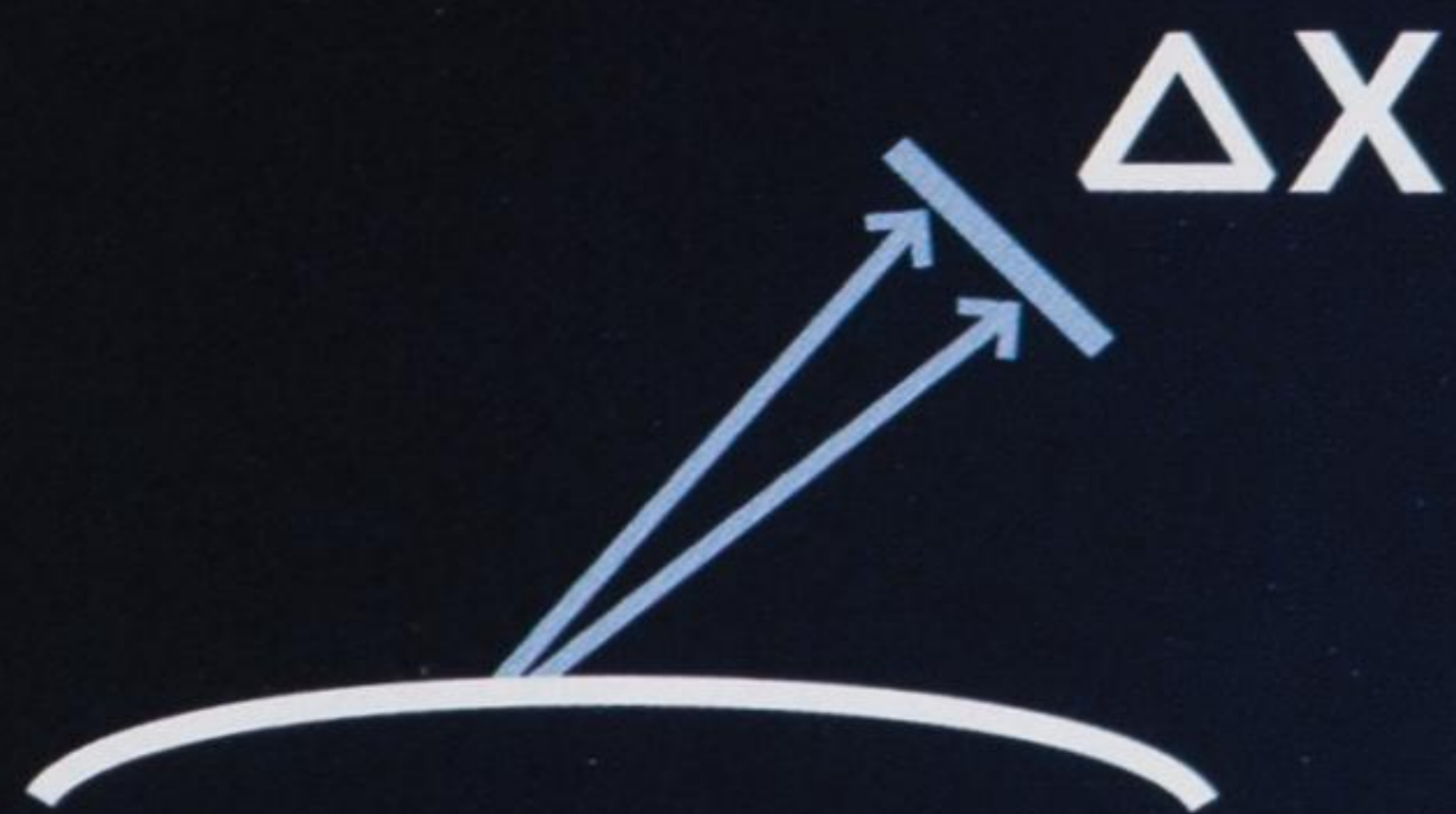
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WIDE BANDGAP NEWS

Arkansas SiC team gets \$1 m to stop blackouts

Engineers at the University of Arkansas (UA) have received \$1 million from the US government to help set up a technology center that will develop SiC chips to upgrade the country's electrical power grid.

The National Center for Reliable Electrical Power has been established in direct response to the 2003 power blackout that hit much of the northeastern US.

Alan Mantooh, a UA professor of electrical engineering and director of the center, said: "We have to limit potentially catastrophic events so that people don't get hurt and equipment doesn't get destroyed."

During the 2003 power outage, obsolete electromechanical current limiters that were supposed to contain surges in power were blamed for failing to contain the blackout.

Mantooh explained that the outage, which cost billions of dollars, was triggered by a storm over Ohio that felled trees onto transmission cables. The fallen trees caused a huge power surge that the current limiters should have contained by grounding the charge.

Instead, those mechanical switches failed or did not function quickly enough. The result was a cascade of surging currents that spread from Ohio to hit New York City and Detroit, as well as the Canadian cities of Ottawa and Toronto. Nuclear power stations in the states of New York and Ohio were forced to shut

down, and air traffic into affected airports had to be diverted.

"Even with the electromechanical switches functioning properly, the entire process is too slow," said Mantooh.

Because SiC chips can react to power surges faster than mechanical devices, as well as withstand higher voltages and operate at elevated temperatures, they have been identified as one of the solutions to the power grid problem.

"We want to get the electric system of our country to react like a computer – at electrical speeds, not mechanical speeds," said Mantooh. "The catastrophe of the [2003] blackout wasn't the trees falling on power lines. It was the cascading effect."

"None of the built-in protection devices reacted quickly enough or properly. What you need is faster acting, more reliable, purely electrical systems – what we refer to as solid-state solutions."

Mantooh and his UA colleagues will generate mathematical models of SiC devices to simulate the design of large electrical systems. Those devices will then be tested and packaged to ensure that they don't break down when subjected to high voltages and currents.

Teams at the University of Wisconsin-Madison, the University of Tennessee, Virginia Tech and Georgia Tech have received funding for related research.

US Navy finances \$12 m power project

Cree has won a \$12.1 million cost-plus-fixed-fee contract to develop high-voltage switches and diodes based on SiC. Under the Office of Naval Research award, Cree will work on the prototype devices between now and November 2006.

The company says that the technology developed in the Phase II contract will significantly reduce the size and weight of power-management equipment aboard the US Navy's next-generation aircraft carriers and other sea vessels.

"Building on the tremendous success of Phase I, during which Cree demonstrated 10 kV, 50 A PiN rectifiers and the first 10 kV SiC MOSFETs, we intend to scale these devices in size, and build power modules capable of 10 kV and 110 A during Phase II,"

noted John Palmour, Cree's executive vice-president for advanced devices. "These devices could eventually be used beyond ship applications to optimize electrical power distribution for greater efficiency and rapid power switching across any major power grid, particularly for long-haul lines."

The project also calls for the development of extremely low defect density *n*-type 4H-SiC substrates and epitaxy required for creating these large-area high-current high-voltage power devices.

Powerex of Youngwood, PA, will perform module design and testing. Raytheon Integrated Defense Systems of Sudbury, MA, and General Atomics of San Diego, CA, will perform systems studies on the solid-state power supplies proposed for this application.

CAP Wireless sets its sights on achieving full X-band coverage

Microwave and RF subsystem supplier CAP Wireless is to develop a 150 W GaN power amplifier (PA) under a US Air Force project.

The company, which is based in Newbury Park, CA, has been awarded \$750,000 under a small business innovation research program to develop the PA, which it says will cover the entire X-band frequency range.

CAP Wireless will base the amplifier on its patent-pending "spatial combiner" technology – branded Spatium – which allows a number of chips to be combined to generate high-power amplification across a decade of bandwidth. The X-band PA development is expected to be complete by the end of 2006.

Currently using GaAs PHEMTs and FETs supplied by Hittite Microwave and TriQuint Semiconductor in its amplifiers, CAP Wireless will source its GaN chips from Cree. Scott Behan, the new vice-president of marketing at CAP Wireless, told *Compound Semicon-*

ductor that Cree also designed the chips that would be used in the X-band amplifier. The PA will feature 16 GaN devices in total.

Founded by GaAs industry veterans Charles Abronson and Paul Daughenbaugh, CAP Wireless has been in "stealth mode" for the past eight years. It now employs 15 people and has an annual revenue of around \$3 million, says Behan.

The Spatium technology, which was developed primarily at the University of California, Santa Barbara, is now subject to a patent infringement lawsuit filed by rival amplifier company Wavestream Corporation.

Wavestream contends that the CAP Wireless technology infringes an exclusive license that Wavestream has signed with the University of California, this time centering on a power-combining method developed at the California Institute of Technology. CAP Wireless denies any such infringement.

HRL debuts GaN fabrication service

HRL Laboratories is offering a device prototyping service for GaN-based integrated circuits. The Malibu, CA, research laboratory, created by legendary aviator Howard Hughes, will provide "selected customers" with design, fabrication and test services for microwave and millimeter-wave ICs and modules.

HRL has produced a design kit and will also provide fabrication services for custom designs. The frequency range covered extends from the ultrahigh through to the "Q-band". It has also developed a process for GaN HFET manufacturing on 100 mm substrates, but MMICs are currently made on 3 inch wafers.

According to the company, HFETs made on the larger wafers have now been demonstrated. The 100 mm substrates allow a 70% increase in fabricated devices per wafer.

Last year, HRL made a 20 W X-band module based on GaN, as well as a wideband low-noise amplifier and a power MMIC operating in the Ka-band for satellite communications.



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Facet etching promises in

BinOptics' etched-facet technology avoids the drawbacks of the standard cleaving process used in laser production, such as poor yields, while allowing on-wafer testing. **Alan Morrow** and **Alex Behfar** describe how the technique can benefit GaN laser manufacturing and speed up the market penetration of next-generation DVD players.

Mechanical cleaving of semiconductor epiwafers is the usual way to define the reflective mirrors, or facets, at the cavity ends of edge-emitting diode lasers. However, for most semiconductor materials this cleaving process is imprecise compared with techniques such as photolithography. In addition, cleaving creates fragile bars and minuscule chips that are awkward to handle during device testing and any subsequent operations. Mechanical cleaving tends to be incompatible with monolithic integration, as the wafer must be physically broken to obtain fully functional lasers.

A problematic procedure

Cleaving GaN is particularly problematic. Nichia Chemical of Japan first used mechanical cleaving to fabricate GaN-based blue lasers on sapphire substrates in 1995 and has since made continuous-wave lasers commercially in the same way. However, the cost of these lasers remains high.

Cleaving sapphire to form GaN-based laser facets is difficult. The substrate has several cleave planes of approximately equal strength that are orientated at such acute angles to one another that minute perturbations occurring during cleaving can redirect a fracture interface from one cleave plane to another. Despite this problem, sapphire's low cost and its stability during the high-temperature growth processes needed for GaN deposition have helped it to remain the substrate of choice for nitride laser fabrication.

Another disadvantage of sapphire and the more expensive SiC substrates is the significant lattice mismatch with GaN that causes the grown layers to have high defect densities. Free-standing GaN substrates could offer a partial solution, but they are only just becoming available. However, unlike InP and GaAs, which have a cubic crystal structure, GaN's structure is hexagonal. This makes GaN much harder to cleave, and it is expected that cleav-

ing will remain a challenging process even if GaN substrates do become the standard.

Several years ago an alternative technology was pioneered at Cornell University, NY. It uses a process based on photolithography and chemically assisted ion-beam etching (CAIBE) to form the facets. BinOptics Corporation, Ithaca, NY, has since developed commercially available InP-based lasers using this proprietary etched-facet technology (EFT).

These devices have precisely located mirrors with a quality and reflectivity equivalent to those obtained by cleaving. In the EFT process, lasers are fabricated on the wafer in much the same way that integrated circuits are fabricated on silicon. This process allows the lasers to be monolithically integrated with other photonic devices on a single chip and to be tested inexpensively at wafer level (figure 1).

The high process yield, the low cost and the potential for fabrication of integrated GaN photonics make etched-facet blue-emitting lasers very attractive. As a result, BinOptics has developed a modified version of EFT for GaN. To obtain the straight surfaces demanded by photonic devices requires high-quality etching of the semiconductor, but negligible etching of the masking material. The smooth etch quality of the GaN facet can be seen in the SEM image in figure 2.

Reducing defect density

The relatively high defect density in deposited GaN layers has had a strong impact on the yield and cost of blue lasers. GaN grown on sapphire substrates has a typical defect density of $6 \times 10^8 \text{ cm}^{-2}$, primarily resulting from lattice mismatch. A few research labs have developed techniques such as epitaxial lateral overgrowth on sapphire that can reduce defect densities to roughly 10^7 cm^{-2} , while densities of as low as $3 \times 10^5 \text{ cm}^{-2}$ have been reported for materials grown on very small GaN substrates.

To reduce the problems associated with defects, manufacturers can produce lasers

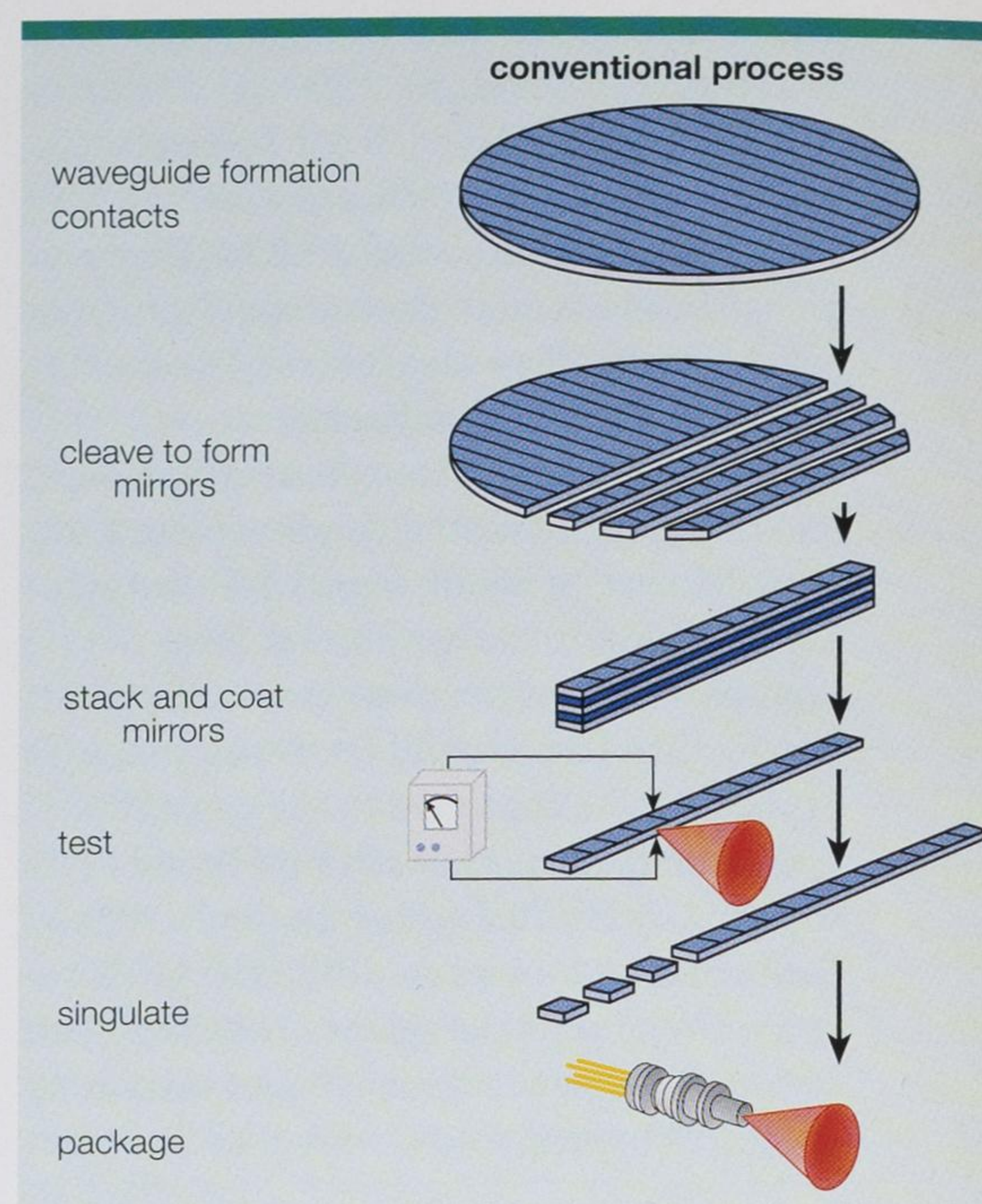


Fig. 1. BinOptics' EFT process (right), which employs photolithography, offers several advantages over the conventional method (left), which involves mechanical cleaving.

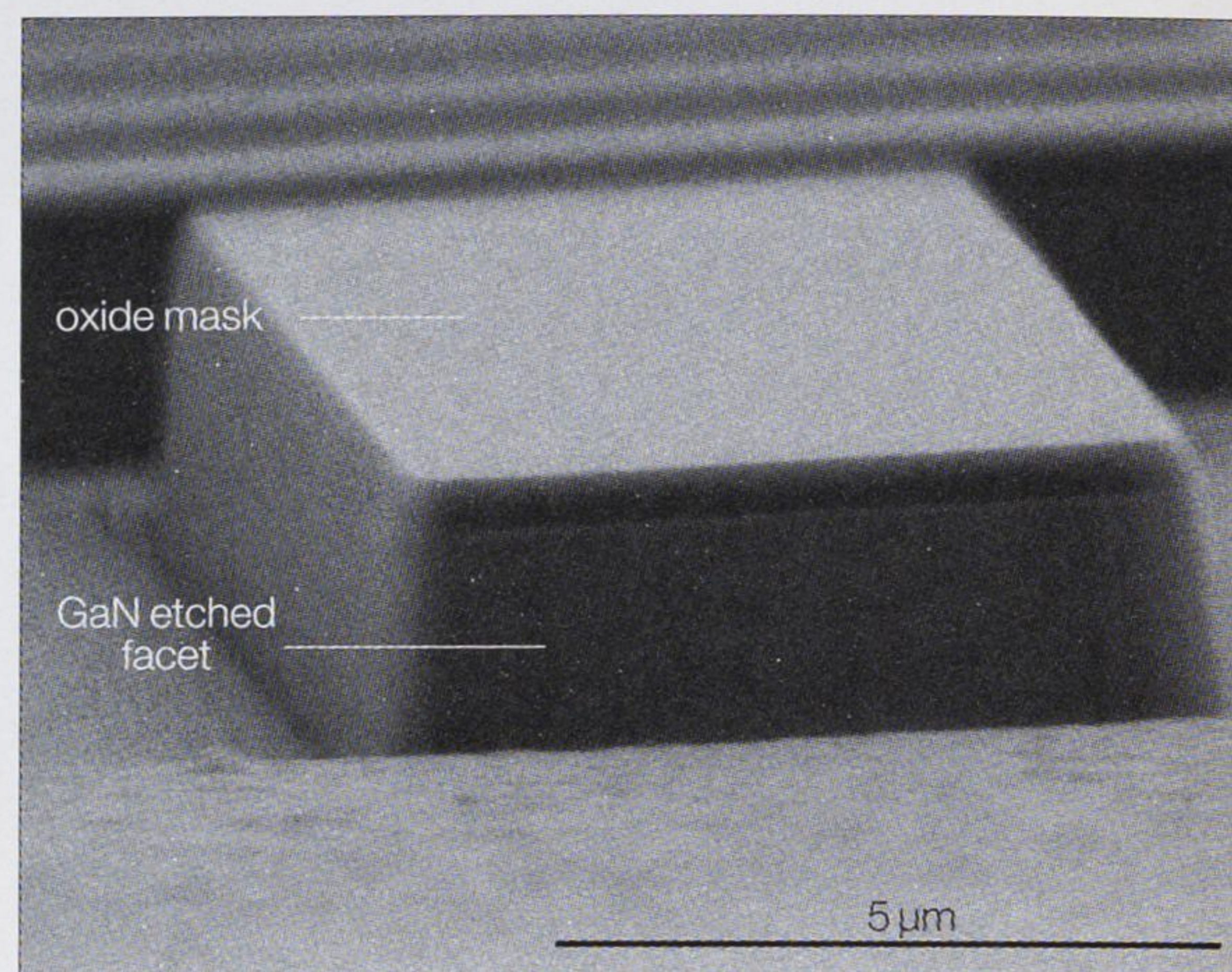


Fig. 2. CAIBE delivers high-quality etched facets in GaN. This technique allows on-chip monolithic integration of lasers with other photonic functions.

