

COMPOUND SEMICONDUCTOR

Three-Fives and Silicon Heterostructures

March 2005 Volume 11 Number 2



DEFENSE

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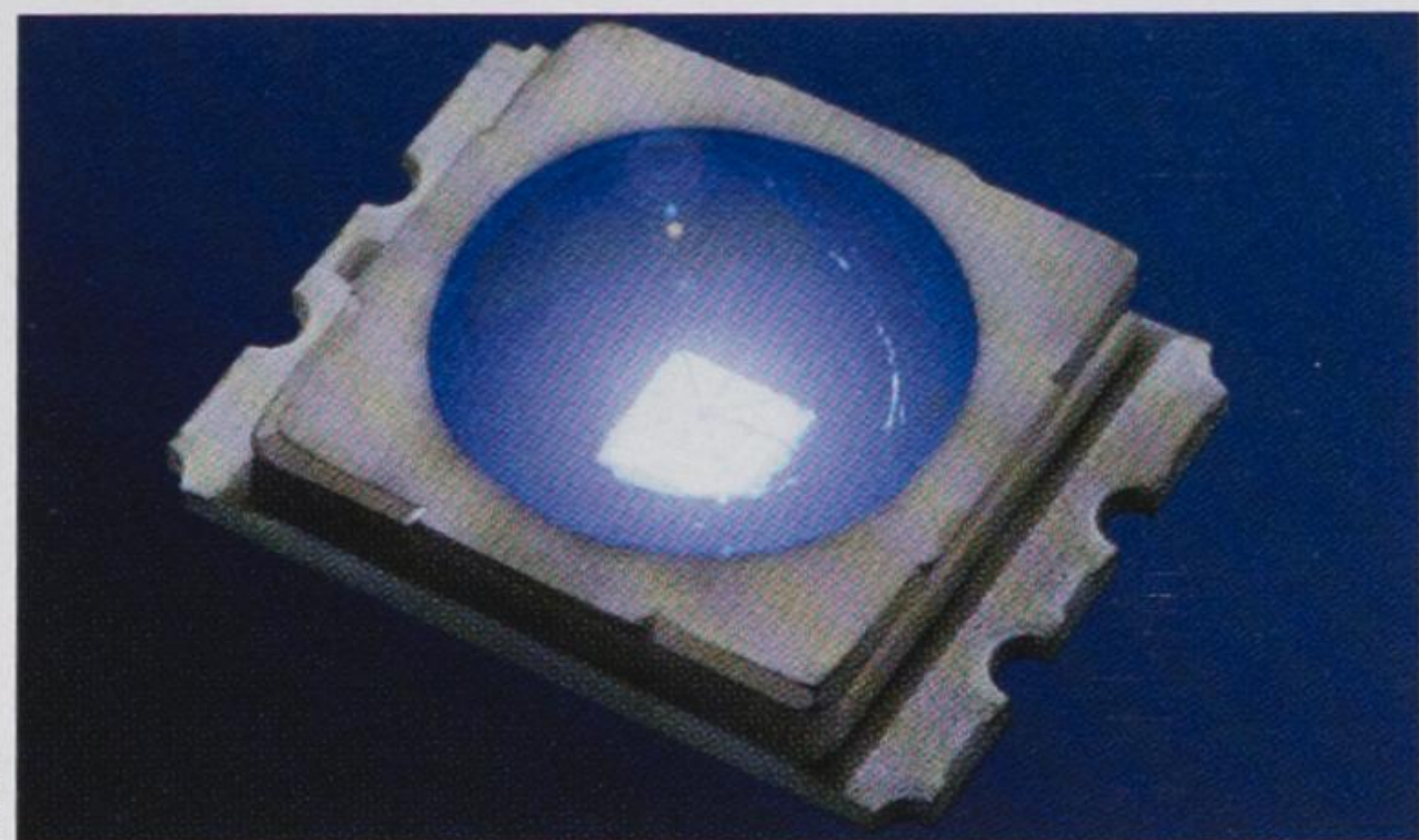
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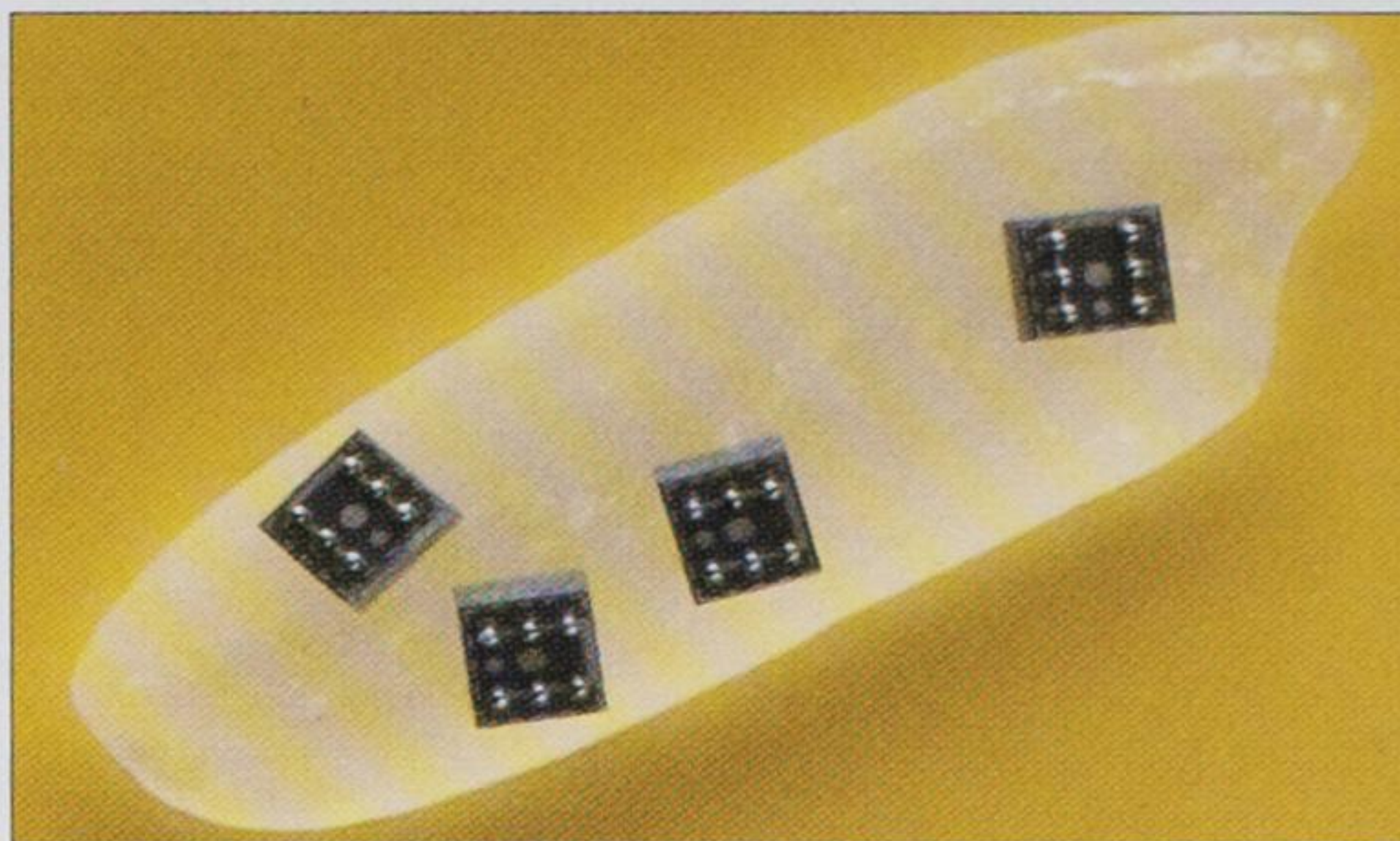
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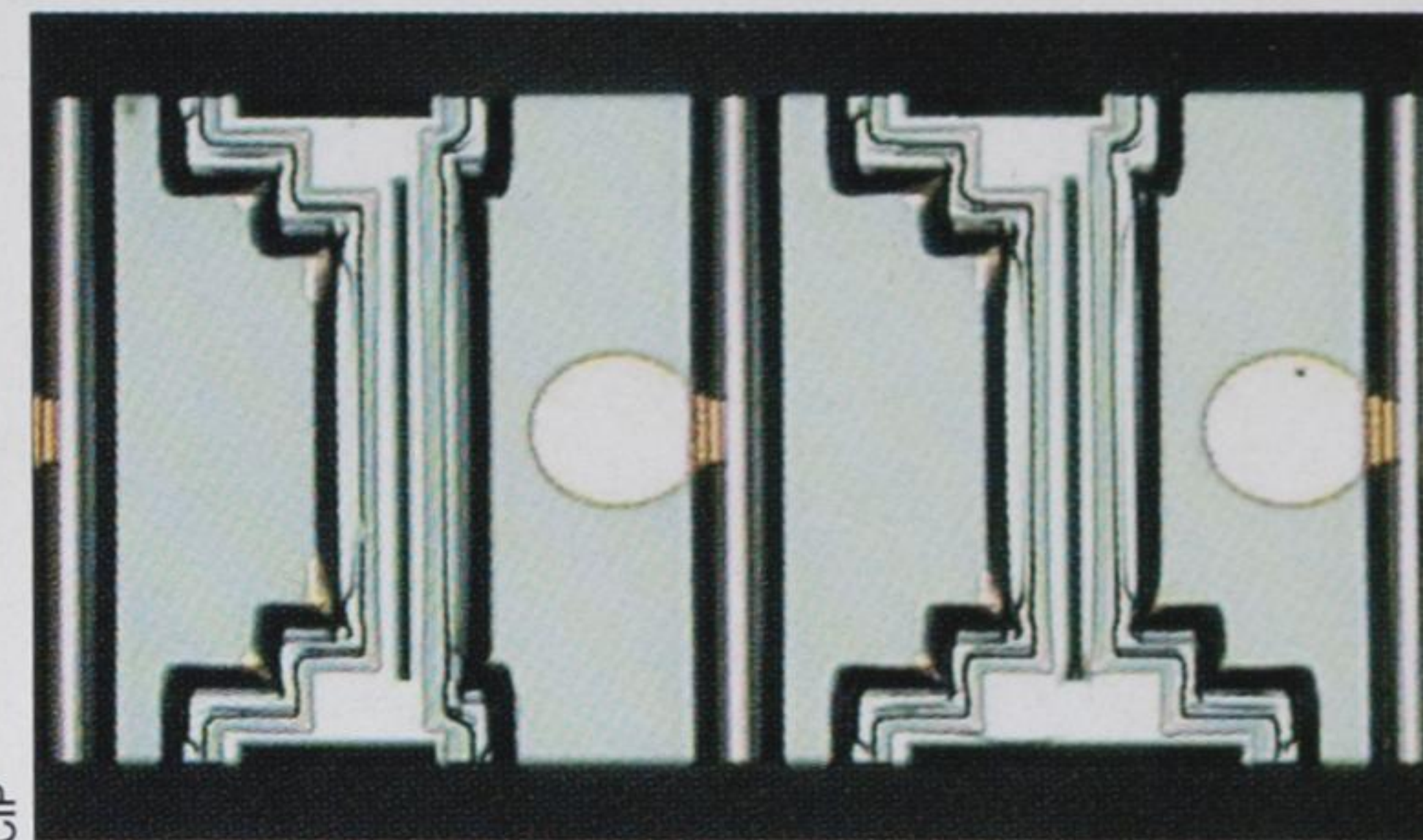
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It's the cell phones, stupid



Cell phones dominate the compound semiconductor industry like no other application today. The symbiotic relationship between III-V chip manufacturers and the killer application in modern technology is spelled out in Jerry Neal's biography of RF Micro Devices, *Fire in the Belly*, from the moment his company's first GaAs-based power-amplifier (PA) chips melted under test through to today's multibillion-dollar market.