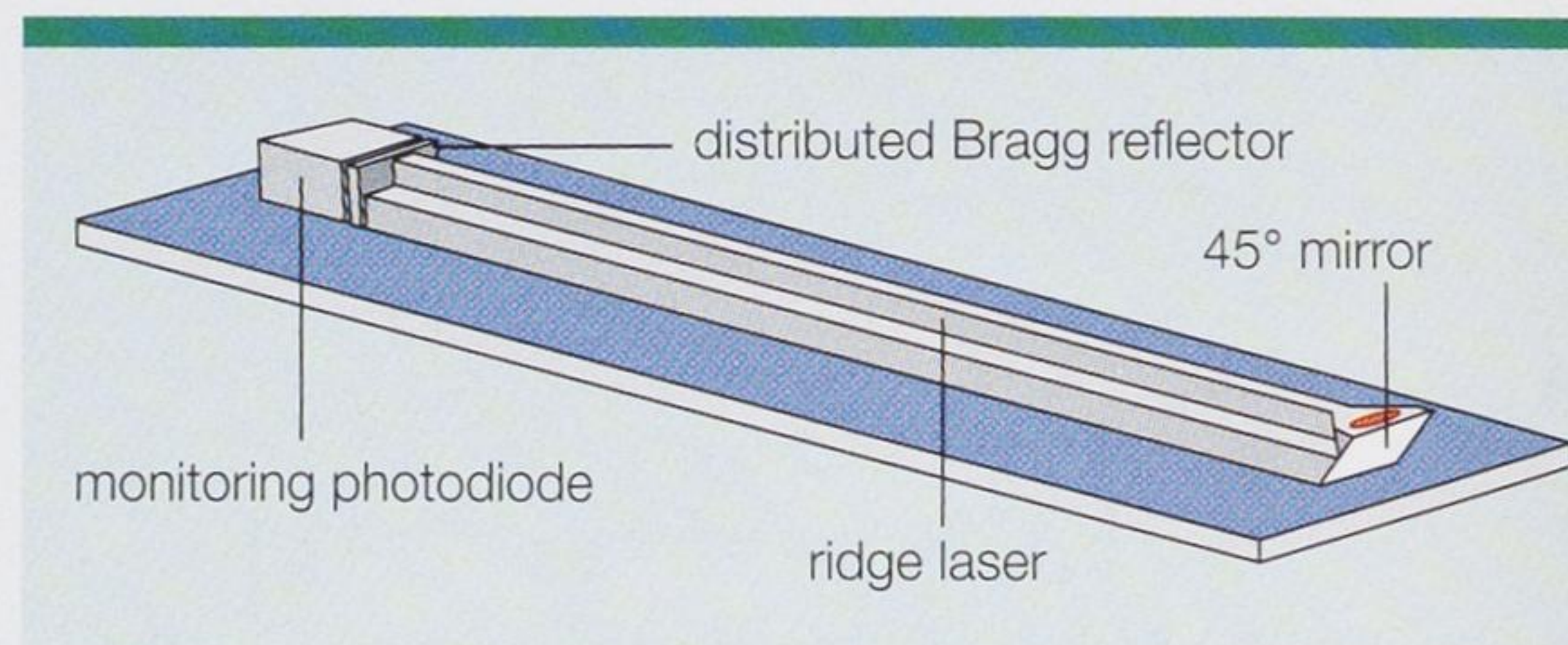
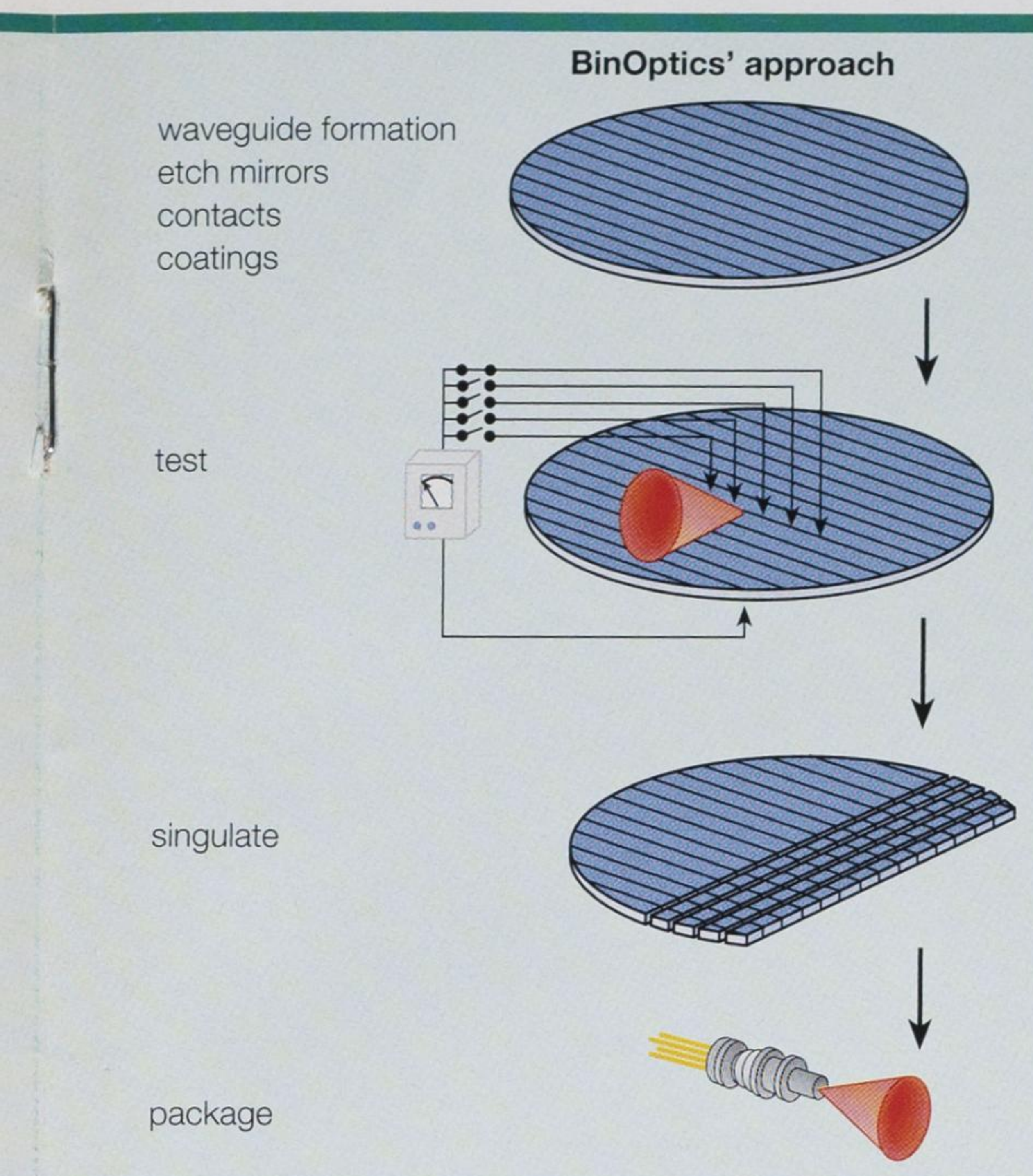


Fig. 3. BinOptics' horizontal-cavity surface-emitting laser is manufactured using the EFT process to produce emission perpendicular to the growth plane.

Increased blue-laser yield



photolithography and CAIBE to etch laser facets, offers which include full-wafer processing and testing.

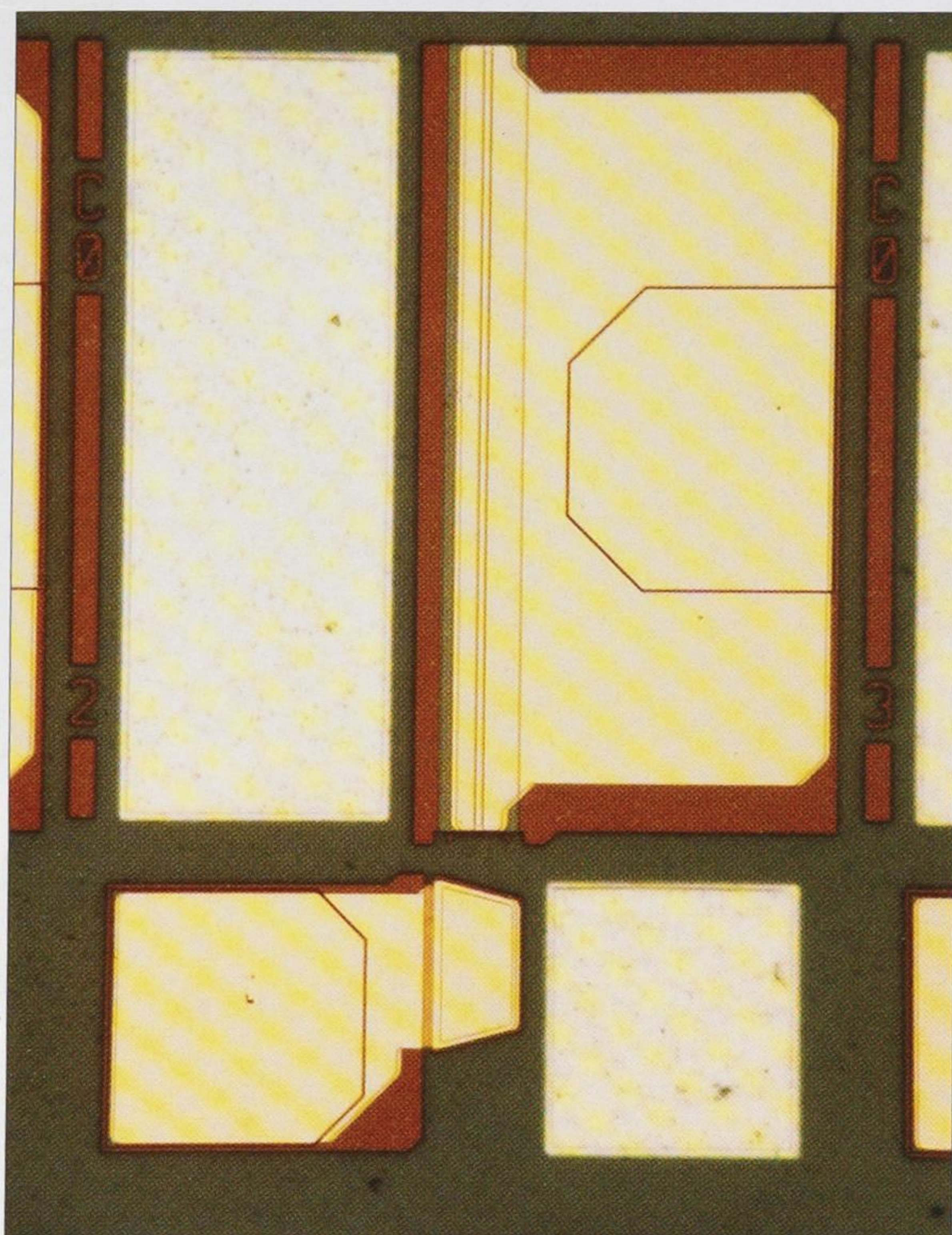


Fig. 4. One advantage of BinOptics' EFT over a mechanical cleaving process is that a blue emitter's cavity length can be reduced from 600 to 100 μm . This miniaturization reduces the number of defects within the cavity, thereby increasing device yield.

with shorter cavities, which results in fewer defects per device and delivers a much higher device yield. While difficulties associated with cleaving restrict the minimum cavity length to about 600 μm , facet etching allows much shorter cavities of 100 μm . Lasers of this size have a lower maximum power rating due to the shorter cavity, but because most will be used in next-generation DVD-ROM applications, a relatively low output power is acceptable. The specific fabrication, integration and full wafer-testing capabilities enabled by EFT also deliver significant benefits to the fabrication of higher-power GaN lasers for writable optical-disc applications.

BinOptics is currently shipping EFT-manufactured InP-based lasers to several customers. The design flexibility offered by EFT can deliver products with exceptionally high power outputs and efficiencies, and low threshold currents. Device reliability has been proved by accelerated-ageing tests, lasting many thousands of hours, in packaged and non-hermetic conditions.

BinOptics has also demonstrated a novel and cost-effective approach to building a horizontal-cavity surface-emitting laser (HCSEL) using EFT. This is a semiconductor laser with an elongated cavity (on a substrate) that is fabricated by etching a 45° angled facet at the emitter end and a 90° facet at the back end of the cavity (figure 3). The rear reflective region can incorporate an etched distributed Bragg reflector next to the rear facet, or dielectric coatings can be used for reflectivity control. Monitoring photo-detectors and receive detectors can also be integrated onto the chip to produce a compact diplexer for two-way communication in access networks.

Mirroring InP progress

The company's development strategy for blue lasers is similar to that used for its InP-based devices. It started by demonstrating effective facet etching with adequate surface quality and selectivity in GaN (see figure 2). This was followed by fabricating edge-emitting blue-laser chips with etched facets – initially Fabry-Pérot ridge waveguide lasers emitting at 405 nm for optical-storage applications. BinOptics has already demonstrated a process to produce this type of structure (see figure 4) and its efforts

are now directed at optimizing the device's optical and electrical properties. The next stage is to demonstrate a surface-emitting blue laser using the HCSEL design.

If surface-emitting lasers can be fabricated, this could lead to two-dimensional arrays for high-power applications and monolithic integration of additional functions. For example, an HCSEL could be integrated with receive detectors to create a compact optical head. BinOptics intends to develop these lasers and integrated devices for other applications that require a wavelength accessible with GaN-based material. The company closed a \$10 million round of financing in February that will partly fund this development.

Potential market impact

In addition to their use in next-generation DVD players (high-definition DVD and Blu-ray), blue semiconductor lasers are key components in other emerging applications, including the detection of biological and chemical weapons, pollution monitoring, projection displays and high-quality laser printers. According to market analyst Asif Anwar of Strategy Analytics, growth in all of these sectors will drive the market for 405 nm lasers from \$9 million in 2003 to \$272 million in 2009, although the data-storage market will dominate.

GaN-based EFT could play a major role in driving this increase in sales through increased device yields, chip-size reduction and functional integration. Affordable blue lasers will accelerate the adoption of the emerging high-density-disc standards and open up additional high-volume market opportunities.

Further reading

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Alex Behfar is chairman and chief executive officer and Alan Morrow is vice-president of technology development at BinOptics Corporation. Enquiries should be directed to Alan Morrow at amorrow@binoptics.com.



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TV evolution breeds business for GaAs chip manufacturers

Advances in television broadcasting, such as interactive services and the delivery of high-definition content, are generating demand for higher bandwidth cable-television networks. This evolution of the medium is driving an increase in shipments of gallium arsenide components, according to two leading RF chip manufacturers. **Richard Stevenson** investigates.

Revenue from gallium arsenide (GaAs)-based content deployed in cable television (CATV) infrastructure is set to rise from \$20 million in 2004 to \$47 million in 2009, according to market analyst Asif Anwar of Strategy Analytics. Anwar believes that this growth will come from increased sales of higher-bandwidth amplifiers used to deliver digital and high-definition TV formats.

This optimistic outlook is shared by Ron Michels, Anadigics' vice-president of broadband products. Michels – who claims that Anadigics is the leading manufacturer of GaAs components for CATV infrastructure and for set-top boxes that convert cable broadcasts into signals suitable for TV inputs – believes that increased sales of advanced set-top boxes will also boost the company's revenue. He says that these latest-generation components require additional GaAs for functions such as viewing one channel while recording another.