The link is similarly evident in optoelectronics, with HB-LED industry analyst Bob Steele's figures painting a clear picture at Strategies in Light 2005 last month. Since 2001, the market for HB-LEDs in mobile appliances has rocketed from \$400 million to reach \$2.1 billion last year. Fueled first by blue keypad backlights, the consumer demand for full-color LCD screens and camera phones ensured that the upward trend continued.

But with the expansion of the cell-phone market expected to slow to about 5–10% unit growth in 2005, things are changing. Steele is expecting further saturation in keypad backlights to extend to LCD backlighting applications.

As many of the PA makers have found, just because an application market is growing 25–30% year on year, this doesn't translate into easy profits. In the most recent financial quarter, which included the traditionally lucrative holiday period of unabashed consumer spending, only one of the major PA suppliers was in the black on the bottom line.

With LED makers facing similar commoditization – allied to likely consolidation among low-cost Asian manufacturers – the challenge for the whole industry is to penetrate more applications so that consumers buy gadgets with more III-V content. For RFIC makers, that means more GaAs in the RF electronics as amplifier stages get more complex in the latest phones, while the obvious area to increase LED content is in camera-phone flashes, for phones such as Nokia's new 6680 model (p10).

While the uptake of 3G technology will go some way to bolstering the market, manufacturers will have to look outside of cell phones and toward other consumer technologies – mobile or otherwise – to ensure future growth.

Michael Hatcher

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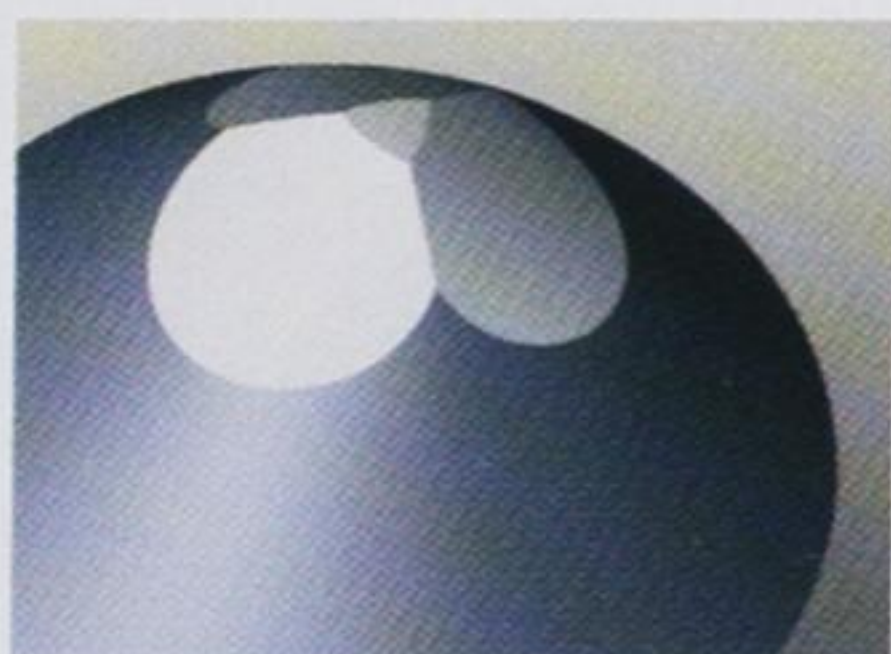
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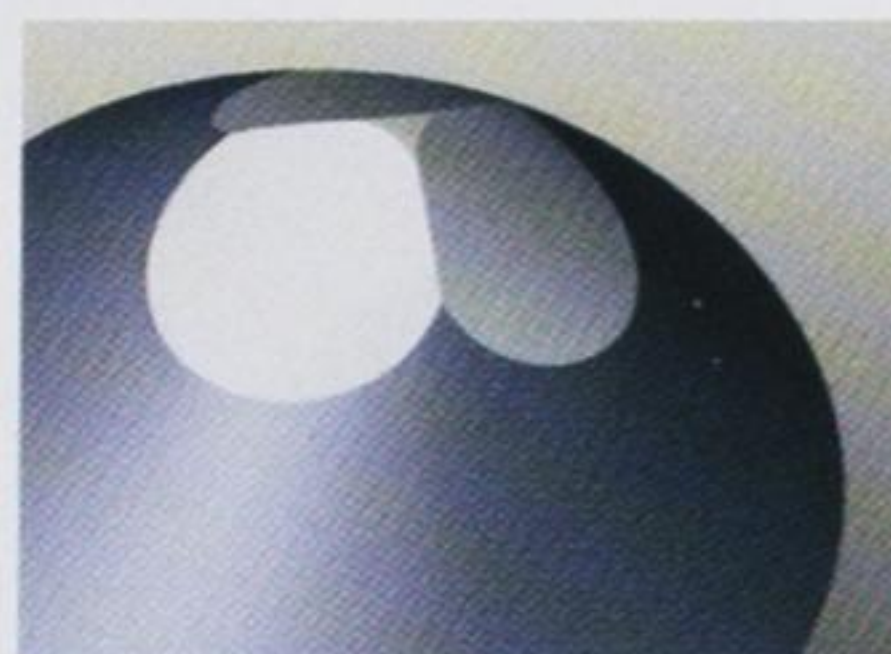
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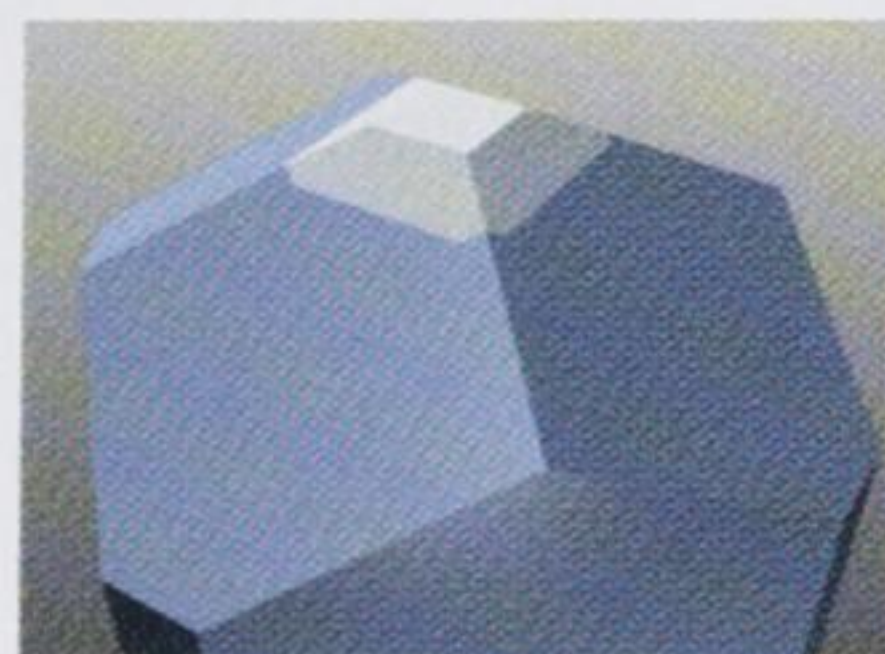
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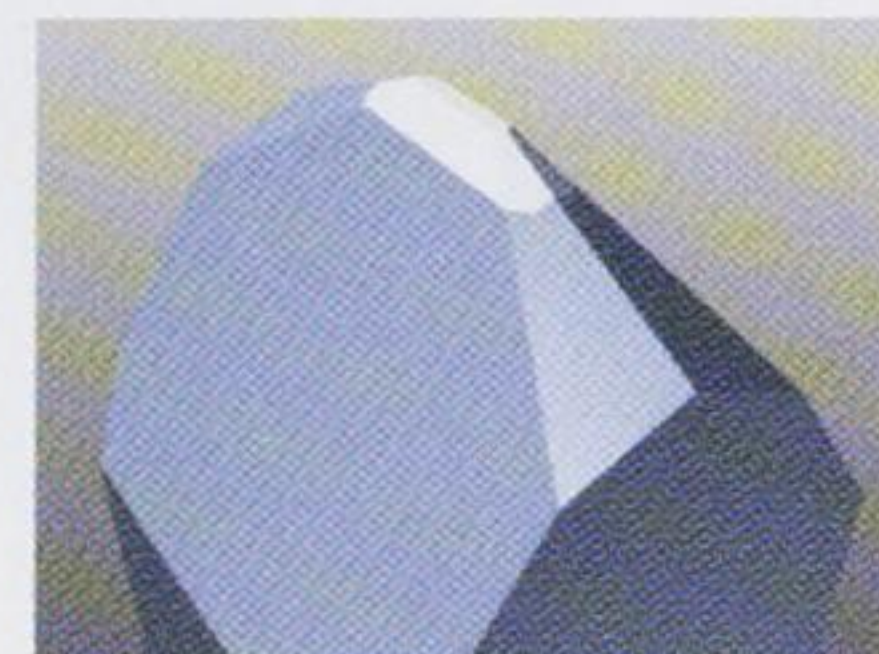
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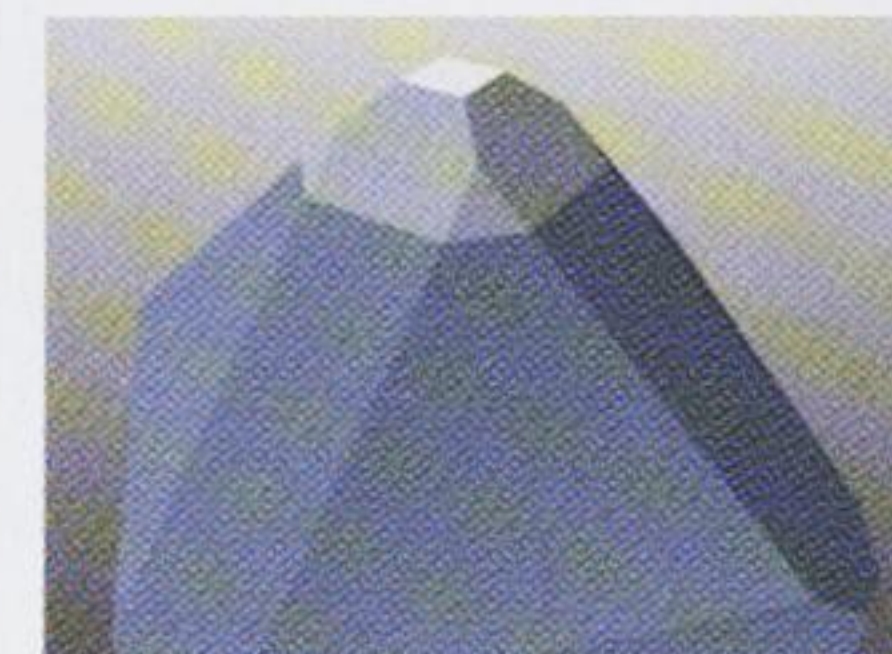
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Shareholders on warpath as improper accounting plagues Veeco TurboDisc

Veeco Instruments has launched an investigation into what it calls "improper accounting" within its TurboDisc division. The division, which Veeco acquired from Emcore in late 2003, makes MOCVD equipment that is widely used in LED manufacturing.

According to Veeco officials, the improper transactions came to light when the company was in the process of switching from the legacy TurboDisc accounting system inherited from Emcore to its business-wide SAP accounting system.

While the investigation is ongoing, Veeco CEO Ed Braun revealed that two senior members of the TurboDisc operation have been fired, including the division's controller.

Although the incident is thought to be limited to Veeco's TurboDisc division, Braun and Veeco CFO John Rein admitted to being "very disappointed" with the development.

Veeco did not say whether it believes the accounting errors to be willful and therefore fraudulent, but the company points out that it has hired a forensic accounting team as part of the investigation.

The New York-based business, which competes with Aixtron in the MOCVD market, could now face class actions from four law firms representing Veeco shareholders own-

ing stock since the Emcore division was purchased. Schiffrin and Barroway of Radnor, PA, will seek to recover damages on the basis that Veeco violated the Securities Exchange Act of 1934. The law firm specifically cited improper accounting procedures, that Veeco lacked internal controls, and that as a result, its financial results were materially overstated.

Veeco officials refused to speculate when asked whether the accounting problem had existed prior to its acquisition of TurboDisc from Emcore. The incorrect entries in the TurboDisc accounts effectively mean that Veeco has been selling MOCVD equipment at a price that is too low to achieve the profit margin that it is aiming for.

Braun says that the incorrect pricing means that MOCVD equipment was essentially being sold at a discount of \$80,000–100,000 per \$1.5 million tool.

To remedy the situation, Veeco will look to increase the amount of revenue it generates per MOCVD tool sale, as well as reduce the bill of materials in each tool that it builds. Braun says that the number of employees in the TurboDisc division will now be cut, and that the next generation of its GaNzilla MOCVD equipment will be introduced in June in a bid to boost margins.

The overall effect on Veeco's bottom line is still to be calculated, and the company has postponed the filing of its full-year accounts as a result. It is now battling to submit its report to the Securities and Exchange Commission before a March deadline.

The company estimates that its last three quarterly financial statements have been affected as a result of the accounting mess, and that the total cost of the mistake is in the region of \$5.5 million–7.5 million.

On a brighter note, Braun says that sales of epitaxy equipment have bounced back from a weak third quarter, although Taiwan and China still have excess MOCVD capacity.

A strong return to form is now expected in 2006 and 2007, especially for blue, green and white LED manufacturing. Braun identifies large-area LCD backlights and automotive applications as primary growth drivers, with the rapid increase of the cell-phone market now set to cool.

Braun also believes that the solid-state-lighting market will start to take off around 2008. "If you visit Lumileds, they will show you four or five of our machines being installed. They will also show you the floor-space that they have allocated for the next 25 machines," he said.

Cree and Nichia combine forces on white lighting

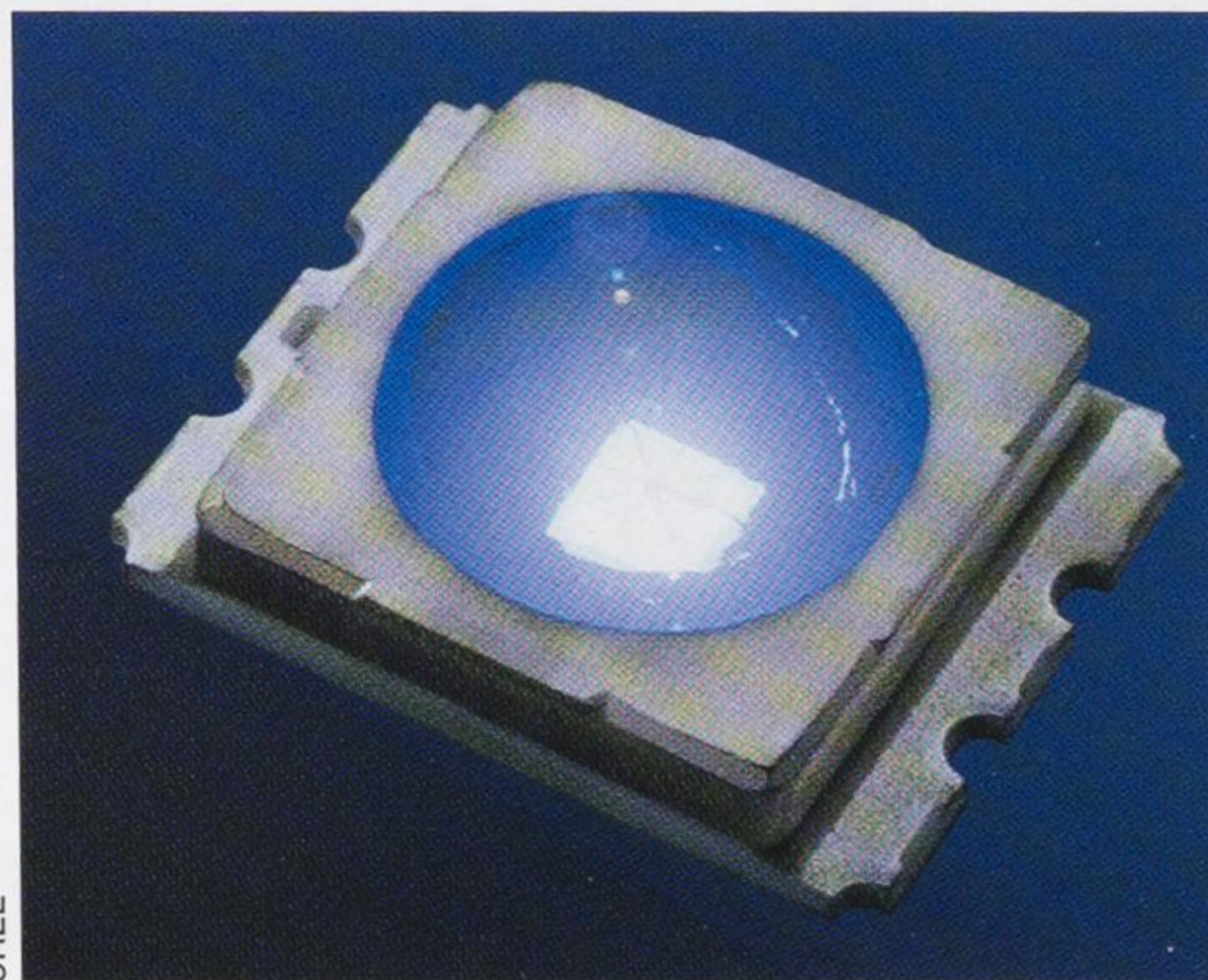
Arch-rival GaN LED manufacturers Cree and Nichia have signed a new patent cross-license agreement that specifically covers solid-state white-lighting technology.

The deal is said to complement an agreement initiated when the two companies first settled mutual litigation claims back in November 2002.

"This agreement gives Cree access to [Nichia's] important technology," acknowledged Cree CEO Chuck Swoboda.

Nichia says that it expects the cross-license to consolidate it and Cree's position as leaders in solid-state lighting technology in the face of future competition. "Our market is getting more competitive," said the Japanese company in a statement.

At the recent Strategies in Light event in Burlingame, CA, Cree also detailed some



As well as teaming up with Nichia on white LED products, Cree is distributing its green and blue GaN-on-SiC LEDs through UK firm Forge Europa. This is Cree's 7090 XLamp product, which is said to deliver up to 60 lm of white light, and 15–19 lm in the blue.

recent progress that it has made with white-light sources, which it says will speed the adoption of LEDs into mainstream lighting applications.

The advances include a standard 5 mm LED emitting 100 lm/W and operating at 50% wall-plug efficiency. Meanwhile, Cree's white XLamp team used power LEDs operating at 350 mA to produce a lamp with a maximum luminous flux of 60 lm.

Chris James, marketing manager at Cree Lighting, said: "I believe the LED industry is advancing toward replacing the light bulb at a more rapid pace than just a few years ago."

● Lumileds has warned all LED manufacturers and users to ensure that they do not make or sell products violating its patents. The warning specifically relates to mirror substrate LEDs.

Finisar and Infineon agree on revamped fiber deal

Infineon Technologies has agreed to sell part of its fiber-optic business to US-based Finisar, just weeks after trashing the original deal to sell the entire unit.

The revised agreement involves Finisar issuing Infineon some 34 million shares, valued at \$50 million, in exchange for Infineon assets associated with the design, development and manufacture of optical transceiver products. The acquisition gives Infineon a 13% stake in Finisar.

Infineon says that 350 of its staff associated with the fiber-optic business will leave the firm, from sites in Berlin and Munich in Germany, and Longmont in the US. They will not be transferred to Finisar through the acquisition.

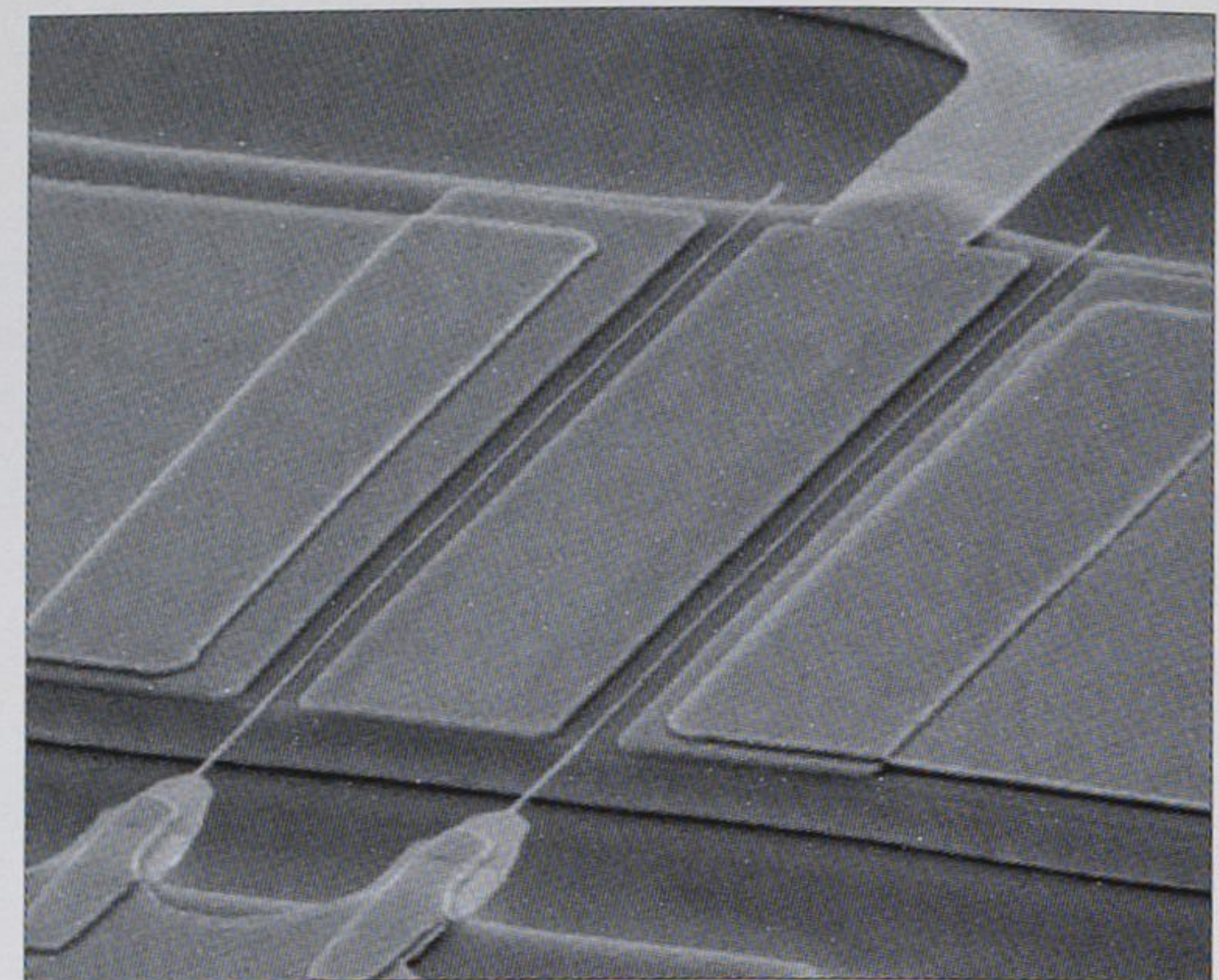
Finisar will acquire 10 Gbit/s transceiver designs for XPAK, X2, XENPAK and XFP form factors. Infineon will retain its components division for parallel optics and

fiber-to-the-home applications, and plastic optical fiber products that are used in the automotive industry.