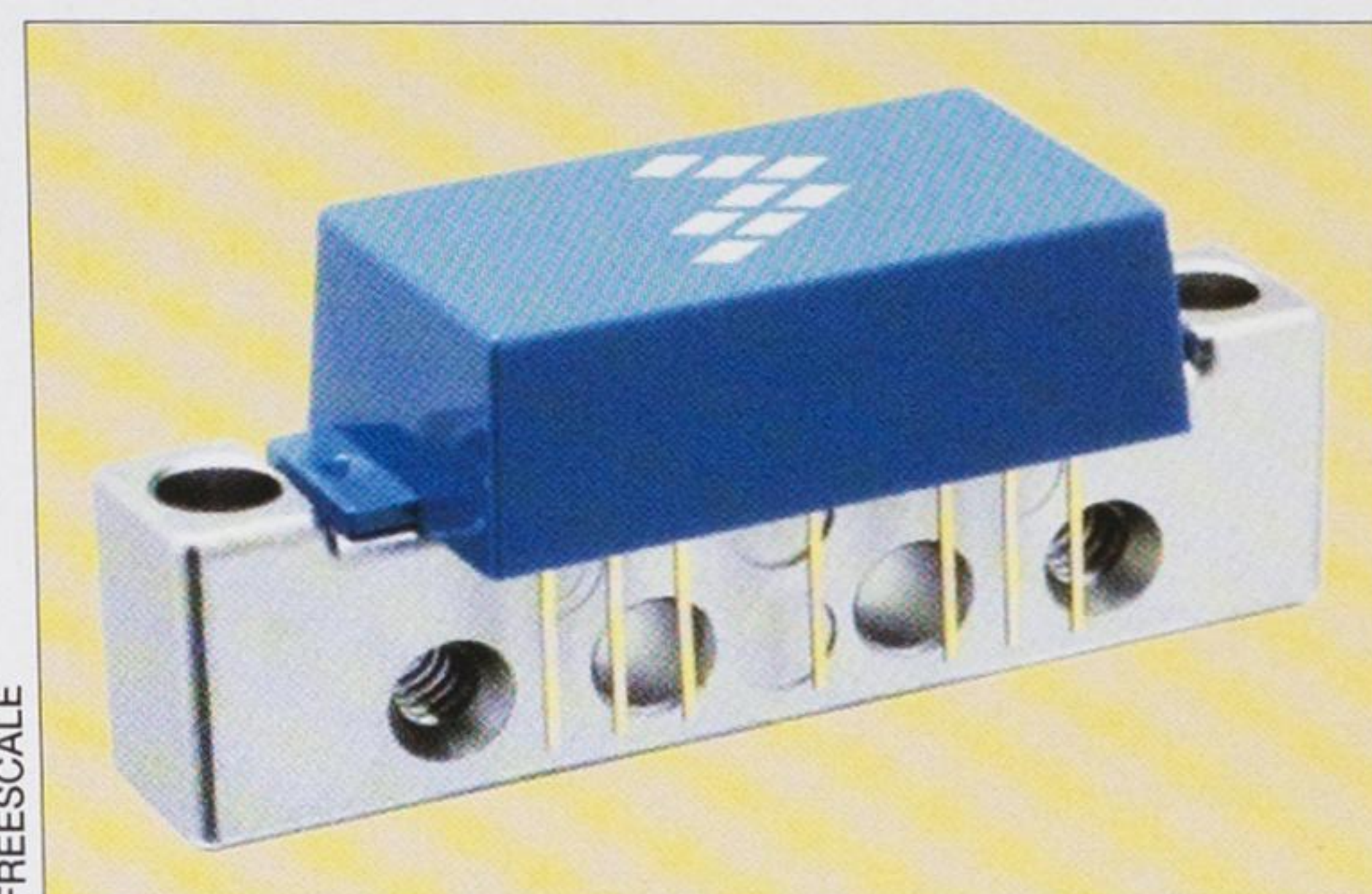
Solid growth

According to Michels, roughly one-third of Anadigics' revenue comes from the CATV sector. In fiscal 2004 this sector equated to about \$30 million. Sales of CATV-related revenue experienced double-digit growth last year, and Michels expects "solid" business from this sector for the next three to four years. He predicts that Anadigics' infrastructure business will maintain healthy revenues, but this will be overshadowed by sales growth of GaAs chips used in set-top boxes, figures that are not included in Anwar's report.

Michel explains that Anadigics' components are used throughout the CATV network. At the "headend", where the broadcast originates, they amplify the transmitted RF signal that is then converted into optical signals transmitted to a local hub; in the 75 Ω , 0.25 inch-thick coaxial cable that connects the hub to the home they are used to boost the signal; and in the set-



Anadigics, which generates one-third of its revenue from CATV products, uses GaAs components in its line amplifiers for infrastructure applications and in integrated chipsets for set-top boxes used in the home.



Freescale, which manufactures line amplifiers for CATV infrastructure, claims to be witnessing a shift in this sector from silicon to GaAs-based products.

top boxes they are used as tuners to select the different channels available.

Anadigics' CATV unit shipments are dominated by chipsets for set-top boxes (2 million per month), followed by infrastructure components (100,000 per month).

Amplifiers for the headend represent the smallest sector of the business, contributing sales of only 5000 components per month.

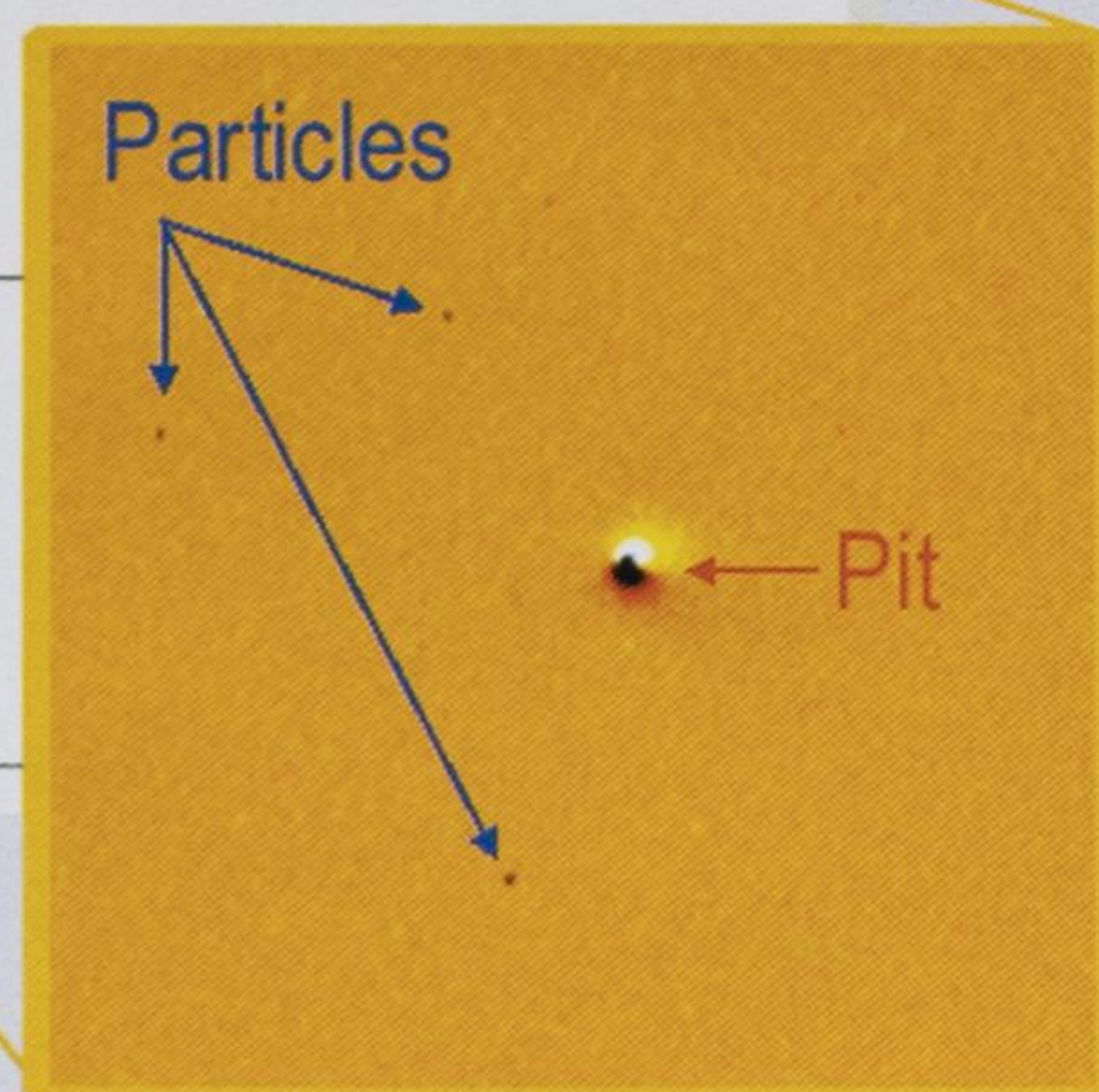
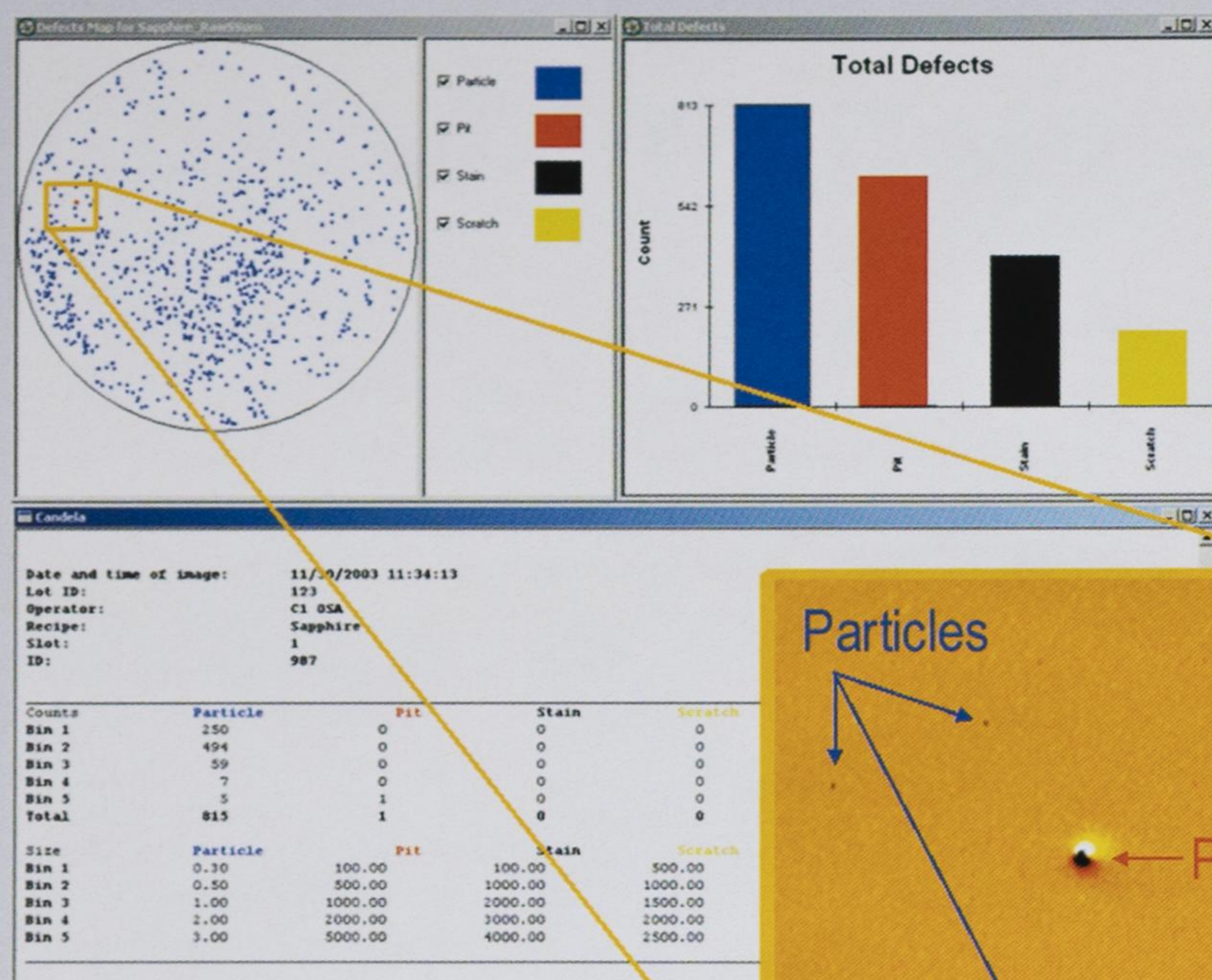
Chipsets are sold by Anadigics for use as integrated tuners in set-top boxes. "Anadigics is the leading supplier for CATV applications specifically for set-top boxes," said Michels. The company has been shipping a module with an up converter and a down converter on separate packages, because when the product was developed it was not possible to deliver an adequate performance from a single package.

Integrated processing

However, Anadigics has just released an integrated tuner in a 6 × 6 × 1 mm package, containing a GaAs and a CMOS chip. "The combination of using GaAs on the front end of the tuner and CMOS for the rest of it gives us a cost-effective, small die area, even though it uses two chips," remarked Michels. The tuner was produced using a derivative of the company's integrated HBT and PHEMT process, which allows production of both transistor types on the same InGaP/GaAs die (see *Compound Semiconductor* June p6). The hybrid chip faces competition from all-silicon tuners, but Michels thinks that Anadigics' product will triumph due to its lower noise.

Anadigics also manufactures GaAs-based active splitters for set-top boxes, which separate the RF signal coming into the set-top box into two or three different outputs. Active splitters are a pre-requisite for the growing market of advanced set-top boxes that contain hard drives. These boxes allow viewers advanced digital functions such as displaying two programs on screen simultaneously, rewinding and pausing live TV, and recording one channel while watching another.

"You have all sorts of silicon manufacturers trying to compete with us for active line splitters, but nobody has been able to come close," boasted Michels. He believes GaAs



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splitters have a significant advantage over their silicon counterparts in terms of linearity, and are better suited to the wide bandwidths needed to deal with several hundred separate channels. Michels adds that when the signals are split into two, 3 dB of power is lost. If no action is taken to compensate for this loss, he explains, then there is a 3 dB increase in noise: "Again, the low noise [associated with] GaAs is the key here, both on the infrastructure side and in the set-top box."

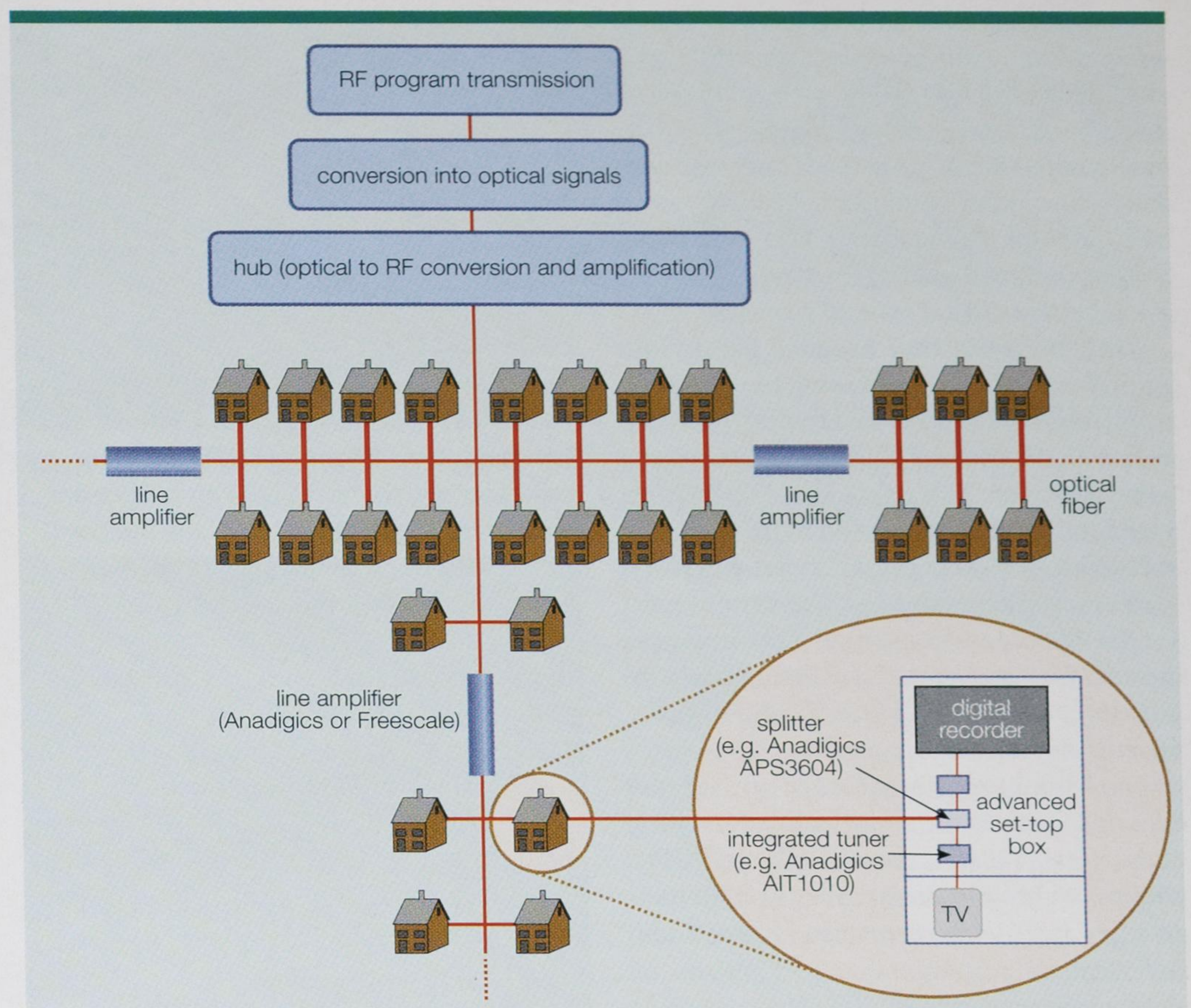
According to Michels, it is the increasing popularity of advanced set-top boxes that are boosting Anadigics' revenue. As the splitter is located at the front end of the set-top box, separate tuners are required for each line after the incoming signal is split. So, for a typical tuner, there could be one splitter, two tuners each containing two separate chips, and occasionally a reverse amplifier that is used to send information back to the headend so that viewers can access interactive services. "That's [up to] six GaAs parts in many of the boxes that are being shipped by Anadigics," said Michels, although he adds that the company is seeing a decline in reverse-amplifier sales.

GaAs beats silicon for noise

Another function of the various splitters and tuners is to amplify the RF signal, says Michels. Although the splitters provide only 4–5 dB of gain, integrated tuners can contribute a further 35 dB. Michels says that this amplification is needed primarily to cater for the large dynamic range of the signal levels entering the box. Gain is only required when the signal is low, which occurs when the distance between the set-top box and the final amplification stage of the CATV broadcast is relatively large.

Anadigics also sells products for CATV infrastructure, such as line amplifiers, to what it describes as the leading supplier of CATV infrastructure and 25–30 second-tier suppliers. These line amplifiers operate over the 50–870 MHz frequency span. The upper end is expected to be extended to 1 GHz to increase the available bandwidth.

Although the upper end of this frequency range is comparable to frequencies used in cellular communications, the amplification requirements are remarkably different. Line amplifiers for CATV infrastructure plug into a mains transformer, and so, unlike mobile-phone power amplifiers, little effort is directed toward improving operating efficiencies. However, CATV amplifiers have to deal with hundreds of different channels, and must



Shipments of GaAs components, which are used throughout the CATV network, are predicted to rise significantly over the next five years. The devices are claimed to offer greater linearity and lower noise than their silicon counterparts.

deliver uniform gain over a broad bandwidth to within a few tenths of one decibel. Line amplifiers must also have low noise levels, because passing several hundred video channels simultaneously through an amplifier can create cross-modulation distortion.

The number of amplifiers installed between hub and home depends on the transmission distance and the number of customers. If the local network serves only 100 homes, then amplification may not be necessary, but most cable systems transmit to 1000–2000 homes, which means that several amplifiers are needed.

GaAs offers more reliability

Aside from greater linearity and lower noise, Michels claims that GaAs amplifiers also offer greater reliability. This is important for its customers because supporting cable networks with only slightly higher failure rates is considerably more expensive.

Another line-amplifier manufacturer is Motorola spin-off Freescale – which targets a small part of its business at CATV. Scott Craft, Freescale's product manager for CATV in the RF division, says that the company pro-

duces hybrid and IC amplifiers for infrastructure applications.

Hybrid amplifiers are driving sales of GaAs components at Freescale. Craft said: "If we look at 2004, the year-on-year increase in GaAs was up 86%, but silicon bipolar was basically flat. The relative share has moved from silicon to GaAs. I would say that, worldwide, more than half of hybrid amplifiers use GaAs right now. That's increasing, and will continue to increase."