Infineon had previously withdrawn from a \$200 million agreement to sell Finisar its entire fiber-optic business unit. Both firms then appeared to be heading for the courts, but since striking this new pact Infineon and Finisar have called off any legal action.

"The acquisition considerably broadens our customer and product portfolio, particularly our 10 Gbit/s product platforms," said Finisar's CEO, Jerry Rawls.

Infineon's CEO, Wolfgang Ziebart, indicates that more changes are on the way for the German outfit. "The transition supports the ongoing consolidation of the fiber optic market, and is the first major step toward the restructuring of our fiber-optics group in order to return to profitability."



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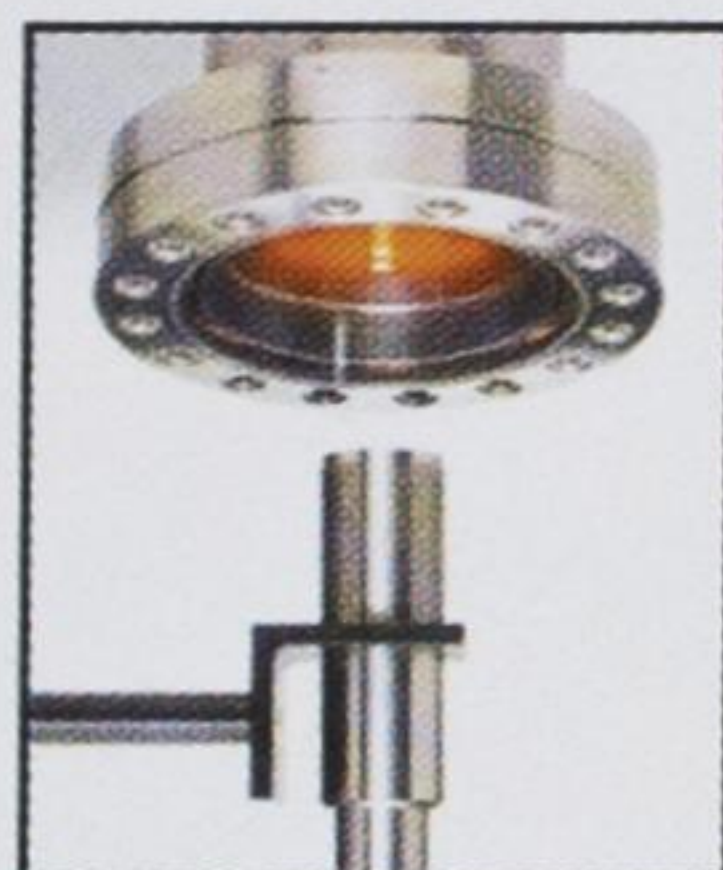
A collaboration between Intel and UK-based Qinetiq has developed InSb transistors with a cut-off frequency of 150 GHz. According to the research team the quantum-well devices, which have a gate length of 200 nm, have a power dissipation of as little as one-tenth of that of state-of-the-art silicon MOSFETs. The low power consumption is due to the higher mobility of the novel material compared with silicon and GaAs at room temperature, which means that the operating voltage of the transistors is just 0.5 V.

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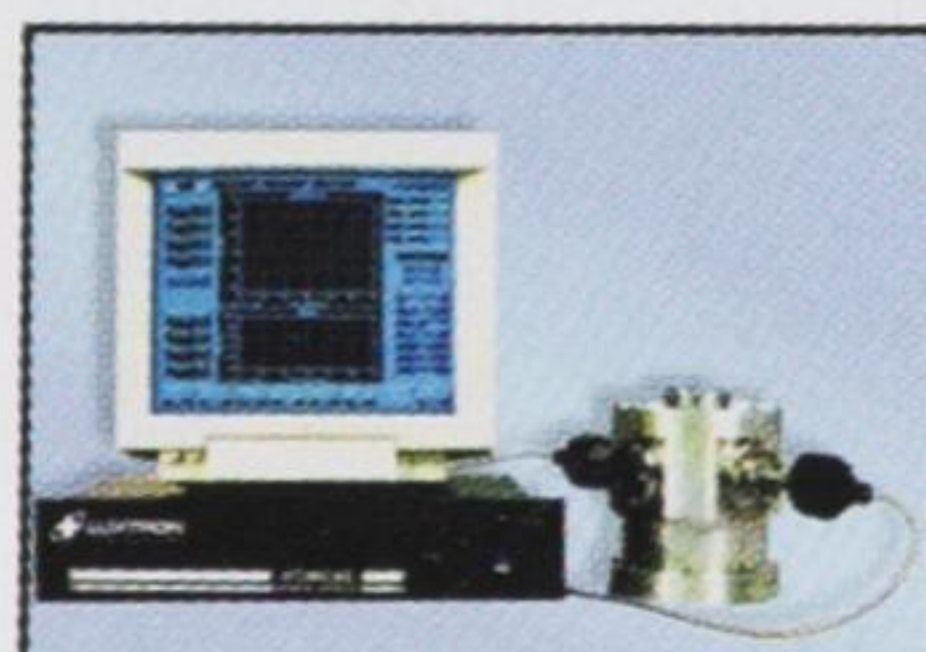


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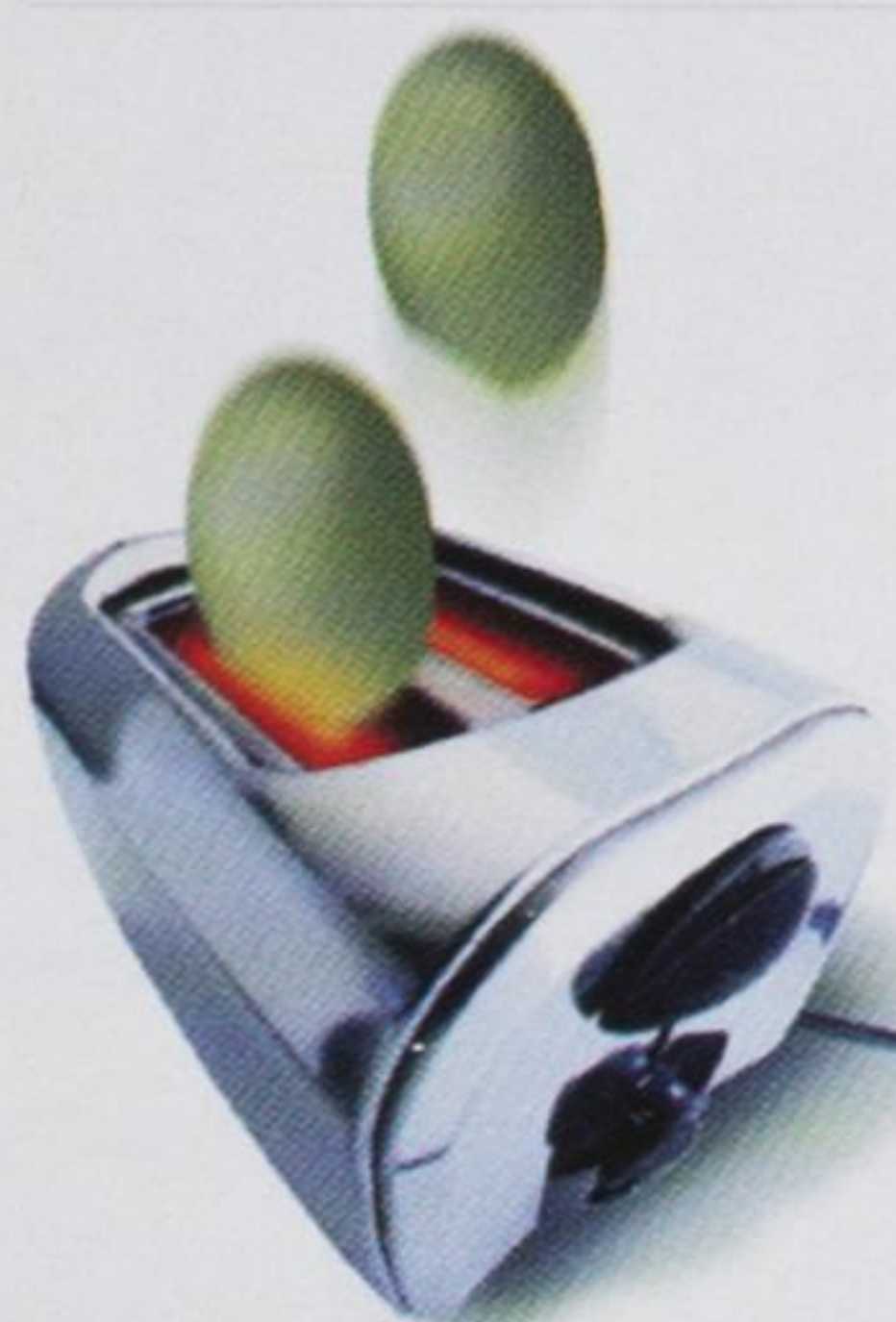
For the first time *The Key Conference* will run alongside the other events in Compound Semiconductor Week 2005. This event is an executive-level meeting that will focus on the key technological themes and market trends that will dominate the future of the compound semiconductor industry. It is a must for senior management who appreciate how vital it is to gain an in-depth understanding of key market developments and competitor strategies.

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GAAs & WIRELESS NEWS

Slowing phone market to top 700 m units in 2005

Cell-phone unit sales are set to hit the 700 million mark in 2005, but the market will grow at a much slower rate than in the past two years. That's the conclusion reached by both a report from IC Insights, a market-research firm based in Scottsdale, AZ, and Nokia, the market-leading phone maker.

Cell phones are the single biggest application area for GaAs IC devices and LEDs.

Last year saw the fastest market growth in unit sales of cell phones since 2000, according to the report. Total shipments rose 29% in 2004 to reach 670 million. But growth in 2005 will be much slower, with the market expanding 5% and 705 million phones being sold, IC Insights predicts. Nokia estimates the 2004 figure to be somewhat lower, but is predicting 10% growth this year.

However, the long-term forecast from IC Insights shows that the rate of growth will then increase every year through 2008. As a result, 2008 will see shipments of more than one bil-

lion handsets, claims the report.

The replacement market will become increasingly important in the future, and handset makers will need to convince subscribers to invest in the latest technology with the newest features to maintain overall market growth. While 63% of phones sold in 2004 were replacements, this figure is expected to rise to 81% in 2008.

Camera phones have driven the replacement market in the past couple of years, reviving the overall sector after it suffered its only yearly decline back in 2001. Since then, the number of phones sold per year has doubled.

IC Insights fully expects that consumers will continue to be won over by new technologies and functions, and predicts that the average time before a cell phone is replaced will drop to just 30 months in 2008.

The market's compound annual growth rate – in terms of units sold – will be 16% over the 2001–2008 period, IC Insights concludes.