Craft identifies lower distortion as the primary advantage offered by GaAs amplifiers over their silicon-bipolar rivals. This characteristic allows transmission of stronger signals, resulting in lower noise and access to a greater dynamic range. "The higher output capability means that you can space your amplifiers further apart, and that has a direct relationship with system cost," explained Craft.

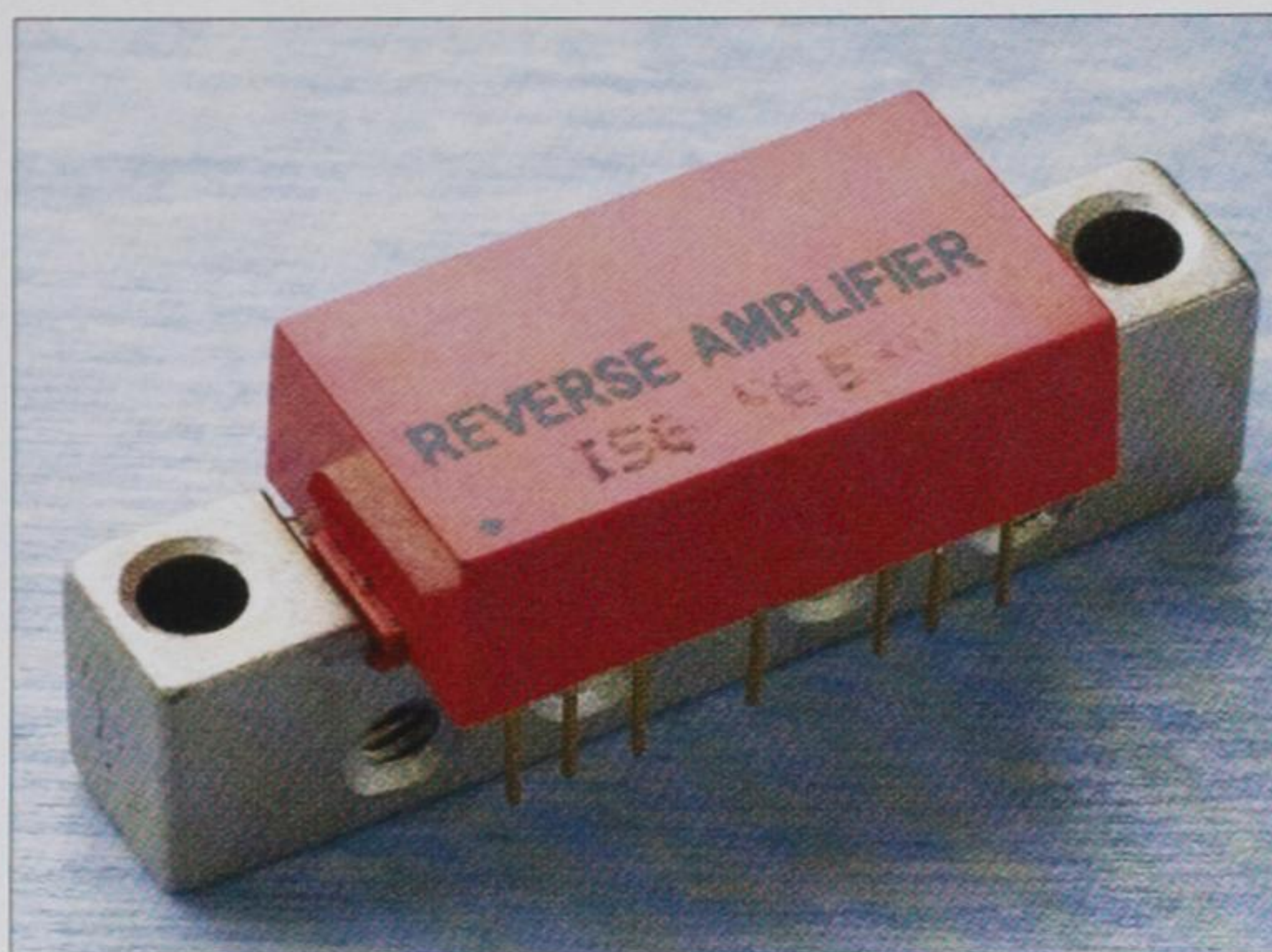
The transition from analog to digital CATV transmission is yet to have a dramatic impact on amplifier requirements, says Craft, because today amplifiers have to support both broadcast formats.

Craft thinks that the CATV market will

expand quickly over the next few years as the network bandwidth grows and transmission is extended to around 1 GHz. "I see CATV going into other countries, but I think you have to be very cautious there," remarked Craft, who adds that in developing countries CATV may never be rolled out, because there are now many options for broadband transmission networks available that did not exist 10 years ago.

Craft believes that broader bandwidth amplifiers will start replacing existing line amplifiers so that CATV networks can keep pace with the fiber-to-the-home systems now being deployed. This upgrade to 1 GHz offers a straightforward way to add more channels, says Craft, who expects steady growth in the GaAs amplifier business. "The overall market for this type of amplifier will grow over the next five years, but it will not be dramatic growth. It will grow for five, maybe 10 years, but will decline further out."

One of the long-term issues with cable, explains Craft, is the significant attenuation of the RF signal at frequencies above 2 GHz, which would limit the number of TV channels that CATV can transmit. However, he



The majority of Sirenza's CATV business is based on silicon. Its reverse amplifiers are used to transmit data back to the headend for interactive services such as pay-per-view authorization.

points out that an all-digital network will allow more channels. If the network operated at frequencies of up to 1 GHz, then with suitable compression 900 channels could be transmitted. That would give viewers a staggering choice of TV channels, although some viewers would have to upgrade their set-top boxes to receive the new transmissions.

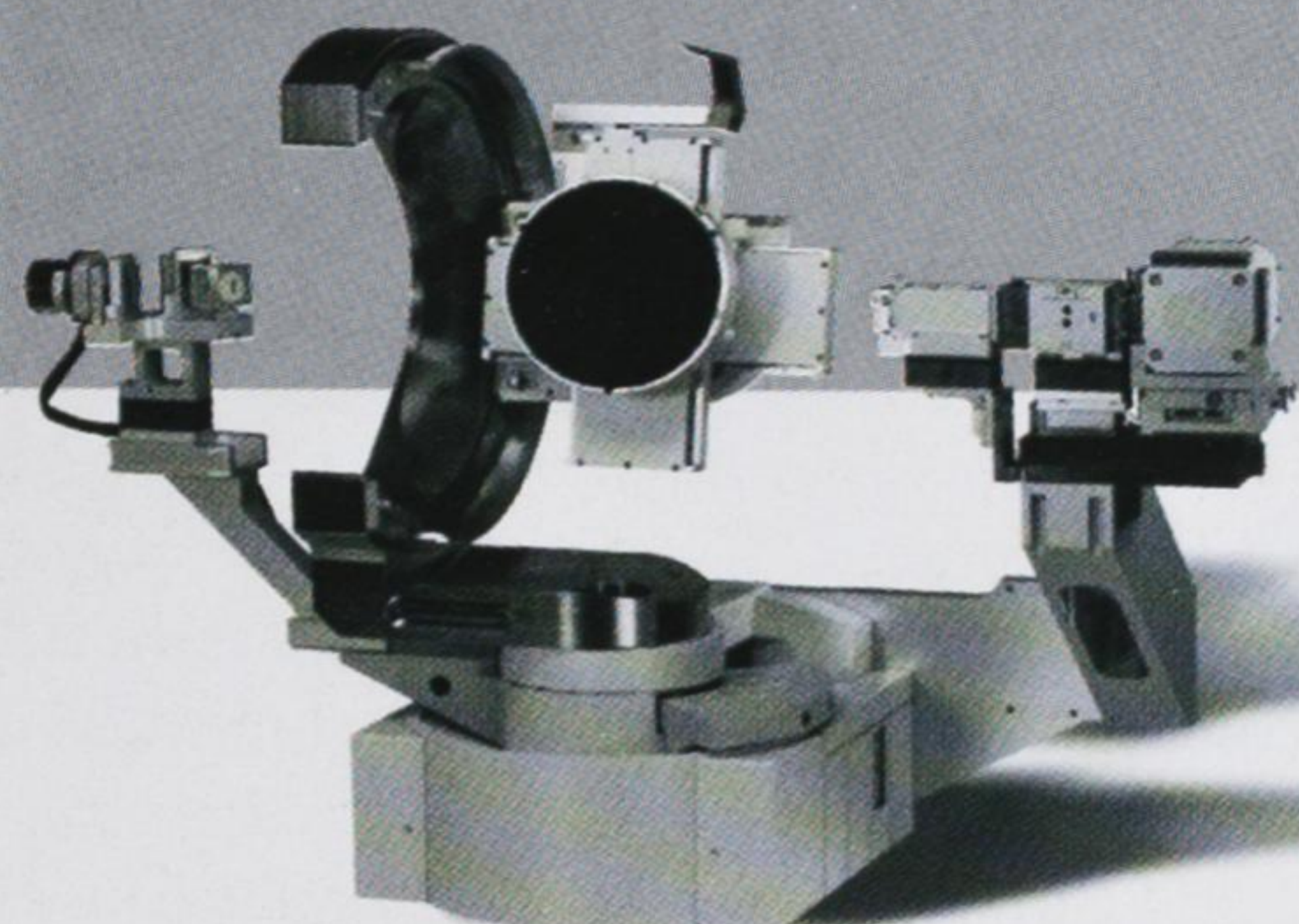
Another US chip maker producing components for CATV is Sirenza Microdevices. According to Dan Wilmot, Sirenza's director of new business development, the firm's CATV business, which is dominated by silicon products, accounts for 3–5% of revenue.

The company is now producing amplifiers and receivers for the return path to the head-end. This path, which gives viewers access to TV-channel guides and allows authorization of pay-per-view content, uses dedicated channels operating at around 80 MHz. Wilmot believes that at these frequencies silicon offers a better performance than GaAs, which can require the addition of bandpass filters to operate in this frequency domain.

Wilmot also believes that the linearity of silicon is good enough for line amplifiers operating at frequencies of up to 1 GHz. "Silicon is sufficiently linear," claimed Wilmot, who disagrees with Michels of Anadigics, and estimates that more than 80% of today's line amplifiers use silicon: "I'm not [aware of] the transition to GaAs myself, but maybe there's something under the radar that I'm not seeing."

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DILUTE-NITRIDE VCSELS

Uncertain future looms for dilute-nitride lasers

Dilute-nitride lasers promise significant cost advantages over their indium phosphide counterparts, but despite this, their future now hangs in the balance following the recent sale of Infineon Technologies' optical-transceiver business to Finisar. **Richard Stevenson** investigates.

Manufacturers of transceiver products for long-wavelength optical telecommunications use lasers based on InP substrates, despite their high cost and fragility. However, 1.3 μm emitting lasers grown on GaAs substrates, with a nitrogen-containing active layer (usually InGaAsN), hold great promise as a cheaper alternative.

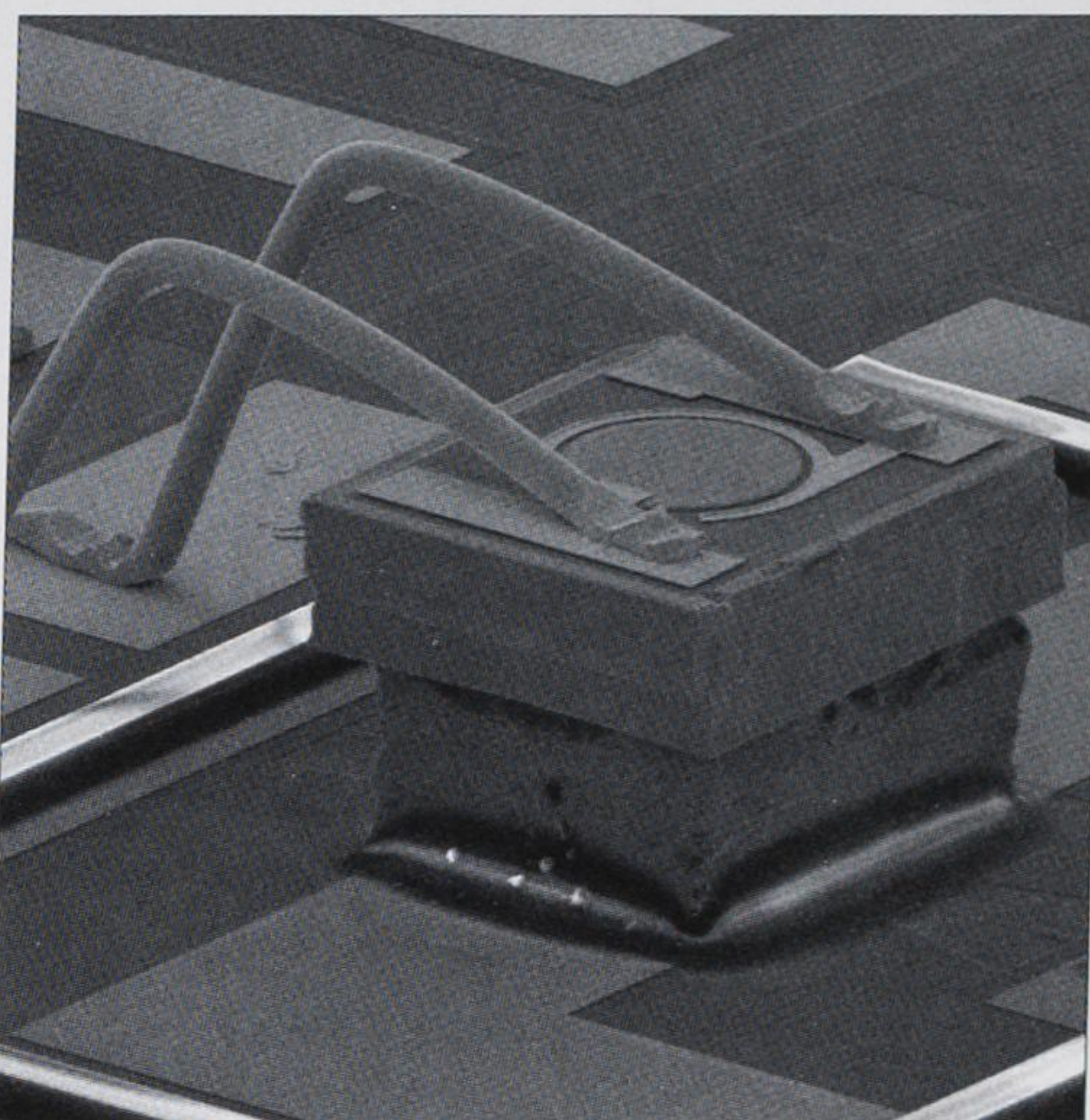
These dilute-nitride lasers can either take the form of edge-emitters, or exploit AlGaAs distributed Bragg reflector technology as VCSELS. This class of emitter also has an intrinsic advantage over InP-based lasers – a higher conduction band offset that is claimed to improve high-temperature performance. Despite these attractive attributes and a significant research effort from academia and industry, dilute nitrides have failed to fulfill their potential, and the material system is still regarded as a difficult one to grow.

Infineon leads the way

One maker of VCSELS containing dilute-nitride active layers is Germany-based Infineon Technologies. The company produces 1310 nm VCSELS at its Munich facility on 4 inch GaAs substrates using MBE growth.

Infineon, considered by many to be the leading exponent of dilute-nitride laser technology, held on to this product range following the sale of its optical-transceiver business to US company Finisar earlier this year (*Compound Semiconductor* March p6). However, the firm is looking for a buyer for its fiber-optic-components business as it does not view this as part of its core activities. Infineon plans to end its involvement in fiber optics by the end of the year.

Ayad Abul-Ella, general manager and vice-president of Infineon's remaining fiber-optics business unit, says that the company started developing dilute-nitride lasers in the mid 1990s. "In 2001, when the bubble burst, cost reduction became a dominant driver in the



INFINEON

Despite the sale of its transceiver business to Finisar earlier this year, Infineon has retained its dilute-nitride technology. It is sampling 1310 nm dilute-nitride VCSEL chips that it claims are ideal for 4 Gbit/s transmission rates over distances of 10 km.

industry. We saw our 1310 nm VCSEL technology as one enabler for cost reduction, and invested heavily from 2001 onwards," said Abul-Ella. This year the firm completed lifetime testing and chip qualification, and produced engineering and qualification samples, but it has not moved into volume production.

Abul-Ella says that Infineon's 1310 nm dilute-nitride VCSELS are cheaper to manufacture than equivalent emitters containing a distributed feedback (DFB) structure. He thinks that the technology could also replace Fabry-Pérot lasers for longer-distance transmission, but cost savings would be modest.

Growing dilute-nitride VCSELS involves a series of trades-offs between achieving a wavelength close to 1310 nm, obtaining a suitable bandwidth, producing sufficient output power, and fabricating a design that can couple sufficient light into an optical fiber.

Abul-Ella says that the greatest of these challenges is getting the right wavelength while coupling sufficient light into the fiber. Many researchers fall short of this target.

Infineon's dilute nitrides have to operate at temperatures of up to 85 °C and comply with internationally recognized standards for optical carrier systems operating at data rates such as 155 and 622 Mbit/s, and 2.5 Gbit/s. Abul-Ella explains that the firm achieves the best all-round performance for its devices by targeting an emission wavelength for its lasers of 1300 nm, which falls within the specifications for the 1310 nm standards. Infineon has qualified its process for lasers operating at data rates of up to 2.5 Gbit/s, and has also produced prototypes that can operate at 10 Gbit/s, although these do not yet conform to the necessary specifications. Abul-Ella says that the company has encouraging data on its 2.5 Gbit/s laser chip, including 5000 hours of laser qualification.