Filtronic is upbeat on prospects as it signs PHEMT supply deal

Filtronic, a UK microwave subsystems manufacturer with a 6 inch GaAs fab, is enjoying increased demand for its products.

In its half-year financial report, the company highlighted rapid growth in demand for power amplifiers (PAs) bound for 3G handsets, as well as in low-cost transceivers for point-to-point microwave links.

Filtronic has also signed a supply agreement that will see it become RF Micro Devices' number-one supplier of GaAs PHEMTs. Filtronic will make the components at its wafer-processing facility in Newton Aycliffe, UK.

Volume production is scheduled to begin in Q2 with the PHEMTs set to be incorporated into RFMD modules destined for cell-phone handset and wireless LAN applications.

Filtronic says that its improved product mix should lead to revenue growth in its compound semiconductor unit as this year unfolds, although it admits that chip manufacturing has been adversely affected by some customer delays in orders for volume production.

But with the PHEMT supply order,

increased demand for more complex, higher-value MMICs, and more foundry activity for handset and wireless infrastructure OEMs, Filtronic has succeeded in broadening its customer base for GaAs devices.

Company chairman David Rhodes says that after what has been a tricky period financially, the company can now take advantage of strengthening markets for wireless infrastructure and US defense.

Recently, Filtronic won a contract to upgrade US military aircraft, and a second PA product should be launched soon as the firm targets 3G applications. "The W-CDMA market for PAs is considered to be showing 20% compound annual growth," said the company.

However, Filtronic is not going ahead with the planned initial public offering of its handset-products division, "in light of market conditions". The division is focused on antenna products rather than semiconductor chips.

Overall, Filtronic posted an after-tax profit of £1.7 million on revenue of £130 million for the six months ended November 30, 2004.

Agilent carves out mobile research base in Korea

Agilent Technologies has increased its focus on the mobile-handset market with the launch of the Agilent Asia Mobile Development Center in Seoul, Korea.

The center will initially employ 50 staff, including the engineering team from Seoul-based Wavics, a fabless designer of ICs for power amplifier (PA) applications. Agilent acquired Wavics in February.

Work at the center will focus on Agilent's mobile-handset components, including PAs for CDMA and W-CDMA. As well as hosting research activity, the base will provide marketing and applications support.

One of the center's aims is to create front-end modules that can integrate Agilent's PAs

with its film bulk acoustic resonator duplexers.

According to Agilent this combination will allow phone manufacturers to significantly reduce circuit-board space, enabling smaller and thinner clamshell-style handsets.

"Korea is a mobile technology leader, and its universities are graduating large numbers of highly educated and skilled electrical engineers," said Young Sohn, president of Agilent's semiconductor products group.

"We chose Korea because it places us close to our mobile-handset customers, where we can better serve them and help define tomorrow's innovative, feature-rich handsets."

● See "Agilent sets out its consumer vision for future profitability", p28.

Endwave bags defense deal

20-year-old NATO aircraft are to have some systems back-fitted with GaAs-based low-power amplifiers in a program that will help to extend the service life of the fleet.

US-based Endwave will initially develop prototype devices at its Sunnyvale, CA, headquarters, while low-rate production is slated to begin next year at the company's new defense systems division.

The \$0.5 million development contract should see the delivery of prototypes toward the end of this year. Production will then begin

in 2006, assuming successful field qualification testing and subsequent authorization.

Amplifier production will take place in Diamond Springs, CA, at the firm's manufacturing center of excellence, and is expected to run for between two and four years.

Chip fabrication will likely take place at Northrop Grumman's foundry, with which Endwave has a strategic alliance.

Endwave recently consolidated its existing defense product division with that of JCA Technology, a company that it acquired from Bookham Technology in July last year, to form Endwave Defense Systems. The division is retaining the JCA brand name for its RF amplifier modules, which is the key technology behind its products.

In brief

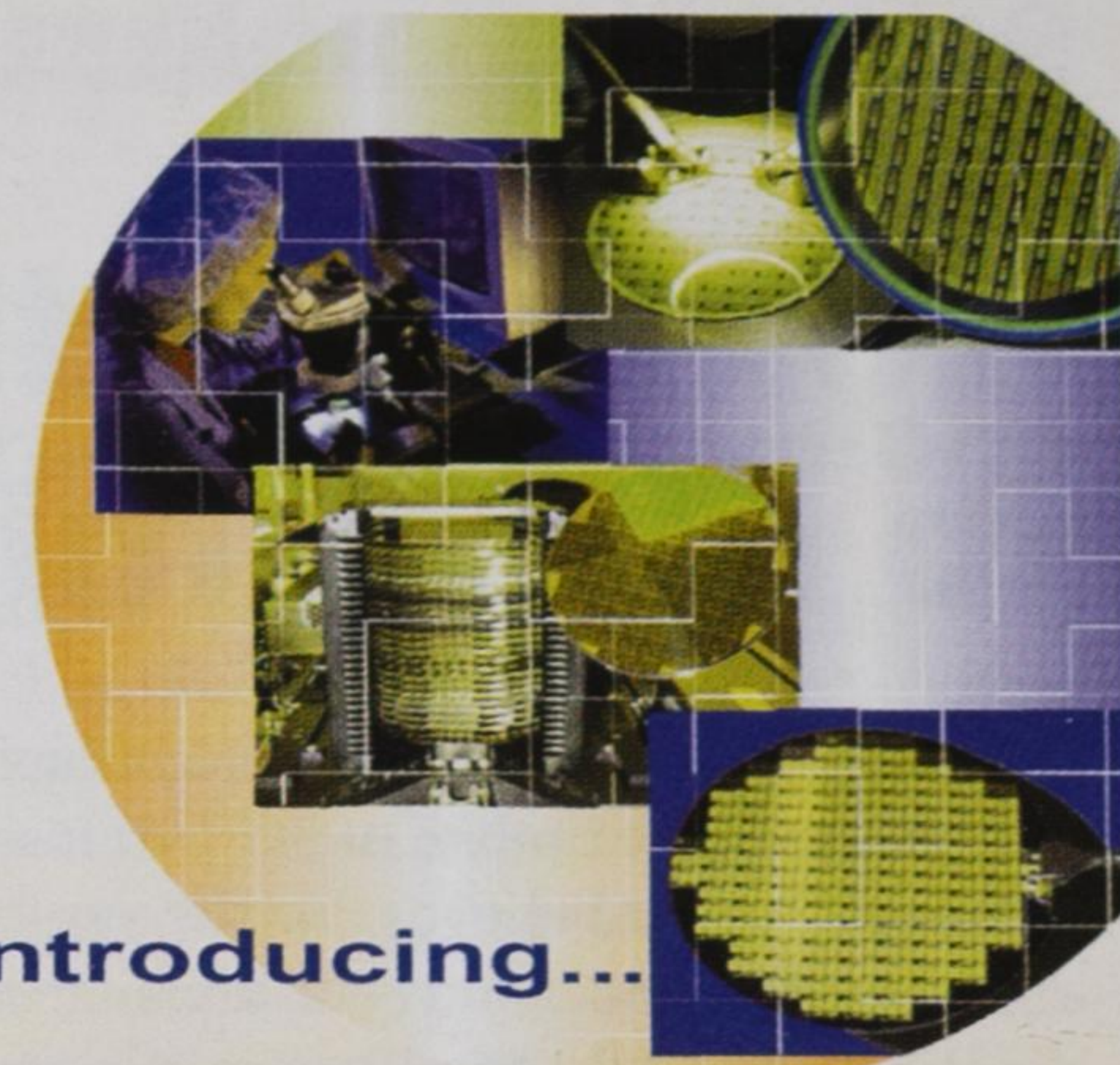
● **RF Micro Devices** has shrunk its GaAs HBT PowerStar power amplifier (PA) modules by 30%. The firm showed off the two new products in the PowerStar family at the 3GSM World Congress event in Cannes, France, last month. Both modules feature integrated battery voltage tracking circuitry, which is said to be an industry first for standard PA modules.

● **Xindium Technologies**, a US firm that is developing advanced RF devices for mobile phones, has introduced a new PA module based on InGaP HBT technology. Xindium says that its product gives handset builders

greater diversity in their supplier base.

● Californian GaAs device manufacturer **Celeritek** made revenue of \$2.8 million in its most recent quarter, following the sale of its defense subsystem business to Teledyne last October. That sale netted the firm \$31.4 million, and as a result Celeritek gave out a cash dividend of \$3 per share to every shareholder – totaling \$38.9 million.

● **Agilent Technologies** introduced an E-PHEMT low-noise amplifier suitable for the 0.5–6 GHz frequency range, including wireless LAN, WiMAX point-to-multipoint systems and cordless phones.



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Nokia predicts 3G-technology uptake to hit 70 million subscribers this year

Leading cell-phone maker Nokia has predicted a massive uptake of 3G wireless services this year. It believes that the number of subscribers to wideband code division multiple access (W-CDMA) will more than quadruple to 70 million in 2005.

The Finnish company is also very bullish on overall subscriber growth, forecasting that the global base will rise to 2 billion this year and on to 3 billion by 2010.

Nokia's forecast came at the 3GSM World Congress, the annual mobile jamboree held in Cannes on the French Riviera.

"We expect to see widespread commercialization of 3G W-CDMA networks during the year," said Simon Beresford-Wylie, Nokia's executive vice-president of networks. "With more than 100 3G networks opened by the end of 2005, Nokia is projecting a sharp rise in the number of 3G subscribers, to 70 million by the end of the year." Only 16 million subscribers signed up to 3G services in 2004, adds Beresford-Wylie.

To reinforce its point, Nokia launched its new 3G smartphone, which it hopes will drive the uptake. The model 6680 has two cameras and also uses white LEDs to provide the flash.

3G phones also require more complex RF electronics that ought to lead to more GaAs content in the advanced handsets. Power amplifier (PA) manufacturers were out in force in Cannes, touting the products that they believe will make the transition to 3G as smooth as possible.

Anadigics, RF Micro Devices (RFMD), Skyworks Solutions, Agilent Technologies and TriQuint Semiconductor were all doing their best to impress handset manufacturers with improved module performance and devices that simplify the design process.

Anadigics unveiled new modules for W-CDMA, enhanced data for global evolution (EDGE) and GSM/GPRS applications.

The Warren, NJ, firm has brought out a family of four high-efficiency PA modules for W-CDMA, under the high-efficiency-at-low-power banner. These are said to reduce average power consumption by 50%.

According to Anadigics, this means that new 3G phones using the PAs will have the same battery life as older phones, despite all of the extra functionality putting an increas-



Nokia's new 3G smartphone features two cameras and a white LED-based flash. GaAs IC manufacturers are vying to win over handset makers with a raft of new power-amplifier products prior to an expected sharp increase in the 3G subscriber base this year.

ing demand on power.

Anadigics is also targeting the "2.5G" market with an InGaP HBT quad-band PA module that it says is the lowest-cost PA option for dual-mode GSM/EDGE handsets.

And in the low-end GSM/GPRS sector, the company says that its PowerPlexer module, which integrates an InGaP HBT PA, a PHEMT antenna switch, harmonic filters and CMOS power-control circuitry, is the industry's smallest transmit module.

Agilent's semiconductor products group, which is trying to increase its market share in handset PAs with its E-PHEMT-based modules, said in Cannes that Japan-based handset maker NEC had selected its ACPM-7881 product to use in a new 3G phone.

Agilent claims that at 46%, the power-added efficiency of its W-CDMA PA module is the highest in the industry, translating to 200 minutes talk time and 130 minutes video calling time with NEC's 338 phone.