The same performance for less

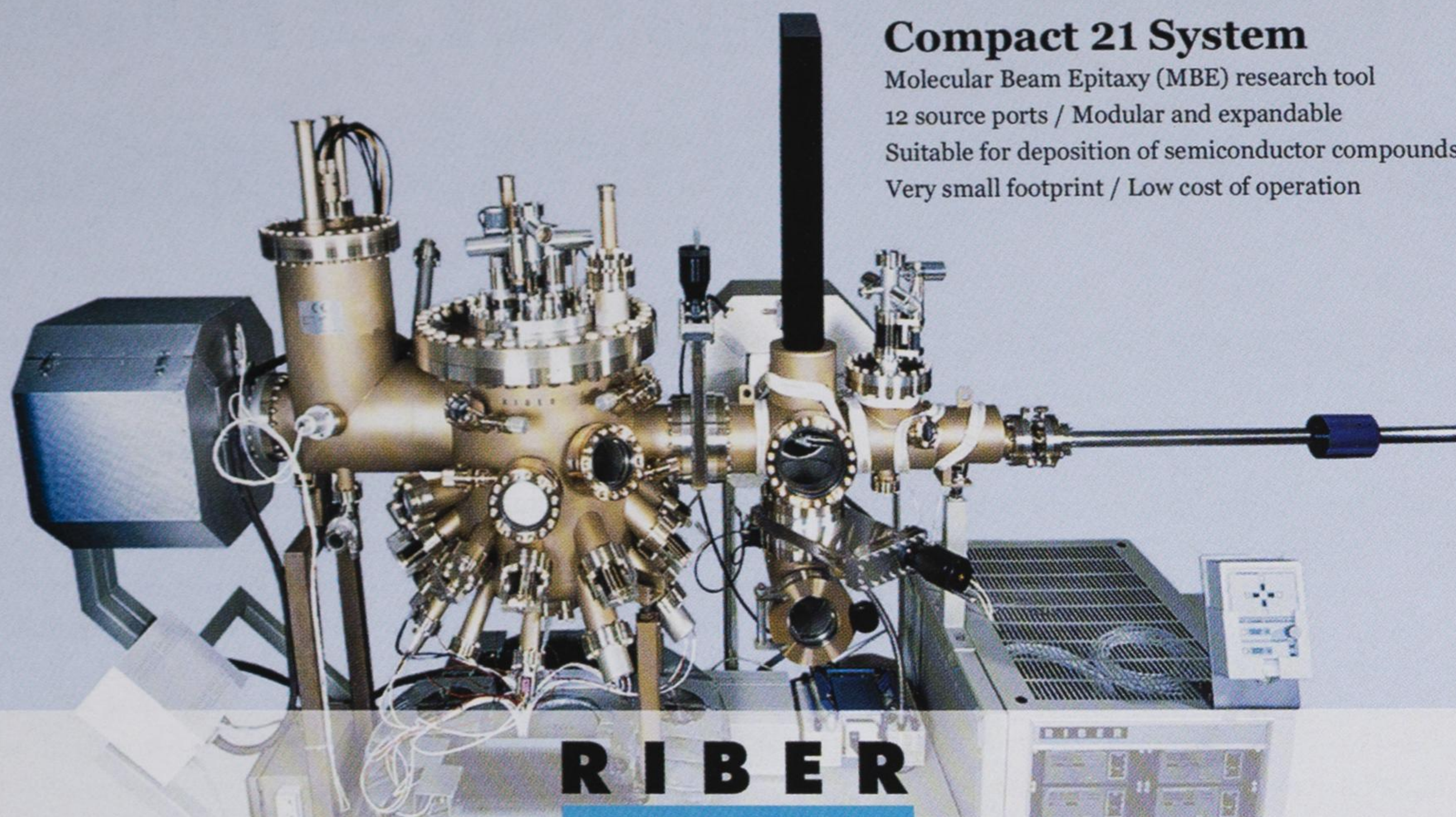
Abul-Ella believes that the first application genuinely demanding dilute-nitride VCSEL technology could be 4 Gbit/s FibreChannel. He claims that this standard can be used in applications requiring transmission through up to 10 km of fiber, which rules out the use of Fabry-Pérot lasers. "The technology generally used is DFB lasers from the likes of Sumitomo," said Abul-Ella. He claims that Infineon's VCSELS are one-third to one-half the cost of the 4 Gbit/s DFB lasers that sell for at least \$20-\$30, while meeting the same specifications.

Abul-Ella explains that efforts must now be directed at chip packaging, which has a big effect on the coupling efficiency of the light into the fiber. However, since Infineon is exiting the fiber-optics business, the company has ceased to invest in the 1310 nm VCSELS that it has spent 10 years developing. →

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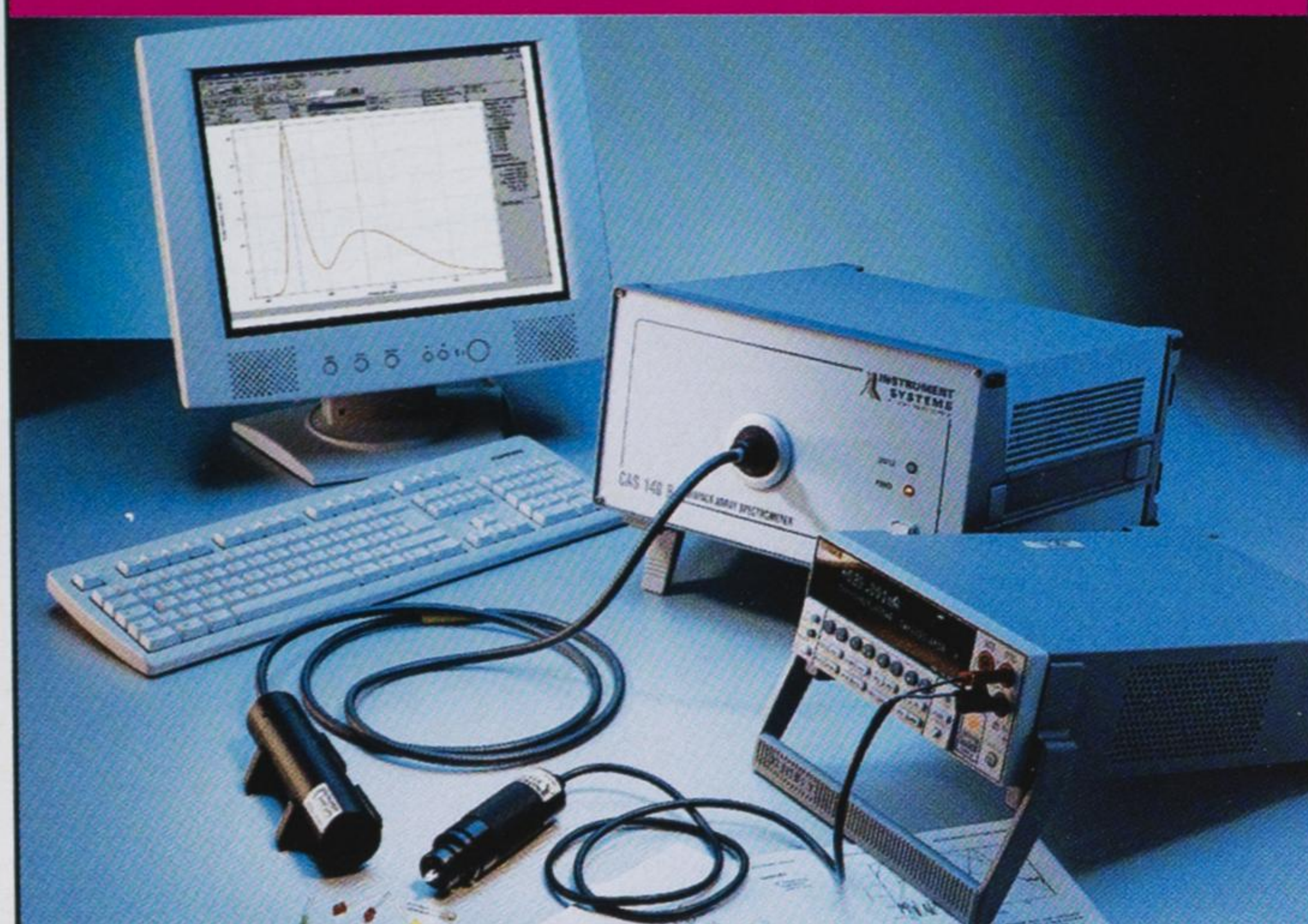


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Chungwa circumvents contamination of the dilute-nitride layer

Although Chungwa has now dropped its dilute-nitride development program, its researchers achieved significant improvements to the quality of the active InGaAsN layer.

Yeh and co-workers thought that the InGaAsN layer was being contaminated by the underlying AlGaAs layers, and confirmed this by comparing a dilute-nitride active layer deposited directly onto a GaAs substrate with one grown on an aluminum-containing layer; the photoluminescent intensity (PLI) of the material grown on the aluminum layer was one-hundredth the strength of that grown on the GaAs substrate. The researchers believe that the contamination is due to aluminum's strong "memory effect" (aluminum remains in the growth cell for too long) and the strength of the aluminum-nitrogen bond.

Two routes to growing dilute-nitride structures were explored

(a) standard structure

200 nm Zn-doped GaAs
1.5 μm Zn-doped AlGaAs
150 nm GaAs
6 nm InGaAsN QW
150 μm GaAs
1.5 μm Si-doped AlGaAs
300 nm Si-doped GaAs buffer
Si-doped GaAs substrate

that avoid contaminating the active layer with aluminum. The variations from the standard process (a), are removal of the wafer part way through the growth (b), and nitride passivation to reduce aluminum contamination after growth of the AlGaAs and GaAs layers (c).

The researchers found that the two-step process (b) shortened the emission wavelength, but increased the PLI to a value above that of the control sample, an InGaAsN

(b) two-step process

200 nm Zn-doped GaAs
1.5 μm Zn-doped AlGaAs
150 nm GaAs
6 nm InGaAsN QW
140 nm GaAs
wafer inserted into chamber
1.5 μm deposition of GaAs
wafer removed from chamber
10 nm GaAs
1.5 μm Si-doped AlGaAs
300 nm Si-doped GaAs buffer
Si-doped GaAs substrate

quantum well grown directly onto a GaAs substrate.

The nitrogen-passivation approach (c) offers a shorter growth time, lower gas costs through reduced material deposition, and greater simplicity, as the wafer remains in the reactor throughout the growth period. The extent of the contaminating aluminum and carbon levels in the InGaAsN layer were determined by secondary-ion mass spectroscopy, which allowed

(c) passivation approach

200 nm Zn-doped GaAs
1.5 μm Zn-doped AlGaAs
150 nm GaAs
6 nm InGaAsN QW
100 nm GaAs
Flow of $\text{AsH}_3 + \text{DMHy}$ into reactor
50 nm GaAs
1.5 μm Si-doped AlGaAs
300 nm Si-doped GaAs buffer
Si-doped GaAs substrate

the researchers to adjust the flow of dimethylhydrazine so that the PLI from this structure equaled that of the control.

Standard photolithography and wet-chemical etching produced 10 μm -wide ridge waveguide lasers. At room temperature pulsed operation (2 μs pulses, 2% duty cycle), the nitride passivation and two-step growth lasers produced 1262 and 1234 nm emission, respectively, and external quantum efficiencies of 58%.

One drawback of the technology is that the yields associated with dilute-nitride device production are not particularly high. However, this has never been a major focus for Infineon, because high-volume production is yet to happen. Abul-Ella does point out, though, that yields must remain reasonable (typically more than 30%) to ensure a stable process, and if volumes increase then yields will improve.

Taiwanese competition

Another company that has been developing 1.3 μm dilute-nitride lasers is Taiwan-based Chungwa Telecom. At the Indium Phosphide and Related Materials conference in Glasgow, UK (see box), Nien-Tze Yeh, a researcher at Chungwa's advanced technical research laboratory, outlined Chungwa's development of lasers emitting at 1.26 μm . He says that when additional nitrogen was added to the quantum well to push emission to 1.3 μm , the crystal quality of the InGaAsN active layer deteriorated and no laser emission was seen. Yeh believes that laser emission could be possible, however, by inserting either GaAsN or

InGaAs layers into the structure.

According to Yeh, several difficulties exist for dilute-nitride growth: nitrogen-incorporation efficiency is low, crystal quality deteriorates with nitrogen incorporation, and it is challenging to grow good-quality InGaAsN layers on top of the aluminum-containing layers that are usually used for cladding regions. As a result, Chungwa is to stop its dilute-nitride laser program and focus on InP-based 1.3 μm emitters. The company is now developing 1.3 μm , 10 Gbit/s DFB lasers, which it intends to release by the end of this year.

10 Gbit/s modulation from edge-emitting dilute-nitride lasers operating at 1.3 μm has been demonstrated by researchers at France's Centre National de la Recherche Scientifique, working in conjunction with the III-V lab owned jointly by Alcatel and Thales. The team used MBE growth to produce structures with three $\text{Ga}_{0.63}\text{In}_{0.37}\text{N}_{0.01}\text{As}_{0.99}$ quantum wells, 7 nm thick, surrounded by 100 nm-thick GaAs barriers. The cladding regions contained *n*- and *p*-doped 1.5 μm -thick $\text{Al}_{0.8}\text{Ga}_{0.2}\text{As}$, as well as thin layers next to the active region

that graded the aluminum content to zero.

The processed lasers contained a 2 μm -wide ridge, typically emitted at 1335 nm, and showed a threshold current density of 1.1 kA cm^{-2} when operated at 20 °C in pulsed mode. One of these MBE-grown lasers, which emitted at 1346 nm was able to produce 2.5 Gbit/s transmission rates along 2 km of fiber at up to 85 °C, and data transfer reached 10 Gbit/s at 25 °C. The researchers have also produced single-quantum well devices with 1.5 μm -thick InGaP cladding regions by MOCVD that deliver 2.5 Gbit/s transmission rates at up to 85 °C.

The French team's results, along with those of Infineon, show that dilute nitrides can compete with their InP rivals. However, with Infineon no longer owning a transceiver unit, and Chungwa ditching the technology altogether, the near-term future of dilute-nitride lasers looks decidedly unpromising. ●

Further reading

Yeh *et al.* IPRM Con. Proc. 2005.

Dagens *et al.* 2005 IEEE Photon. Technol. Lett. 17 p971.

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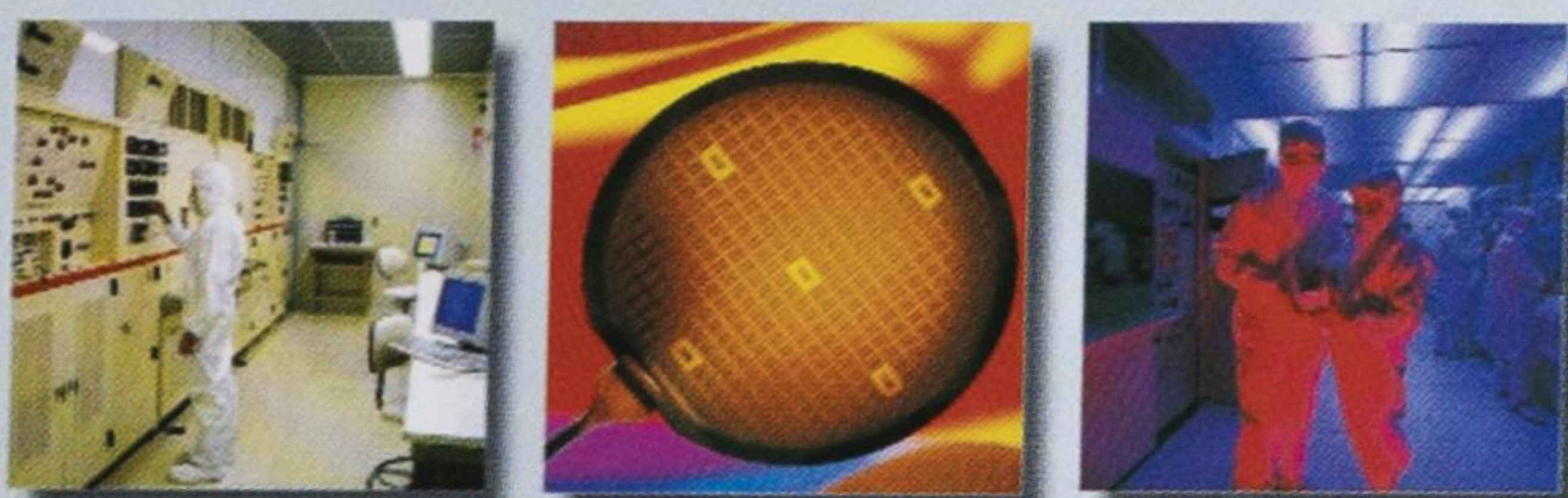
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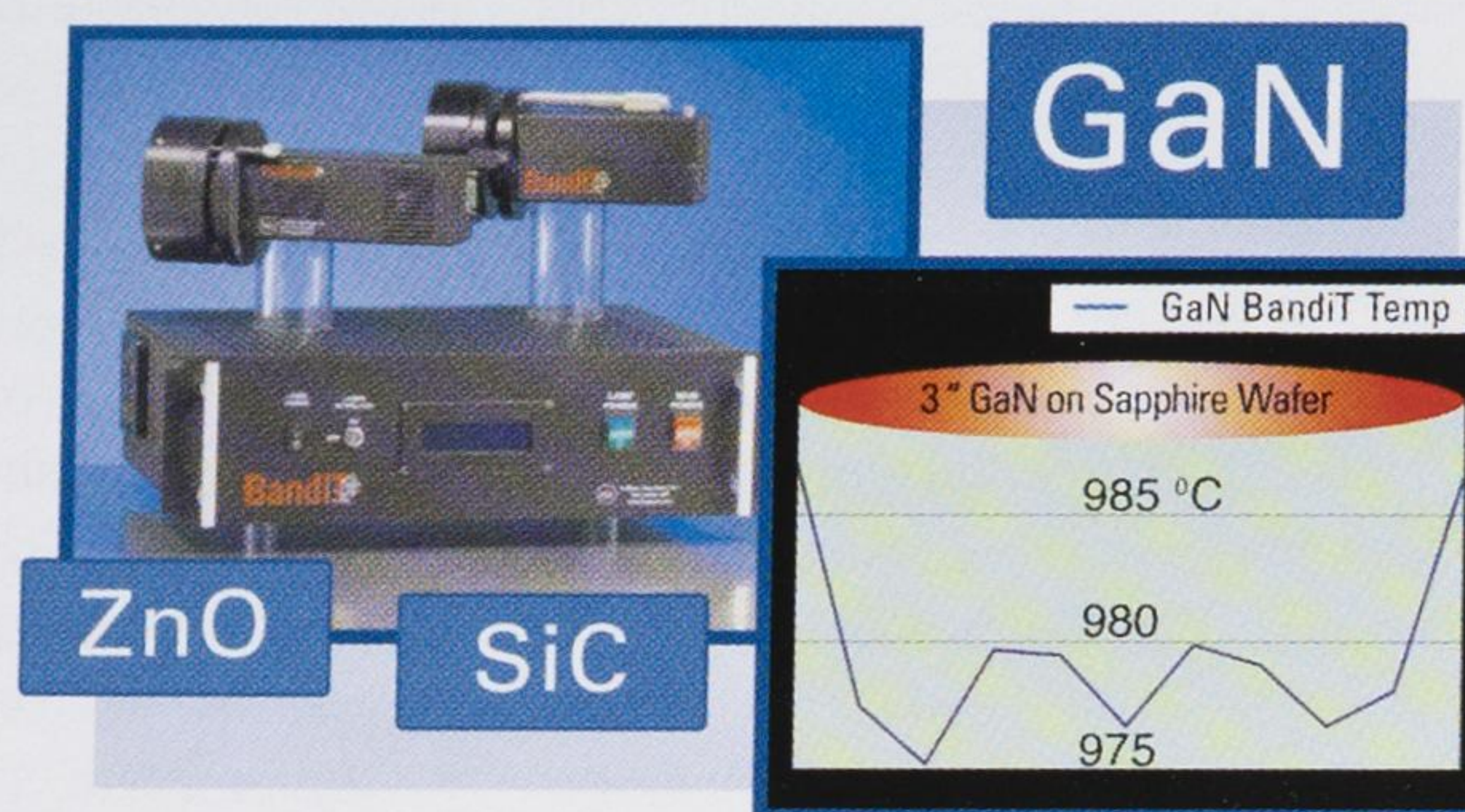
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Rising patent awards hint at a future increase in litigation

With Nichia settling a number of recent disputes concerning unauthorized suppliers and Cree issuing licenses under its own white-LED patents, it might appear that the nitride LED intellectual property “wall” is indeed crumbling. But not everybody agrees, as **Michael Hatcher** discovers.