Meanwhile RFMD, the leading PA sup-

plier, launched what it called the world's smallest linear PA module to include an on-chip power detector. The Greensboro, NC, company says that integrating this function in a $3 \times 3 \times 0.9$ mm module makes handset design a much less complex task. Manufactured using RFMD's third-generation InGaP HBT process, the module is set for mass production in the spring.

TriQuint and Skyworks also launched new products in Cannes. TriQuint says that its quad-band PA module, which is manufactured using flip-chip assembly, is 30% smaller than any other quad-band PA module for GSM, measuring $5 \times 5 \times 1.1$ mm. It integrates two InGaP PA die with a CMOS controller and a GaAs passive die. All four die are flip-chip mounted to minimize thermal excursions.

Also claiming "world's smallest" plaudits was Skyworks, whose Helios Mini dual-chip radio subsystem is said to improve phone talk time by 10% by increasing PA efficiency in EDGE mode.

DVD demand accelerates AlGaInP-market growth

Booming sales of DVD players and drives will spur the market for AlGaInP laser diodes to \$1.5 billion by 2009, according to a new report from Strategy Analytics.

The current market, estimated to be worth around \$970 million, is dominated by Japanese firms such as Sony, Sharp, Mitsubishi and Matsushita, with a market share of about 75% between them. Samsung in Korea is another major producer, while a handful of Chinese and Taiwanese companies make up the remainder.

While the market will grow at around 7% annually through 2009, stiff competition from new entrants in China and Taiwan will mean that an increasing proportion of the devices will be made in South East Asia rather than Japan. "Commodity LED production has already moved from Japan to lower-cost countries," said Asif Anwar, the director of Strategy Analytics' GaAs service. "Taiwanese and Chinese manufacturers will press for a similar migration of laser-diode production and compete on price."

This trend can be observed at Huaguang Optoelectronics, mainland China's largest domestic producer of 650 nm laser-diode chips, which is planning to double production capacity this year. Currently manufacturing around 10 million chips per month, the company says that it will invest in processing equipment to increase output of the red lasers, which are used in DVD applications, laser pointers and barcode scanners.

Huaguang, which also makes a range of yellow and red LEDs, started red-laser production two years ago, and chief technology officer Xiangang Xu believes that the company has a market share of 50–60% in mainland China. Xu says that products are based on proprietary technology developed at Shandong University.

Despite the drive toward cheaper production, Anwar does not see a major switch away from Japanese manufacturers in the short term, however. He expects that some technical challenges in the design of devices will require the attention of established vendors, and that this will slow the progression to lower-cost sites. These design challenges include making the chips suitable for high-temperature operation so that they can be used for faster DVD burning.

Indeed, production capacity for high-power lasers used to write data in DVD recorders is expected to double at Japan-based Mitsubishi Electric. According to the *Nihon Keizai Shimbun* newspaper, the company, which is believed to have a 70% share of the global market for such devices, will invest \$20 million – 30 million at its Hyogo manufacturing base in a bid to raise production volume to 10 million units per month by September.

Mitsubishi previously ramped production from 1.5 million to 3.5 million units per month in December 2003, and then to 5 million units per month last spring.

Laser-diode makers push power envelope

Bookham Technology and nLight have launched high-power laser diodes that target applications including materials processing, medical treatment, and act as pump sources for other solid-state, fiber and disk lasers.

Bookham's 120 W multimode laser, which was developed at its Zurich, Switzerland, facility, is claimed to be the most powerful commercially available continuous-wave (CW) laser-diode bar in the world. Standard products emit at 915, 940 and 980 nm.



nLight's high-power Cascades range targets materials-processing and medical applications, and can act as pump sources for solid-state, fiber and disk lasers.

"We are confident that the high brightness and reliability of our industrial laser-diode bars will continue to attract new customers and accelerate the growth of diode-pumped laser systems," remarked Greg Smolka, Bookham's vice-president of sales and marketing, commercial products.

Bookham's laser-diode bar is suitable for applications as diverse as multimode pumping of cable-TV amplifiers, optical pumping for frequency-doubled lasers operating in the visible range, marking and printing, hair removal, and intersatellite communication.

US-based nLight's diodes are aimed at similar markets, and, although they are a little less powerful, they cover a wider spectral range. According to the company, its 1 cm-wide water-cooled "Cascades" bars provide 50, 60, 80, or 100 W of CW power at 790–980 nm, and 20 W at 1435–1570 nm.

The Cascades range is based on nLight's proprietary MOCVD-grown structure that has produced a diode with a CW output power of 364 W in the lab, and which was developed under the DARPA-funded super-high-efficiency, high-power-diodes program.

Nichia develops UV and blue-green lasers

By Jacqueline Hewett in San Jose

With mass production of high-power pulsed and low-power continuous-wave (CW) 405 nm lasers set to begin in a couple of months, Nichia is working to develop similar devices emitting in the ultraviolet and the blue-green. Such devices should be useful for biological, medical and display applications.

Reporting on progress at the recent Photonics West conference in San Jose, CA, Nichia researchers told delegates about a new LED structure with an increased aluminum content that emits at 365 nm, the same wavelength as its commercial i-LED.

The structure consists of an AlInGaIn single quantum well layer, with $\text{Al}_{0.13}\text{Ga}_{0.87}\text{N}$

$\text{Al}_{0.09}\text{Ga}_{0.91}\text{N}$ cladding regions and an $\text{Al}_{0.065}\text{Ga}_{0.935}\text{N}$ waveguide. The laser, which has an expected lifetime of 2000 h, works in CW mode at room temperature, with a threshold current of 50 mA at 4.8 V.

Progress in the blue-green region has been less significant because of the poor crystal quality of the InGaIn active layer. Nichia said that it was proving difficult to make 485 nm lasers. The best result achieved so far is a 482 nm laser with 5 mW continuous operation at room temperature, which is said to be the longest-wavelength laser diode based on GaN yet made.

Jacqueline Hewett is technology editor of Optics.org and Opto & Laser Europe magazine.

Ask the Expert



Rajiv K. Agarwal, Ph.D.

Lead Research Engineer

Q

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

A

Higher background levels of n type dopants in GaAs and AlGaAs structures are caused by trace levels of germanium, silicon and sulfur species present in the arsine. As customer applications evolve, the purity requirements for arsine must as well. Until recently, background doping levels of $10^{15}/\text{cm}^3$ were considered acceptable in most applications. In general, most currently available high-purity grades of arsine can satisfy these requirements. However, process changes and demand for more sophisticated devices have resulted in the need for lower background doping levels. To address these more stringent requirements, Air Products is introducing Megabit™ III arsine, our purest grade available. Our new Megabit III arsine has significantly reduced the amounts of germanium, silicon and sulfur species. Testing done at an independent laboratory proved the effectiveness of Megabit III on thick gallium arsenide films, with excellent results. In all cases, the background doping level was $<<10^{14}/\text{cm}^3$. Our research has shown that Air Products' Megabit III arsine will perform more consistently and produce fewer defects in our customers' finished products.

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Kopin sets up InGaN LED-production venture in Asia

By Michael Hatcher

Kopin Corporation has formed a joint venture company to spin off its LED technology to a low-cost manufacturing operation in Asia.

The Taunton, MA, firm will take a share in Ko-Brite Corporation in return for its technical knowledge relating to InGaN LED production and a \$3 million investment.

In addition to Kopin's investment, venture-capital group WK Technology Fund, Taiwan-based Kopin subsidiary KTC, and LED packaging company Bright LED have committed \$11.5 million to the project.

The initial deal puts only a small value on Kopin's InGaN technology, but the US firm stands to receive \$7.5 million by providing training services and transferring equipment to Ko-Brite. Overall, the transfer is expected to net Kopin around \$3 million.

Under the deal, GaN-materials-growth capability will be established in Taiwan, along with die-production facilities near Hong Kong in mainland China. Ko-Brite will market the packaged LEDs globally.

Kopin has been trying to find a low-cost LED-manufacturing partner to pair with its technology for some time. It made the decision to switch to a different manufacturing structure after LED prices, in particular for blue

cell-phone backlights, plummeted in 2003, thanks largely to low-cost Asian chip makers.

"Current trends affecting the LED industry clearly indicate that successful participants will need both leading-edge technology and a competitive cost structure," said John Fan, Kopin's CEO. He claims that the best business model for LED manufacturing is to perform epitaxy in Taiwan and labor-intensive packaging in mainland China. He believes that China provides the biggest market for solid-state lighting applications of LEDs.

"This joint venture...will position Ko-Brite as a technology leader with a strong management team and one of the lowest manufacturing cost structures in the industry," said Fan. He adds that Kopin had decided to form a joint venture, rather than establish an Asian subsidiary to make its LEDs, partly because it would allow the company to focus on its two remaining core products – HBT wafers and microdisplay technology.

Kopin plans to stop the costly exercise of manufacturing LEDs itself by March 31, and is aiming to have completed training and transfer of its LED operations to Ko-Brite by July 1. The production transfer will leave one of Kopin's two manufacturing sites in the US 90% empty and probably up for sale.

HB-LED market will be worth \$7 bn by 2009

By Richard Stevenson in Burlingame

The market for high-brightness LEDs grew by 37% in 2004 to reach \$3.7 billion. That's according to Bob Steele, who opened last month's Strategies in Light 2005 conference in Burlingame, CA.

Once again, applications in mobile terminals dominated HB-LED sales. Cell phones and their like accounted for 58% of the market (\$2.15 billion), followed by 13% shares for automotive and signage applications.

According to Steele, the application of white LEDs in full-color-display backlighting enjoyed 75% market growth in 2004. In fact, LCD backlighting overtook keypad backlighting as the biggest sector for HB-LEDs in mobile appliances, and was worth 48% of the \$2.15 billion market. In 2003, LCD backlights represented 42% of this market.

Keypad backlights represented 38% of the mobile-appliance market for HB-LEDs in 2004, down from 45% in the previous year.

In automotive applications, center high-mounted stop lamps continued to show modest growth. European sales of these products are now beginning to saturate, with an estimated market penetration of more than 80%.

Steele believes that in 2004 the largest growth in epitaxy and chip processing activity took place in Asia. However, he also noted that overcapacity in the region has led to severe price pressure, especially in low- to mid-range applications such as keypad backlights.

Looking ahead, Steele predicts that the HB-LED market will nearly double by 2009, increasing to a value of around \$7 billion. Strong though this growth is, it represents a slow-down compared with the tremendously fast expansion seen between 1999 and 2004.

III-N Technology unveils novel single-chip power AC-LED lamp

By Tim Whitaker

III-N Technology, a company located in Manhattan, Kansas, has developed single-chip power AC-LED lamps that can be plugged directly into standard power outlets and lamp sockets without power conversion. The company has applied for patent protection covering its invention.

While standard power LEDs operate from a DC supply with a voltage of around 3.5 V (for blue devices), the new chips are capable of operating directly from an AC supply with a voltage of 110 V (in the US) or 220 V (in Asia).

The announcement was made at the Photonics West conference on January 26 by Hongxing Jiang, who founded III-N Technology with fellow Kansas State University professor Jingyu Lin.

III-N Technology says that its AC-LEDs were demonstrated to the US Department of Defense community in a forum held in May 2004 in Reston, VA.

Seoul Semiconductor unveiled a similar technology at a press conference in Korea around the same time that III-N made its announcement.

III-N Technology's invention came out of the micro-LED array technology devised by the same team and which featured on the cover of *Compound Semiconductor* in November 2000. The micro-LED array consists of several tens of nitride LED devices fabricated on a single semiconductor chip. The emitters can be individually addressed so that the chip acts

as a multipixel microdisplay.