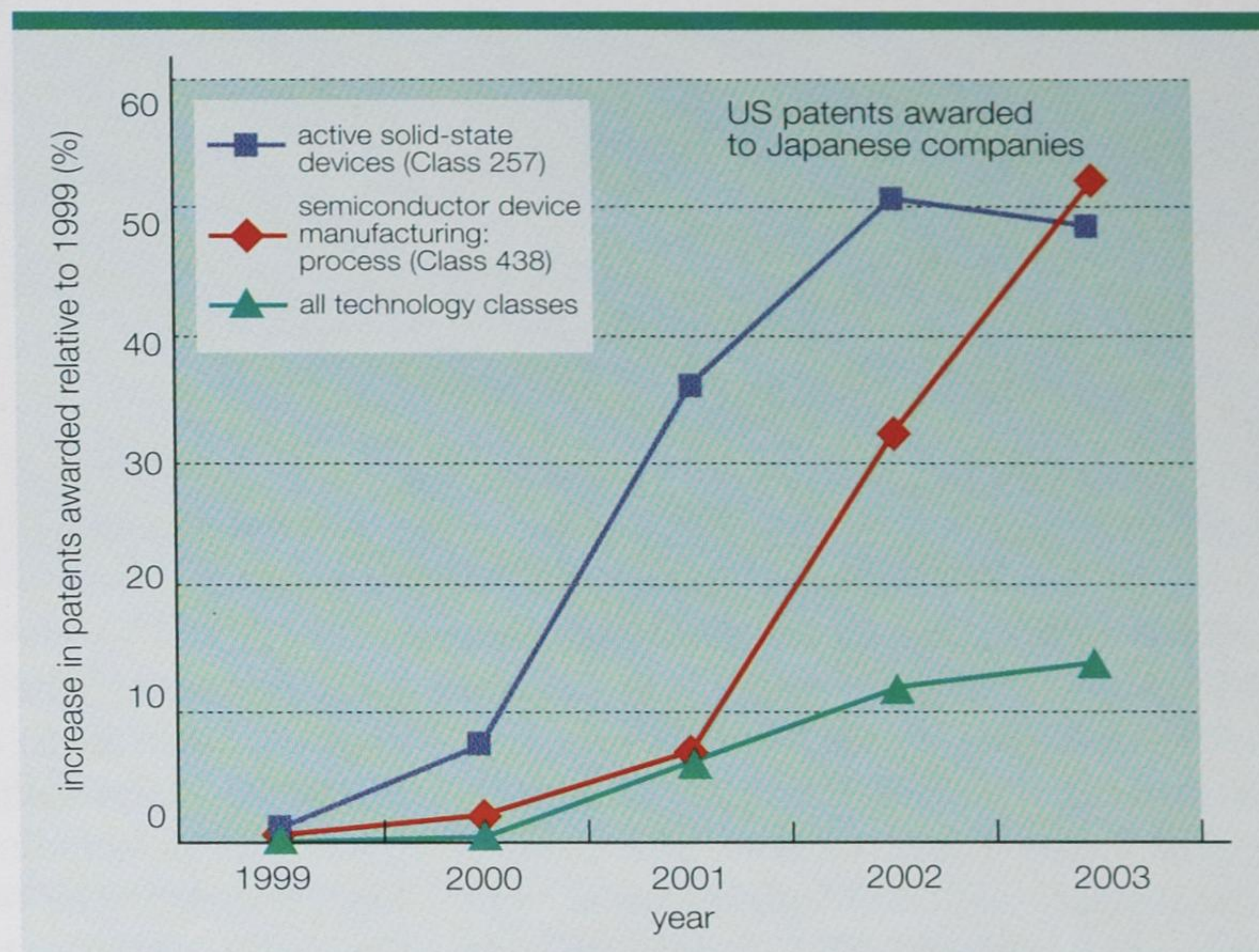
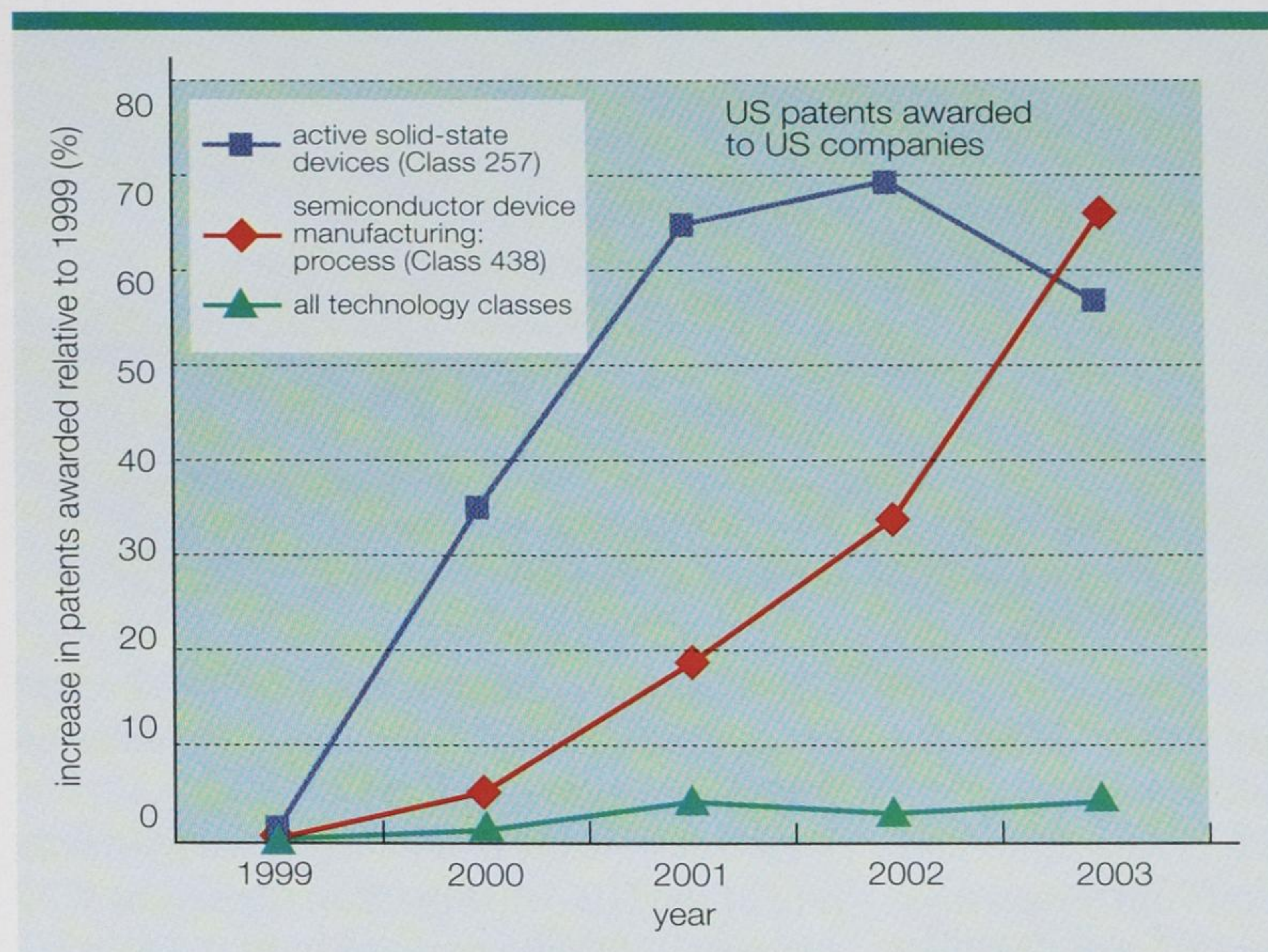


Fig. 1. In the past five years, growth in the number of US patents awarded in classes “257” and “438” have far outstripped that in technology classes overall. According to patent-law specialist Patricia Martone, this means that HB-LED manufacturers should brace themselves for more litigation in years to come as the field expands in a repeat of the tactics already employed in the silicon industry.

So far this year, LED manufacturers seem to be entering something of a “truce” period over their intellectual property (IP) rights, with the number of cross-licensing deals and settlements outweighing new litigation activity.

One example is Cree’s recent decision to license a key white-LED patent to three firms in the Far East, which could mark a watershed in the evolution of solid-state lighting.

One of those three firms now able to sell white LEDs incorporating Cree’s InGaN-on-SiC dice is Cotco Holdings, which is based in Hong Kong. Shortly after signing the deal, Cotco announced that it had already seen a big increase in white-LED sales and that it expected Chinese manufacturers of products containing white LEDs to fuel a strong upswing in demand.

Cotco’s white LEDs will now be labeled with the all-important US patent number (6,600,175) and the message “powered by Cree”. This branding approach is highly rem-

iniscent of the “genuine Nichia LED” labels adorning products featuring the Japanese company’s white emitters that were introduced exactly one year ago.

If Cotco’s predictions are accurate, there could be a surge in business from China, with some commentators suggesting that the wall of intellectual property that has previously separated LED makers is now “crumbling”.

Calling a truce

Cree and Nichia seem to have set the tone when they announced early this year that the two companies had signed an extended cross-license agreement specifically covering white LEDs. In the past few months, Nichia has resolved litigation with US retailer Sharper Image, Korea’s Luxpia, and, most recently, US companies JM Group and ASP Inc.

But at the recent Blue 2005 conference in Hsinchu, Taiwan, patent-law specialist Patricia Martone suggested that while one part of the IP wall relating to LEDs may be crumbling,

more lawsuits are inevitable as the solid-state lighting industry grows in size, and litigation becomes a more attractive business tool.

Martone, who is a partner in the Fish & Neave IP group of Boston law firm Ropes & Gray, says that the LED industry’s patent strategy looks very similar to that of the wider semiconductor world. As a result, it is perhaps instructive to look at the developments that took place in the silicon industry when it underwent major expansion.

While initially there was a “patent peace”, with cross-licensing agreements to ensure that early silicon-device manufacturing could get off the ground without concerns over IP violations, this came to a halt in the 1980s when chip sales revenues became large enough to make expensive lawsuits look like an attractive business ploy.

“Beginning in the mid-1980s, Texas Instruments (TI) began an aggressive licensing program to generate needed revenue,” said Martone. “Prior to that, semiconductor firms

regularly entered into royalty-free licenses.”

TI has since made billions of dollars from this policy, which has reportedly netted the firm \$1 billion over 10 years with Hyundai alone. Similarly, IBM initiated its own licensing program in the early 1990s and increased its annual royalty revenue from just \$50 million in 1988 to around \$2 billion by 2002.

Martone has noted a rapid recent increase in the number of US patents filed into the Class 257 and Class 438 patent sectors that respectively cover LED technology and the manufacturing processes used to make the devices (figure 1). Much of this activity has taken place outside the US, with Japanese firms being issued with almost as many Class 257 US patents as their domestic colleagues over the past five years. Next down the list is Taiwan, while Martone expects awards to Chinese companies to surge in the future.

Litigation on the rise

While this shows that innovation is strong in the LED industry, it also indicates that litigation is likely to become an even more effective business tool in the future. And despite the recent cross-licenses and settlements, German firm Osram is enforcing its own IP against Japan-based Citizen Electronics. Citizen makes white LEDs under license from Nichia, and although Nichia and Osram have signed a cross-licensing agreement, it does not give third parties such as Citizen free access to Osram's technology.

Martone warns manufacturers that litigation will increase in the future, suggesting that firms not currently regarded as a threat, perhaps not even device manufacturers, will emerge to issue legal proceedings. “Companies not on your competitive radar screen may sue you to generate licensing revenue,” she said.

While various elements of the LED industry face the prospect of more lawsuits, it looks like packaging and phosphors are the primary target of 2005 litigation, with less of a focus on chip-manufacturing technology.

Adams Harkness analyst Jed Dorsheimer, also speaking at Blue 2005, made his own predictions for 2005 and beyond. He expects to see more strategic relationships evolve, as a way to marry the high cost of technological innovation with low-cost volume manufacturing.

Dorsheimer and Martone both say that the current difficulties over patent enforcement in China will be reformed in years to come, as political pressure is applied from other countries and local judges gain experience in IP law.

Hans Mosemann from US investment com-

Table 1. Issued US patents (Class 257: active solid-state devices)

Country	Year				total
	2000	2001	2002	2003	
US	1093	1232	1388	1724	5437
Japan	1052	1103	1366	1575	5096
Taiwan	190	225	282	303	1000
South Korea	140	147	206	244	737
Germany	77	91	111	149	428
China	0	1	0	5	6

Source: US Patent and Trademark Office

Table 2. Issued US patents (Class 438: semiconductor device manufacturing processes)

Country	Year				total
	2000	2001	2002	2003	
US	2000	2451	2510	2317	9278
Japan	887	1118	1240	1225	4470
Taiwan	945	1170	753	606	3374
South Korea	349	454	483	456	1742
Germany	84	105	112	140	441
China	1	0	1	2	4

Source: US Patent and Trademark Office

pany Moors & Cabot also made some predictions at the Taiwan event. Mosemann, who is a senior analyst and has covered key compounds firms including Cree, Anadigics and Skyworks during his time on Wall Street, says that there will be “significant” consolidation in the Asian LED industry as chip packagers and the “big five” global LED firms agree partnerships, set up joint ventures and establish vertical business models.

“The IP wall is no longer a wall,” Mosemann told delegates in Hsinchu. “One year ago, this wall began to crumble as the top five [HB-LED manufacturers] started to license white-enabling technology.” The analyst believes that Asian players now have all of the necessary elements not only to make and sell devices, but also to drive innovation in the global HB-LED market.

According to Mosemann, Wall Street does not consider the compound semiconductor field to be a particularly desirable one currently, and many institutional investors with large portfolios of blue-chip firms tend to regard the HB-LED sector in the same light, despite some very different market drivers. Some investors even compare the HB-LED industry to highly commoditized silicon markets such as that for dynamic random access memory (DRAM) chips.

Mosemann takes another view: “HB-LEDs are not like standard DRAMs. In DRAM, whoever has the biggest fab wins.” In contrast,

HB-LED manufacturers serve diverse markets and chip design is a major differentiator from supplier to supplier.

And despite the inevitable slowing growth rate of the HB-LED market, the sector will still expand twice as quickly as the overall semiconductor field, he says. As a result, Mosemann predicts that institutional investors in the US will increase their interest in the HB-LED sector in the coming years as the business matures.

Fertile ground

Mosemann says that while the days of the cellphone handset as the major GaN LED market driver are beginning to end and therefore the days of 50% annual growth rates will soon be over, the HB-LED sector remains an attractive one for the investor community.

Although Mosemann, whose company currently has a “sell” rating on Cree stock (meaning that it expects the company's share price to underperform the market in the next 12–18 months), is expecting something of a lull in LED demand this year, he believes that investors will be keen to cash in on the growth of applications such as the backlighting of large LCD screens. In addition, the blue laser field – which shares much of the same manufacturing requirements as GaN LEDs, and in which Nichia, Cree and Osram are also likely to dominate – is seen as a fertile area for future investment. ●

Fluorescent substrate offers route to phosphor-free LEDs

Using a phosphor to convert blue emission from an LED chip into white light fundamentally limits the efficiency of solid-state lighting. Now, a research team in the US is looking to remove the need for phosphors by using fluorescent, doped-zinc-oxide substrates instead, as **Jeff Nause** explains.

The relative immaturity of native gallium nitride (GaN) substrates currently limits high-quality GaN epitaxy for LEDs. One alternative material that ought to provide a better substrate solution is zinc oxide (ZnO). There are two reasons for this: ZnO offers better lattice-matching between the epilayer and substrate; and the material makes new device configurations feasible.

Better matching arises because ZnO shares the same hexagonal crystal structure and "P6₃mc" crystallographic space group as GaN and indium gallium nitride (InGaN). As a result, the lattice mismatch between ZnO and pure GaN is only 2.2%, while there is a perfect lattice match between ZnO and InGaN with an 18% indium content.

Furthermore, ZnO is conductive. This means that a bottom-contact device can be easily fabricated from the material – something that is not an option for the current generation of sapphire-based LEDs. While ZnO presents these obvious advantages, several technological hurdles remain to be overcome before the material gains acceptance as a useful substrate.

First and foremost is the fact that atomic hydrogen and dissociated ammonia both attack ZnO. Since these species are present in large concentrations during standard MOCVD growth of GaN and InGaN, alternative methods or gases must be used.

Under a project valued at \$4.8 million that has been funded to the tune of \$3.8 million by the US Department of Energy, Cermet and Georgia Tech's Ian Ferguson and Alan Doolittle are working on an LED technology that exploits the fluorescence of doped ZnO. The potentially disruptive result would be phosphor-free solid-state light sources.

The aim of the project is to integrate large-area ZnO fluorescent substrates with state-of-the-art, lattice-matched nitride epitaxy to address the various technological limitations of current approaches to solid-state lighting.



Fig. 1. Cermet has produced these ZnO substrates with a range of dopants to induce self-fluorescence. Eventually, this could lead to the fabrication of high-efficiency, phosphorless white LEDs. With a defect density of only $1 \times 10^4 \text{ cm}^{-2}$, the lattice-matched InGaN that has been grown on this ZnO should result in high-performance nitride devices.

Using established nitride-deposition technology, white light could be produced by self-luminescence in the doped ZnO substrate. Blue emission from the GaN material would excite the fluorescence in doped ZnO, and the emission spectra of the fluorescence and the original blue emission could then be controlled to produce the desired white output.

Technical challenges

Several technological steps were identified as critical milestones for this approach to solid-state lighting to be successful. The first was the development of high-quality, doped ZnO to act as a nitride-matching substrate and as a luminescent light source. This required the production of commercial grade, doped ZnO substrates that combined excellent crystal quality with optical transparency in the visible spectrum.

The second key challenge was to deposit low-defect-density nitride structures on the doped ZnO substrate. If successful, this would yield lattice-matched nitride layers grown on ZnO substrates with excellent crystal and optical quality.

To date, the project has yielded impressive results regarding both of these developments. In meeting the first challenge, Cermet has pro-

duced large-diameter doped ZnO (figure 1) that generates light when stimulated thanks to the kinds of dopants that are incorporated into the crystal.

In tackling the second material challenge, the team demonstrated defect densities of around $1 \times 10^4 \text{ cm}^{-2}$ for lattice-matched InGaN on ZnO. This is an important milestone as it shows that the low defect density inherent in the bulk substrate can be replicated in the active nitride layers. This should improve LED performance by reducing non-radiative decay mechanisms in the active layers.

As well as the projected energy savings that all solid-state light sources offer, this self-fluorescence approach has the potential to further drive down the cost of white LEDs. Using a self-luminescent substrate should allow production of a white-light emitter without the need for a traditional phosphor.