III-N Technology has further developed the manufacturing technology to fabricate arrays of emitters linked in series by on-chip interconnects. The number of linked emitters is chosen so that the sum of the voltage drop across the individual emitters adds up to the voltage of the AC supply.

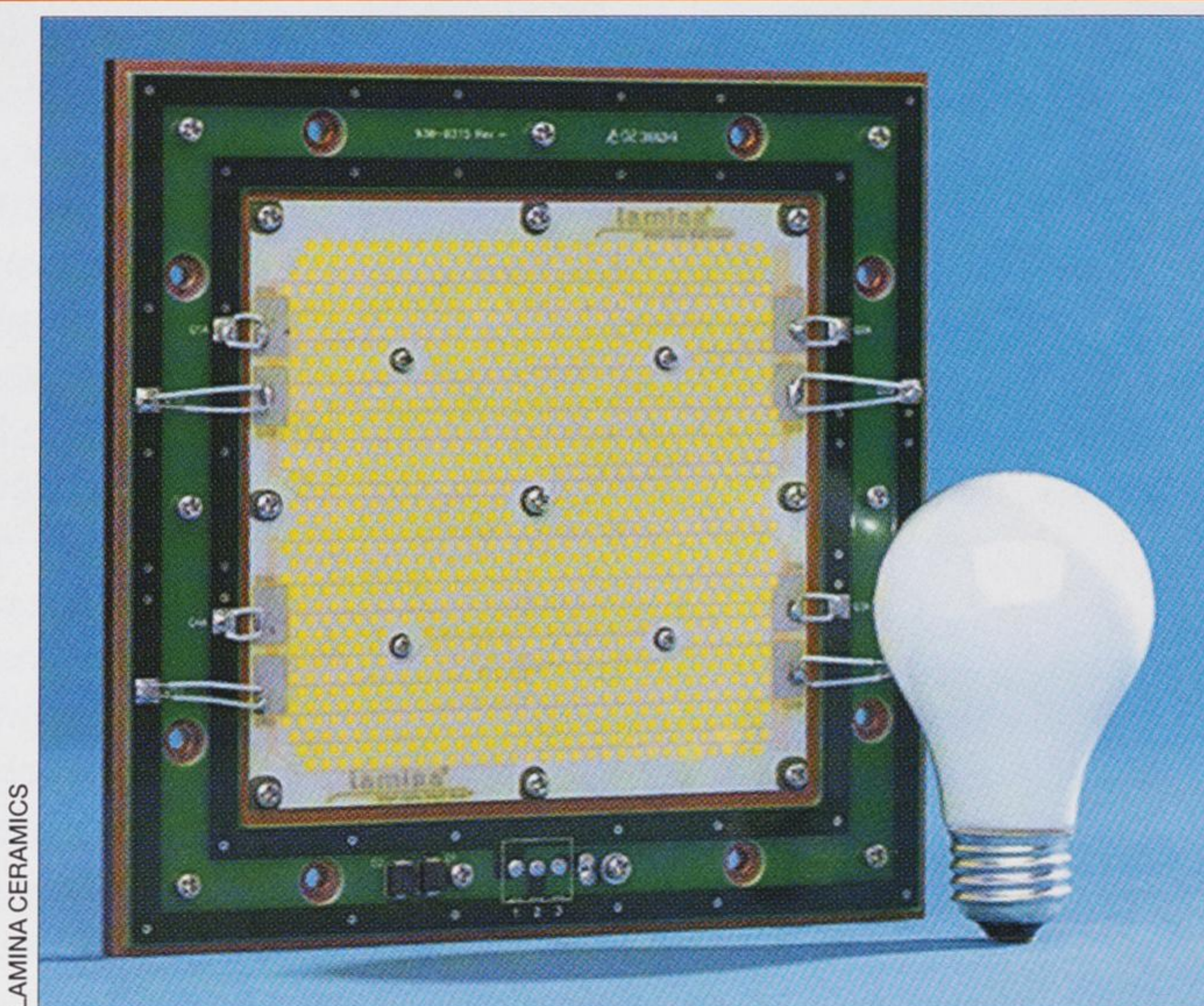
Since LEDs only emit light when they are forward biased, two arrays are created, one of which lights up during the first half-cycle of the AC power source. The second array lights up when the polarity of the source is reversed. It is also possible to use a single array and a high-voltage DC source, if required.

The technology eliminates the need for an AC/DC power converter, which is expected to lead to significant cost savings, while the chip-level architecture could lead to improvements in efficiency compared with single-chip high-power LEDs. The main advantage, however, is its compatibility with the existing lighting and electricity infrastructure.

III-N Technology says that its power AC-LEDs have comparable luminous efficiency to existing DC power LEDs of the same chip size. Hongxing Jiang says that the company is seeking to license its technology to manufacturers of DC power LEDs, and that the chip-fabrication technology is fully compatible with DC power LED production lines.

Tim Whitaker is editor of LEDs Magazine, see www.ledsmagazine.com.

New Jersey, US, firm Lamina Ceramics claims to have developed a white-LED array that emits 28000 lm. The 5 inch square module, which consumes 1.4 kW in power, is said to be twice the brightness of the red-green-blue light source Lamina unveiled last year. Called "Aterion White", the array contains 1120 LEDs. Its color-corrected temperature is 5500 K, while the color rendition index is rated at 80.



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4 inch HBT wafer line makes InP lasers

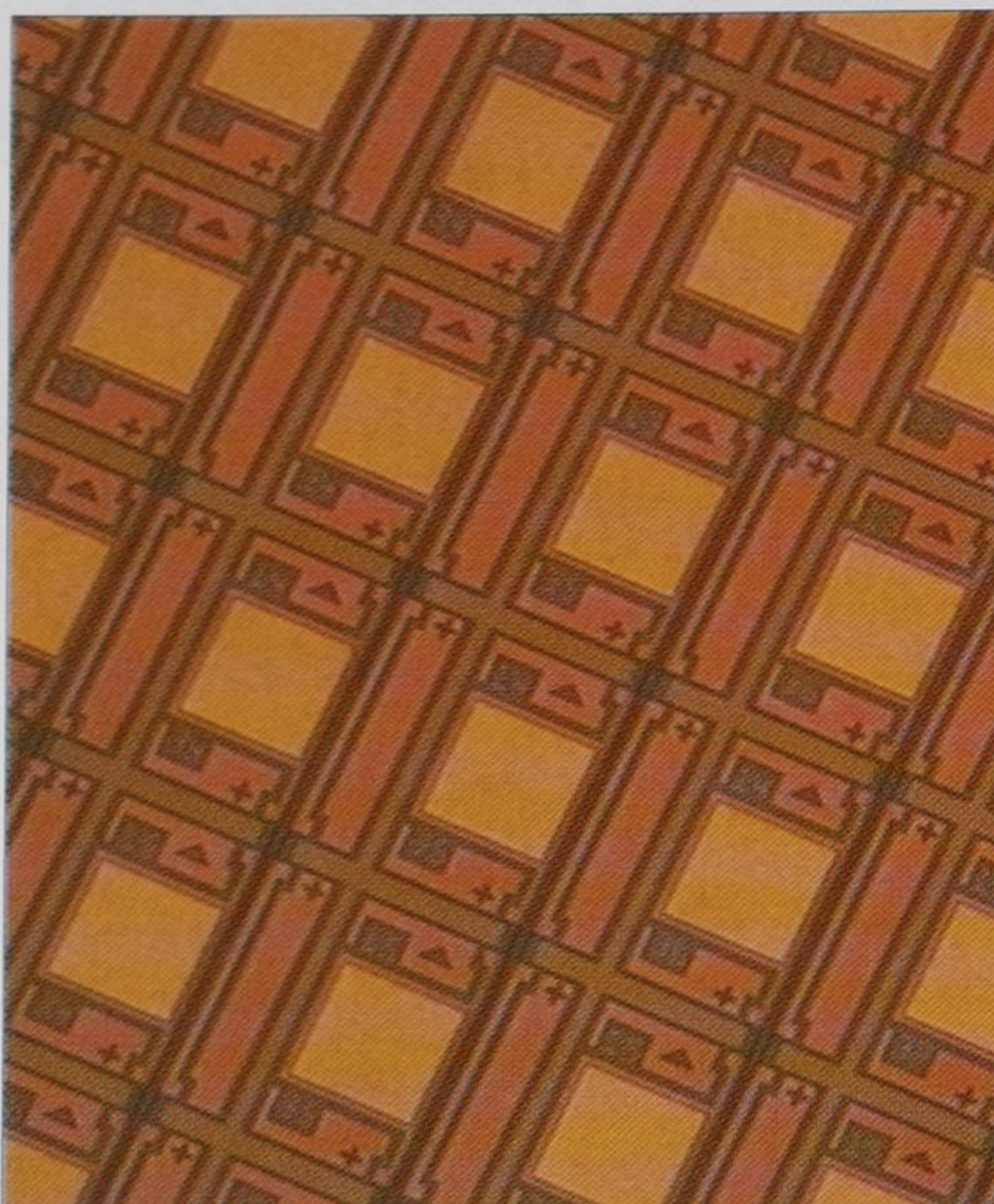
US firm Vitesse Semiconductor and Ireland's Eblana Photonics have applied a standard HBT manufacturing process to fabricate laser chips on Vitesse's 4 inch InP wafer line.

The two companies have also signed a manufacturing agreement, and Eblana is planning to start ordering materials and fabricating chips around the middle of this year.

Vitesse and Eblana believe that the low-cost process, which avoids the costly regrowth steps normally used in laser fabrication, demonstrates that optoelectronic chips can be made in very high volumes in a way that imitates silicon IC manufacture.

Eblana CEO James O'Gorman says that conventional laser fabrication is totally unsuited to very-high-volume manufacturing, and therefore only useful for niche applications such as the long-haul market. He claims that his technology platform is suitable for access, metro and long-haul applications.

O'Gorman believes that with huge fiber-to-the-home build-out programs promised in



EBLANA PHOTONICS

Eblana CEO James O'Gorman is confident that his laser technology will find widespread application as broadband fiber-to-the-home networks are rolled out.

Japan and South Korea, as well as smaller developments in progress in the US currently, there is a need for low-cost, high-volume laser-manufacturing technology. "This is a once-in-a-lifetime infrastructure build-out," O'Gorman told *Compound Semiconductor*.

The performance of the lasers fabricated on Vitesse's 4 inch InP foundry line is said to be as good as those made using distributed feedback technology. The singlemode lasers emit at 1.54 μm , with a threshold current of 12 mA. The sidemode suppression ratio is better than 40 dB, with a 20 mW laser output.

Eblana's technology, developed by O'Gorman and others at Trinity College Dublin and the Irish National Microelectronics Research Center in Cork, uses "photon-mode engineering" to control laser modes.

This means that after growing the laser's epitaxial layers, the wafer is structured to form photonic bandgaps that control the device output. Because there is no need to regrow semiconductor heterointerfaces, claims Eblana, the technology is inherently cheaper to manufacture and is more reliable than its rivals'.

"Since Eblana's technology only uses standard electronics design rules and mature processes, it achieves performance and product consistency typical of ICs, which to date have not been a feature of photonics products," said Ray Milano, vice-president of optical technologies at Vitesse.

Milano, who is not aware of any similar approaches to laser production that avoid the regrowth step, adds that he sees no drawbacks to Eblana's technology. "To my knowledge, nobody else has established this kind of process flow," he said.