Such a device would eliminate much of the cost, complexity and decreased yield associated with the traditional phosphor approach. LED efficiency would be enhanced by reducing the defect density in the emitters, and by increased blue-white light conversion efficiency through enhanced luminescence directly from the substrate. Costs would be driven down through cheaper bulk substrate

ZnO initiatives and US Department of Energy projects

Cermet and Georgia Tech's approach to solid-state lighting is just one of several projects that have received generous funding from the US Department of Energy (DoE). The DoE's Energy Efficiency and Renewable Energy project portfolio for the development of solid-state lighting, published in January this year, details a host of programs that are primarily focused on novel chip manufacturing and phosphors.

The Piscataway, NJ, firm Structured Materials has been working on ZnO deposition on a variety of substrate materials for several years now, and is looking at ways to make blue or near-ultraviolet LEDs based on ZnO *p-n* junctions. While *n*-type ZnO material is relatively easy to make, this is not true for *p*-type ZnO and this is one focus of current research at the firm.

Gary Tompa, formerly at Emcore and the president of Structured Materials, says that his team has successfully deposited the material on 2 inch ZnO substrates. The advantages of ZnO over GaN



Structured Materials is selling an MOCVD system, which is specially developed for ZnO deposition, to commercial and research customers.

include the use of relatively benign process gases that are easier to handle and dispose of than the highly toxic ammonia that is generally used for nitride growth. In addition, growth can take place at a much lower temperature.

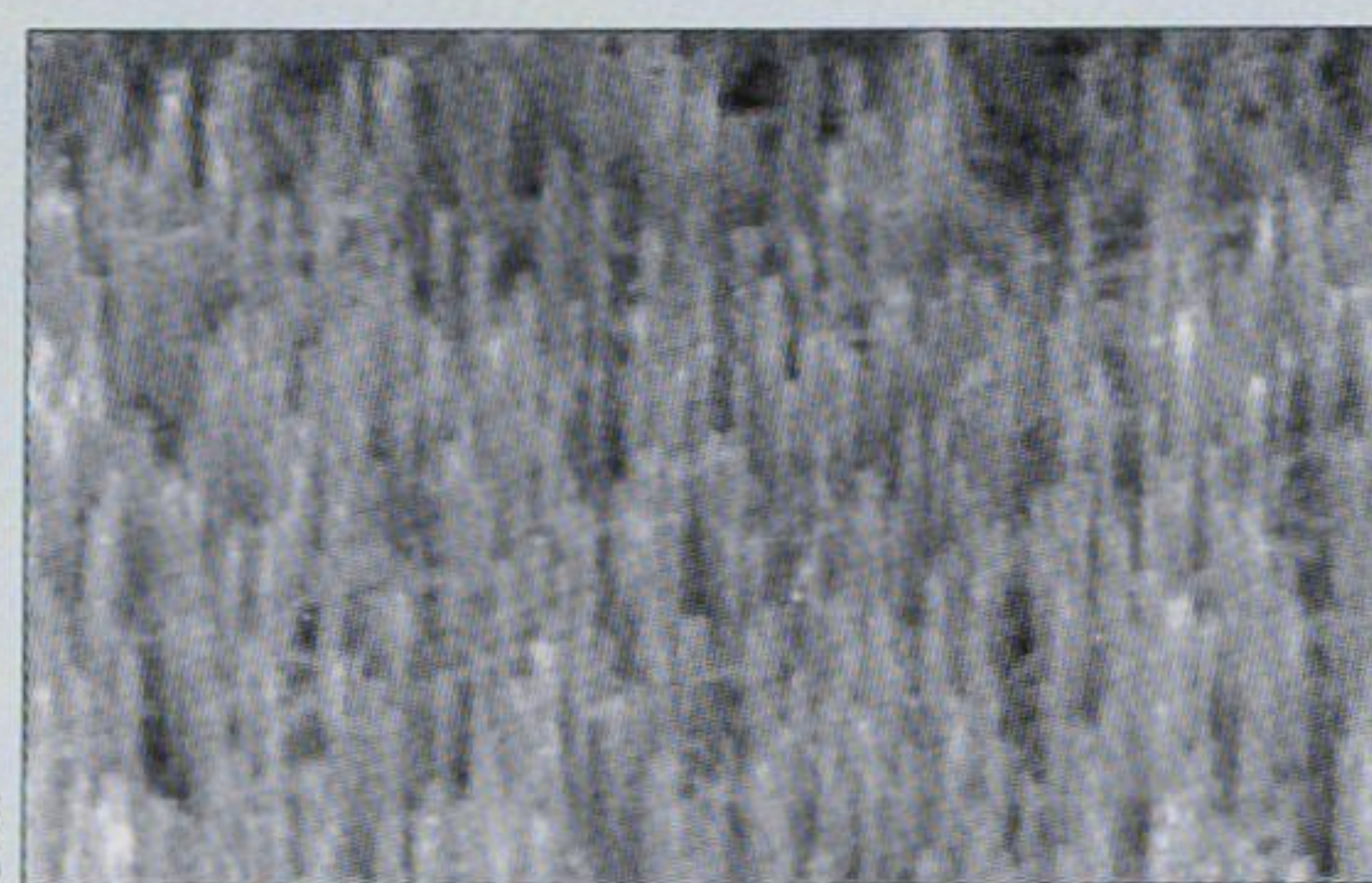
Structured Materials has been focusing on oxide growth for the past five years or so, and has recently sold MOCVD tools for ZnO film growth to commercial customers for use in applications involving

superconductors and ferroelectrics.

ZnO-based blue LED development is still in its infancy, although blue-light output has been recorded by a group at Tohoku University in Japan.

Using their specialized MOCVD technology, Tompa and colleagues have also demonstrated ZnO nanowire growth. Nanowire structures may be of use in future chemical sensors, transparent transistors and possibly LEDs.

In other ZnO-related DoE efforts, a University of Florida



Devices containing nanowires can be fabricated by growing ZnO films on a ZnO substrate using diethyl zinc and oxygen as source materials. Such devices could find applications in chemical sensing, LEDs and transparent transistors.

team led by David Norton is developing devices featuring ZnO-based junctions. Under a \$1.1 million project, Norton and colleagues are working on key issues such as achieving high *p*-type carrier concentrations in epitaxial ZnO alloyed with magnesium. They are also hoping to make homojunctions and heterojunctions with band-edge emission.

Meanwhile, the company ZN Technology (ZNT) in California has also been working to develop ZnO-based LEDs under a Phase 1 small-business innovation research effort.

Principal investigator Gene Cantwell at ZNT has patented a method for the *p*-type doping of ZnO. Using ZNT's own ZnO substrates, Cantwell is developing LEDs incorporating a cadmium zinc oxide quantum well and magnesium zinc oxide barrier layers.

In this device configuration, a phosphor is required to generate white light. Cantwell also has plans to make ZnO-based lasers emitting in the blue and near-ultraviolet region.

growth and the elimination of phosphors. Lastly, economies of scale can be met by using large-area melt growth technology to fabricate ZnO substrates, and existing volume GaN epitaxy solutions.

Integration challenge

Having met the initial technological challenges, the remaining problem is to integrate these two achievements and fabricate a white-light LED. These emitters demand high carrier concentrations in both *n*- and *p*-type layers in the diode, as well as quantum-well compatibility and wavelength-tunable emission.

The precise nature of the light emitted by white LEDs is an important issue, and is often defined by the color temperature. By employing this self-fluorescence approach, there are two ways to control color temperature. Since the white light emitted is actually a combination of the blue "pump" emission from the

ZnO offers better lattice-matching between the epilayer and substrate; and makes new device configurations feasible.

GaN material and the substrate's fluorescence, there are two control mechanisms available.

The pump wavelength can be tuned at the chip level by growing structures emitting at longer wavelengths suitable for optically pumping bulk ZnO with a fixed dopant content. Alternatively, the dopant content in the bulk ZnO can be tuned to fit a fixed pump wavelength. By tweaking both of these variables it is possible to cover a broad range of "white" color content.

To date, the greatest technical challenge in this LED development has been to prevent

hydrogen reacting with the ZnO substrate. The alternative approach has been to use nitrogen as the carrier gas instead, to employ lower growth temperatures and to shield the substrate. An additional option is to develop alternative sources of nitrogen. Compounds with a significantly lower dissociation temperature than ammonia would allow lower growth temperatures to be employed.

At the conclusion of this project in October 2006, Cermet plans to market the developed technology to the semiconductor lighting industry. The product offerings are set to include lattice-matched device layers integrated onto Cermet's doped ZnO substrates. It is Cermet's intent to develop revolutionary LED sources for solid-state lighting that will become an industry standard.

Jeff Nause is president of Cermet Inc. E-mail: jnause@cermetinc.com.

Investment firm shakes up Unaxis management

Swiss process equipment supplier Unaxis has appointed Thomas Limberger as its new CEO, at the request of the company's major shareholder, Austrian investment firm Victory Industriebeteiligung.

Limberger, who is a member of the Unaxis board, will start his new role on August 1. He leaves General Electric Germany, Austria and Switzerland, where he has served as CEO since 2002.

Limberger replaces Harald Eggers, who has acted as Unaxis' interim CEO since January 2005.

As well as the CEO switch, the other members of the Unaxis

board resigned from office during an extraordinary general meeting (EGM) of shareholders on June 2.

No official reason has been given for the resignations, according to Unaxis spokesperson Nicolas Weidmann. However, the move is expected to give Limberger an opportunity to transform the company.

Victory's request for Mirko Kovats, Robol Günther, Christian Schmidt and Georg Stumpf to be elected to the board was also granted at the EGM. Kovats, who is now chairman of the board, is also the co-owner of Victory.

Engis opens polishing lab

Polishing and planarization specialist Engis Corporation has opened a new laboratory in the UK that is focused on improving manufacturing processes.

The facility, located in Henley-on-Thames, is described as a resource for developers looking

for technical support in polishing and thinning advanced materials like GaN and SiC.

"Materials such as GaN and SiC pose specific challenges to developers," said Engis managing director John Wellings. "We understand those challenges."

In brief

- UK-based semiconductor equipment supplier **Surface Technology Systems (STS)** has opened a sales office in Singapore. The office will be headed by Ian Wright, director of Asia business development, and will provide local sales and service support to the company's customers in Asia and Australasia.

- Taiwanese HB-LED manufacturer **South Epitaxy** has installed an X-ray diffraction instrument to investigate quantum well structures. The Vektor tool, which was supplied by Accent Optical Technologies, is designed specifically for GaN device metrology.

- **Aixtron** has delivered an Aixtron 200/200 RF system to the Center for Micro- and Nanotechnologies at the Technical University of Ilmenau, Germany. The reactor will be used for growth of heterostructures and nanostructures based on SiC, metal oxides and group-III-nitrides.

Aixtron has also established a European wing that will be responsible for the sales, service and spare parts business for Thomas Swan, Epigress and Genus. Heading up the new division will be Frank Schulte, who has been at the Aachen-based company for 15 years and who set up Aixtron's Japanese subsidiary.

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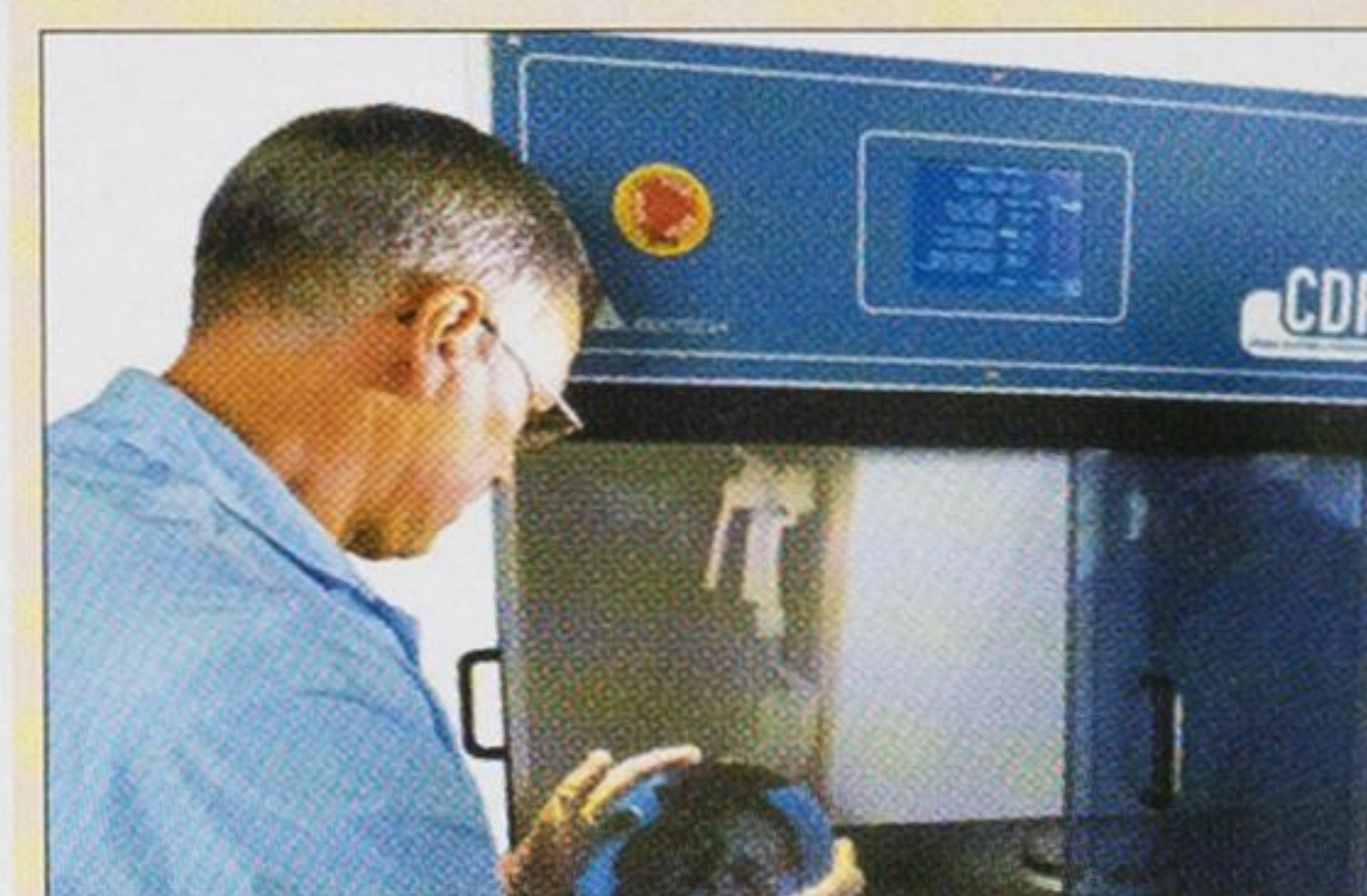


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Circular holes lead to brighter LEDs

Researchers from Kyoto University, Japan, have succeeded in fabricating two-dimensional (2D) photonic crystals that could have a dramatic effect on LED brightness. The photonic-crystal structure reduced in-plane spontaneous light emission in a GaInAsP slab to one-fifth that of the normal intensity (*Science* **308** 1296). Emission is redistributed from the 2D plane to the direction normal to the photonic crystal, thereby increasing the intensity of useful light output.

According to team member Susumu Noda, employing these 2D photonic crystals could boost the extraction efficiency of light from optoelectronic devices such as LEDs. Theoretical studies by the researchers indicate that 100% light-extraction efficiency is possible, because no emission is allowed in the 2D plane.

Noda says that this approach could also redistribute spontaneous emission into the cavity mode of an LED or laser by introducing artificial point defects into the 2D photonic crystal. This could lead to ultrahigh-efficiency laser diodes, because cavity dimensions that are comparable to the emission wavelength can be designed.

The Kyoto team used a combination of electron-beam lithography, and plasma and chemical etching to define triangular periodic arrays of circular holes in a 245 nm-thick GaInAsP slab. The series of pho-

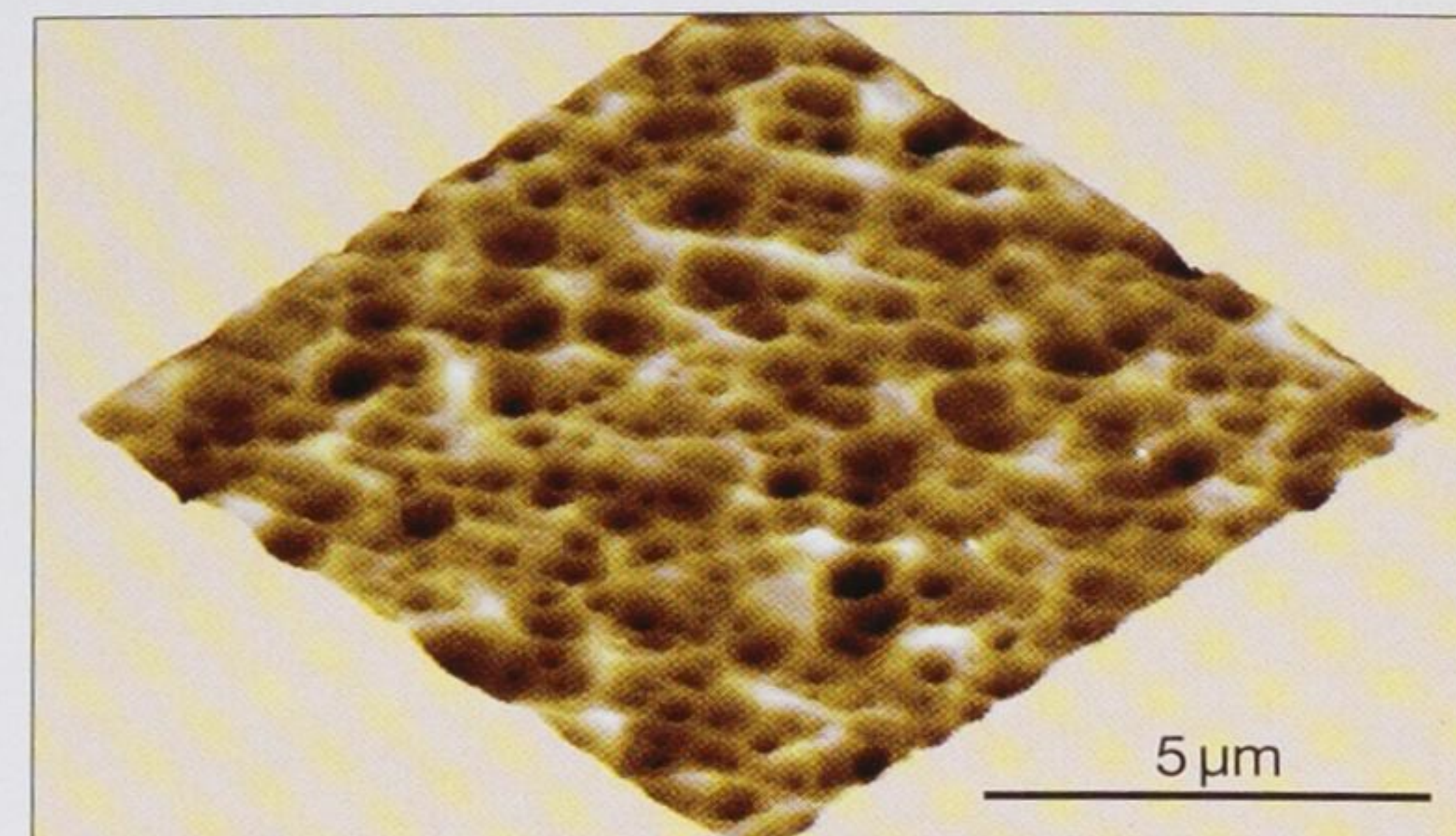
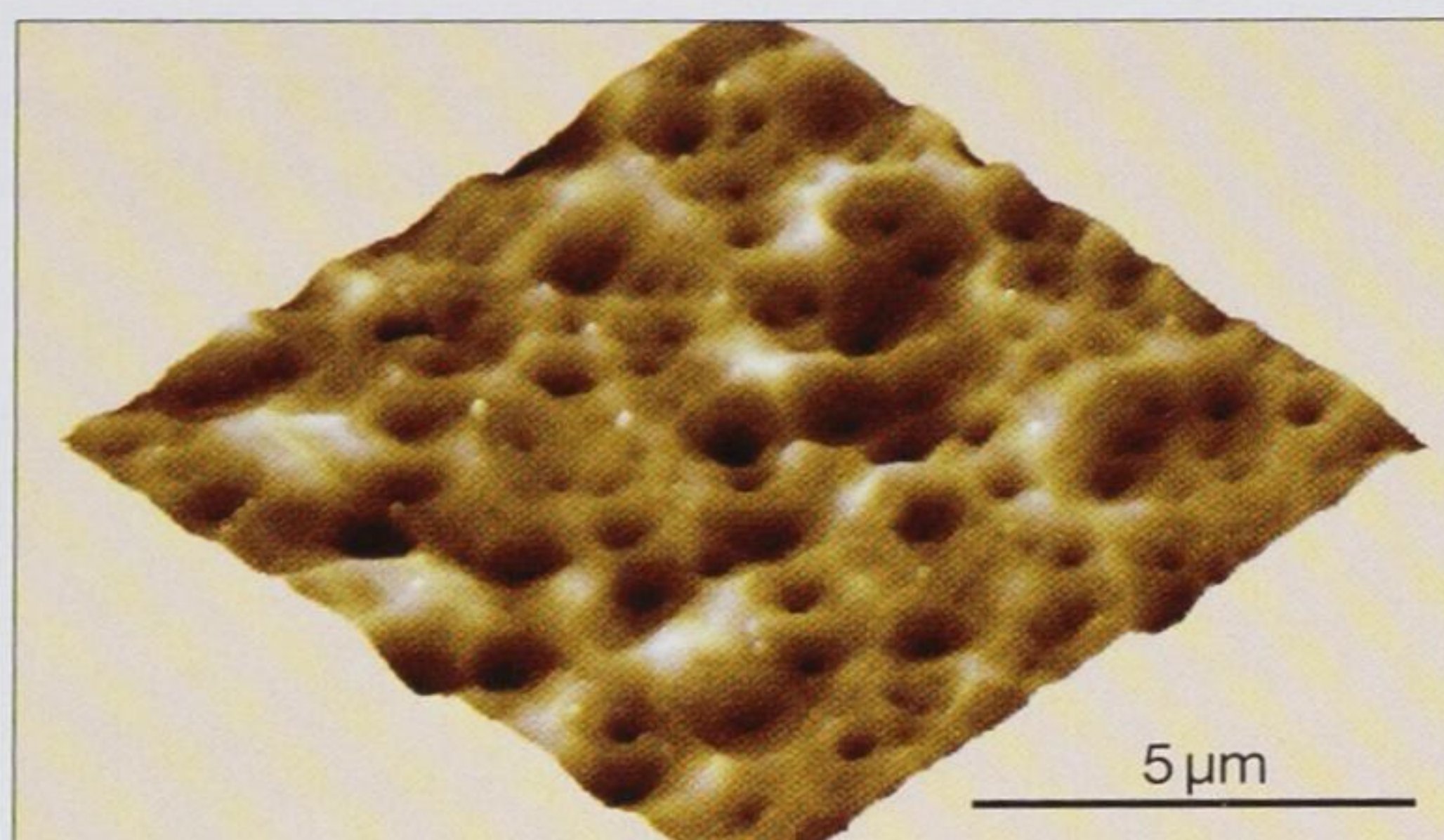
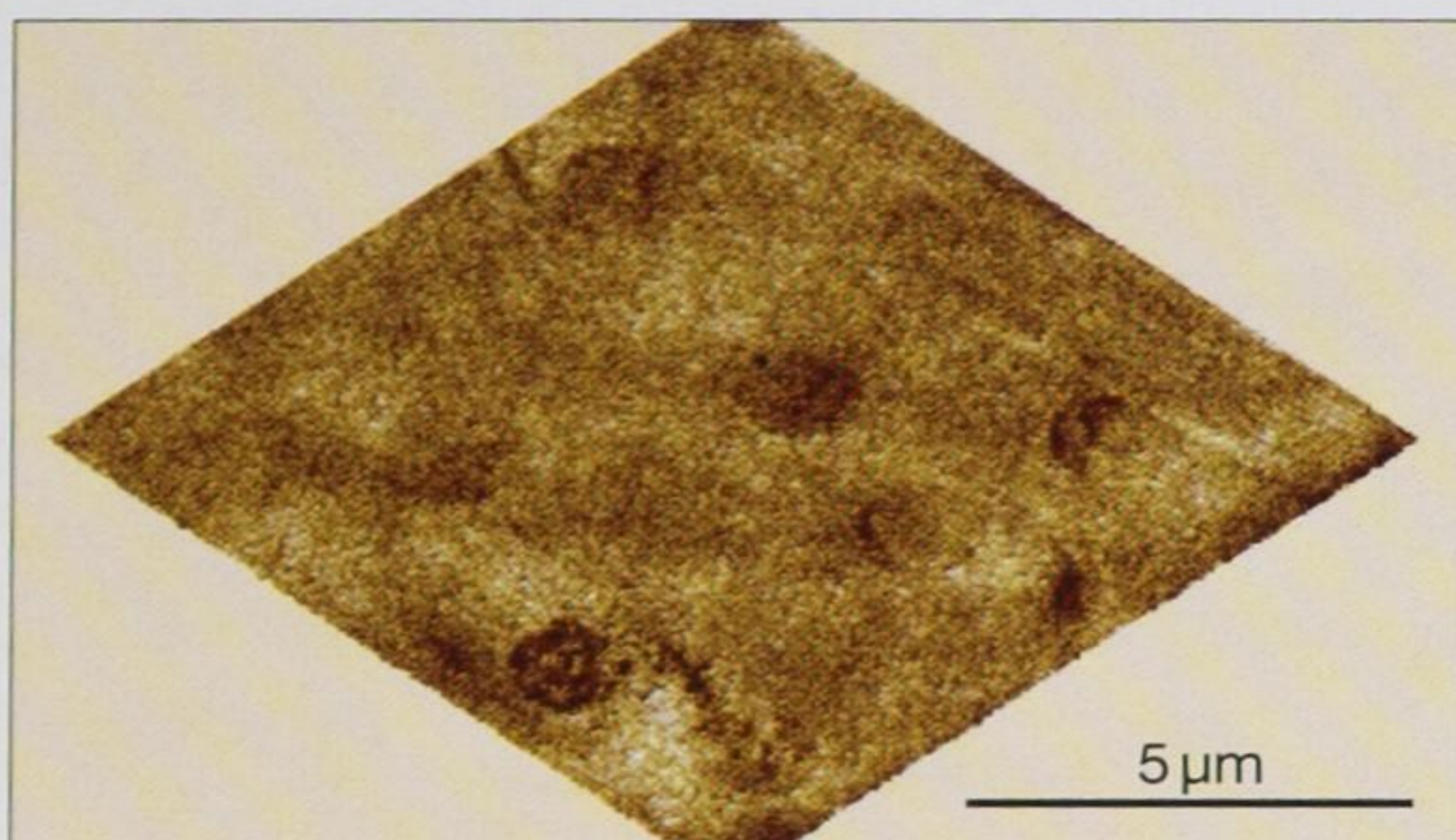
tonic structures had a lattice constant, a , varying between 300 and 500 nm in 10 nm intervals, and holes with a radius of $0.29a$.

Using a Ti-Al₂O₃ laser to generate photoluminescence from a 5 nm-thick quantum well sandwiched in the GaInAsP slab, Noda and colleagues recorded the emission with a multichannel GaInAs detector. When the emission wavelength was within the photonic bandgap ($a = 390$ to 480 nm) the overall emission rate fell by 80%, but the emission efficiency propagating out of the plane of the slab increased. When quantum well emission lay outside the photonic bandgap, the optical properties of the photonic structures were similar to those from unmodified GaInAsP slabs.

Noda thinks that it would be reasonably straightforward to implement these photonic structures into commercial LEDs. However, he believes that efforts should begin with surface treatments of air holes to reduce non-radiative relaxation. The design of the photonic crystals in the vertical direction should also be optimized.

Although electron-beam lithography, which was used to produce the photonic structures, may be too time-consuming for volume manufacturing, Noda believes that the LED industry could use a nanoimprinting technique that he has developed to make wide-area structures.

Nanoislands reduce GaN epilayer defect densities



With an underlying layer of GaN islands, the dislocation density of GaN-on-SiC epilayers is one-hundredth that of conventionally grown GaN-on-SiC. The improvement in epilayer quality can be seen in the AFM images above. Left to right: (a) a 1.5 μm -thick layer of GaN grown on top of GaN nanoislands; (b) a 1.5 μm -thick layer of GaN grown over an AlN buffer; (c) a 1.5 μm -thick layer of GaN deposited directly onto a SiC substrate.

A team from the National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan, has reduced the dislocation density of GaN layers grown on 6H-SiC substrates to around 10^7 cm^{-2} by inserting a layer of GaN nanoislands (*Appl. Phys. Lett.* **86** 191908).

The 100-fold improvement in typical GaN-layer quality grown on a SiC substrate could enhance optoelectronic device performance, and encourage manufacturers to move away from sapphire substrates that have inferior thermal conductivity.

The researchers grew three different structures on 6H-SiC(0001) substrates by MBE, using a radio-frequency-activated nitrogen source. The first contained a layer of Stranski-Krastanov nanoislands with a defect density of $4 \times 10^{11} \text{ cm}^{-2}$ and was capped with a 1.5 μm GaN layer, while of the two other structures one had an AlN buffer layer and the other had no buffer at all. All of the substrates were prepared by chemical etching, then gallium deposition followed by annealing to form gallium-terminated flat surfaces.

Dislocation densities were assessed by chemical etching with hot phosphoric acid, followed by atomic force microscopy. Phosphoric

acid strongly attacks defect sites on the GaN surface, producing etch pits that reveal the dislocations.

The nanoisland structure was relatively resistant to etching, and the team estimated the defect density at 10^7 cm^{-2} . The other samples had defect densities of approximately 10^9 cm^{-2} , leading the team to conclude that the underlying nanoislands can effectively counteract dislocation propagation.

Team member Jeganathan Kulandaivel says that although this study was restricted to 10×10 mm SiC substrates, the process would be suitable for high-volume manufacturing as long as constant fluxes of gallium and nitrogen can be delivered across larger-area substrates.

Work has been restricted to undoped substrates so far, but Kulandaivel believes that the process could be extended to conducting substrates featuring dopants that do not alter the compressive strain of the GaN/SiC system. Some dopant atoms can act as surfactants for GaN nuclei and prevent the two-dimensional growth required for nanoisland formation. Kulandaivel and colleagues now intend to fabricate AlGaIn/GaN HEMTs featuring nanoisland layers.

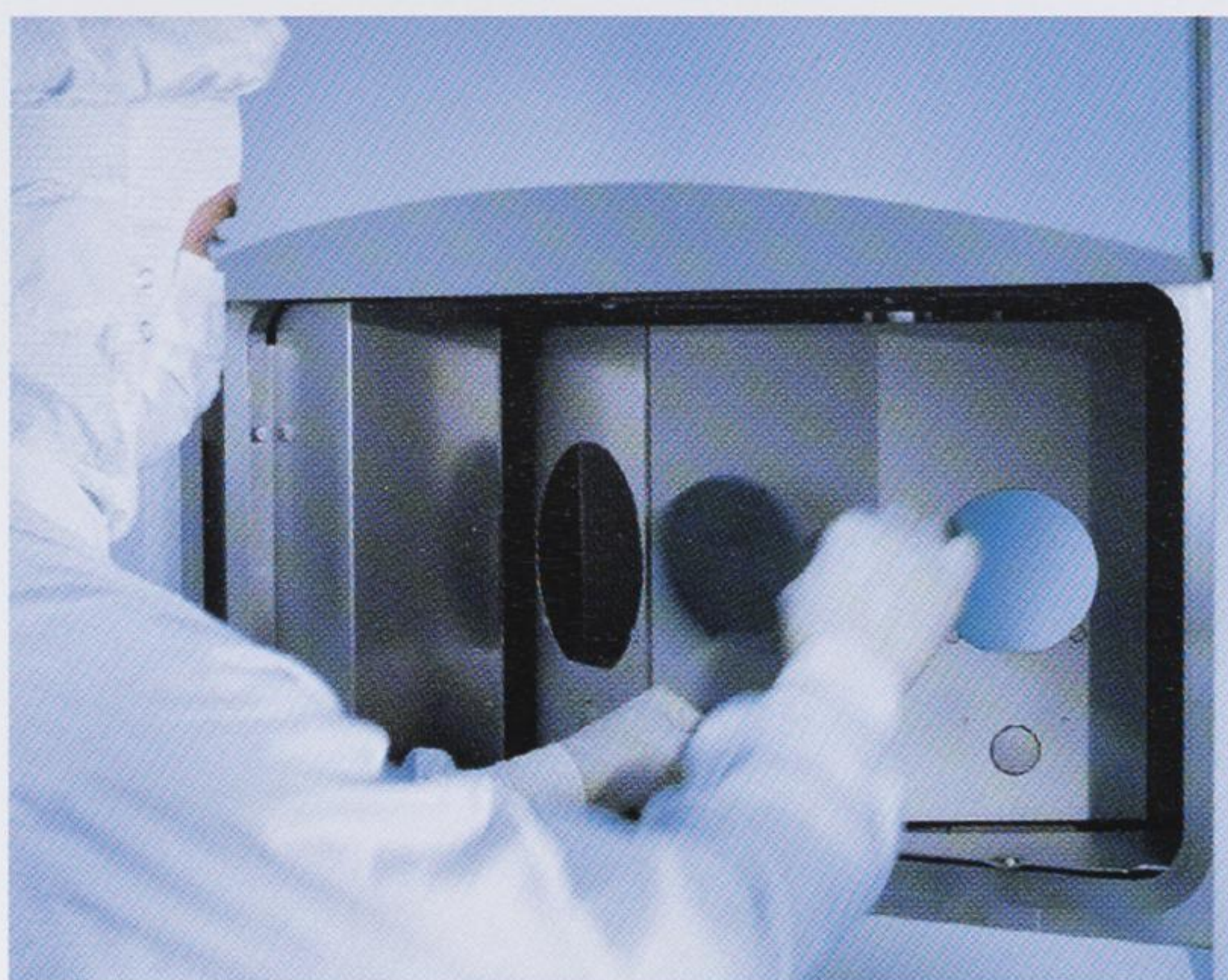
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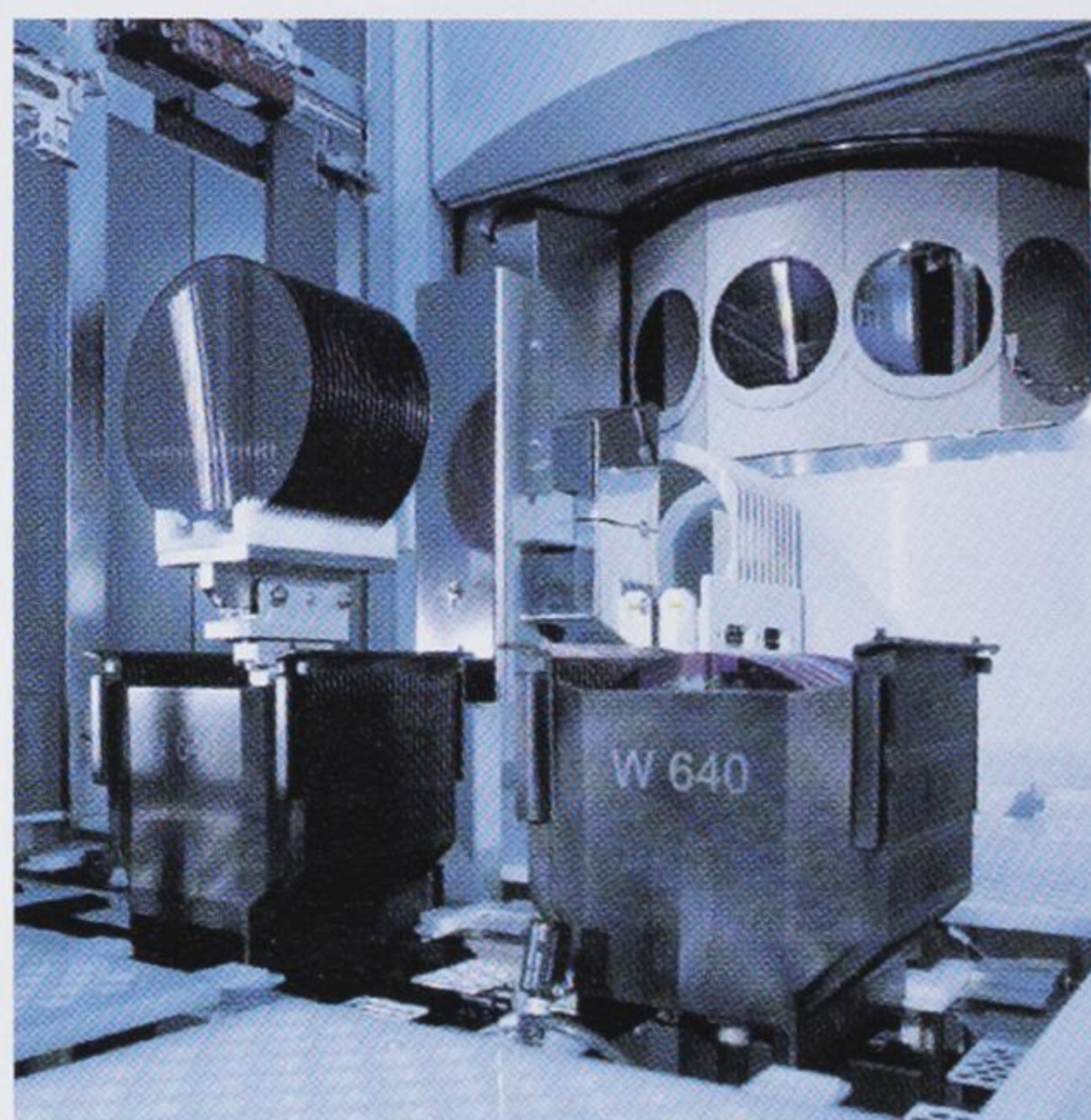
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