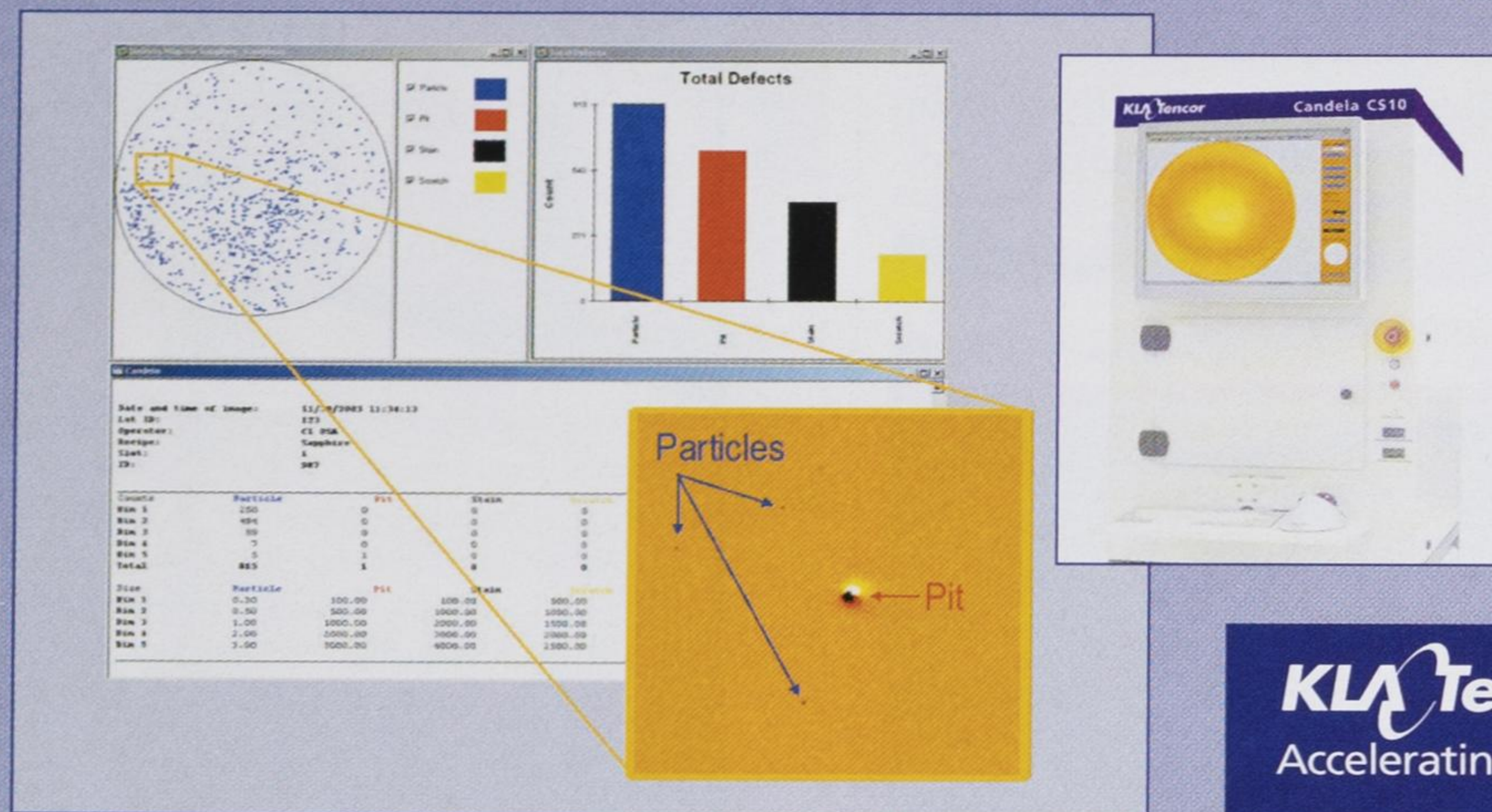
Milano added that as well as being more manufacturable, Eblana's lasers also had some advantages: "[Our] process, with its photolithographically defined features, ends up producing a tighter spread in wavelengths."

Using Vitesse's standard VIP-2 InP HBT process will reduce the overall cost of transceiver manufacture by more than 50% in volume applications, claims Eblana.

O'Gorman says that Eblana is in discussions with potential customers and has booked foundry time with Vitesse. He adds that the company hopes to be ordering the necessary materials by the middle of this year.

Eblana, founded in late 2000, had raised a total of \$7.75 million after it closed its Series B funding round in February 2003.

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BinOptics to scale up production following \$10 m funding scoop

BinOptics, the US company that makes etched-facet lasers, has raised \$10 million in Series B funding.

The company says that it will use the money to scale up its production capability for its existing InP products, while it also plans to target the emerging next-generation DVD market with blue diode lasers based on GaN.

"BinOptics has shown that its etched-facet technology is advantageous for a wide range of semiconductor materials," said Dan Brown, a partner at ArrowPath Venture Capital, one of two new investors in the company that led the funding round.

Greg Hulecki, managing partner at the second new investor, FA Technology Ventures, added: "BinOptics will play a significant role in reducing the cost of its customers' equipment and systems through efficient manufacturing and functional integration." Hulecki says that BinOptics will now move its products to full-scale production.

Those products include the proprietary horizontal-cavity surface-emitting laser

(HCSEL) – a chip technology that integrates a horizontal laser cavity with a 45° etched reflecting mirror to direct the beam vertically (*Compound Semiconductor* July 2004 p14).

Unlike most laser fabricators, which use a cleaving technique to create laser facets, BinOptics uses etching. This means that a distributed Bragg reflector can be used instead of an optical coating to produce high reflection of the laser light.

BinOptics' InP-based HCSELs emit at wavelengths of 1310 and 1550 nm, and the company plans to integrate these devices with high-speed detectors to create transceiver chips for passive optical networks. It expects to have a commercial product available before the end of this year.

The etched-facet laser technology was first developed at Cornell University, and BinOptics remains based at the nearby Cornell Business and Technology Park in Ithaca, NY.

The firm was founded in 2000 with funding from Draper Fisher Jurveston, Cayuga Venture Fund II and Stanford University.

In Brief

● **JDS Uniphase's** communications business is seeing solid growth as the fiber-optic market settles down. The group has reported a sequential increase in revenue for five consecutive quarters.

For its second quarter of fiscal 2005 ending December 31, 2004, JDSU reported total revenue of \$180.5 million. The communications group contributed \$106.7 million, or 59% of this total. The other \$73.8 million came from the company's commercial and consumer products group. For much of the past two years, the two product groups have reported roughly equal revenues.

● Californian optoelectronic chipmaker **InPhenix** has received ISO 9001:2000 certification for its manufacturing of optoelectronic components and modules. The Livermore company owns a wafer fab that produces GaAs and InP chips, where it also offers foundry services.

● Fiber module and InP chipmaker **Bookham Technology** saw revenue increase 5% sequentially to \$45.8 million

in its second quarter, which ended January 1, 2005. However, the company's negative gross margin widened, something that the company attributed to the weakness of the US dollar versus UK sterling.

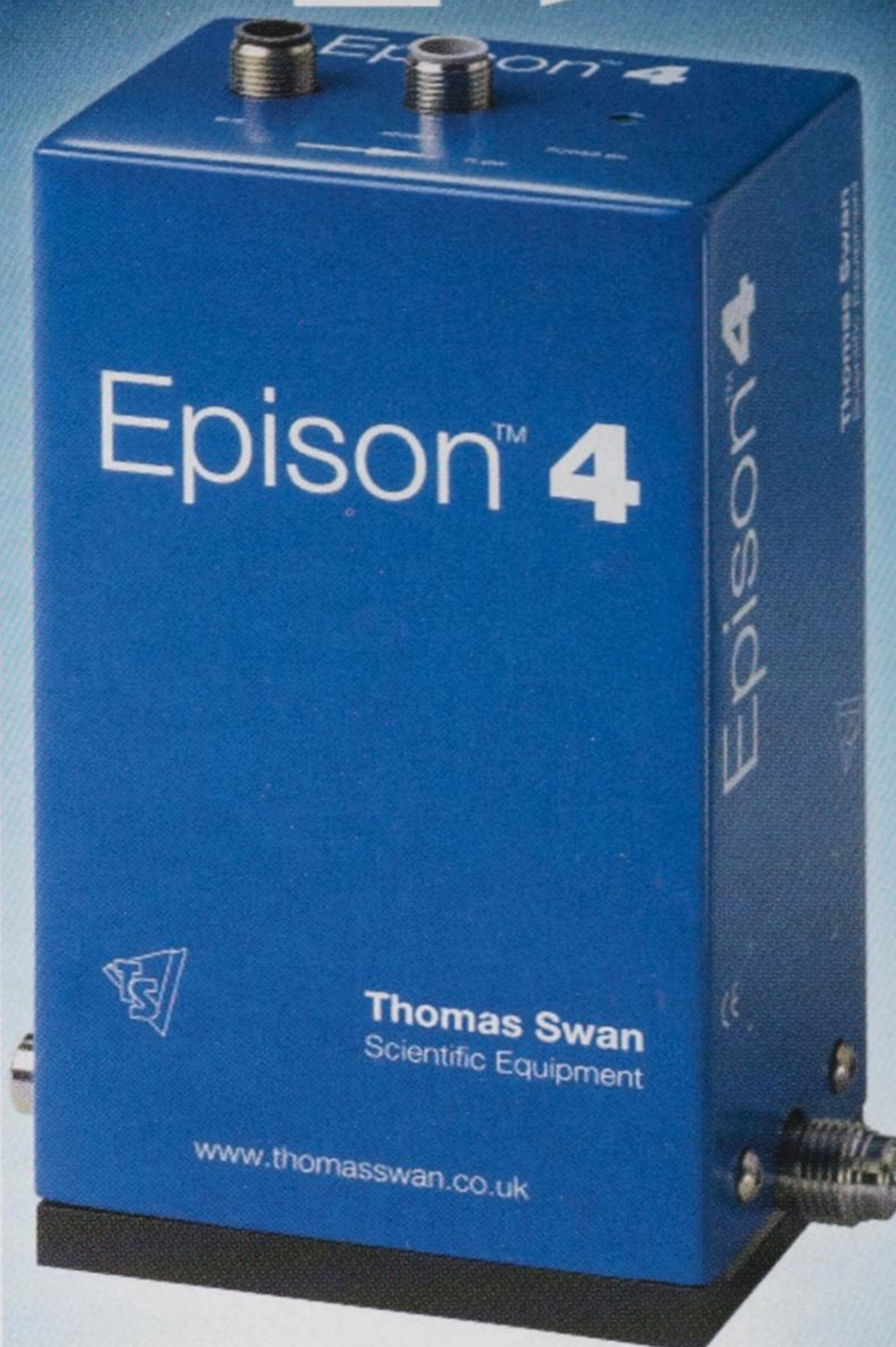
Despite improving revenue, net loss came in at \$41.1 million, compared with just \$10.6 million this time last year. The firm's costs have escalated as it is running two production lines while switching much of its assembly operation to China.

● **Emcore** reported a 17% year-on-year revenue increase as it made sales of \$27 million in its first fiscal quarter of 2005, which ended on December 31, 2004.

Having cut some research and development costs, the firm posted a loss of \$9.1 million.

● **Avanex**, the US firm that acquired Alcatel Optronics in May 2003, posted a net loss of \$24.4 million on revenue of \$41.9 million in its second quarter, ended December 31, 2004. Although the loss is slightly greater than that of the prior quarter, it represents a substantial improvement on the \$33.5 million net loss seen one year ago.

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In late 2004 The Centre for Integrated Photonics (CIP), an independent research and development firm with a rich heritage in InP-based optical components, released its first products. Electro-absorption modulators (EAMs), which operate at either 1300 or 1550 nm and at 10 or 40 Gbit/s, are the result of a development program that began when British Telecom (BT) owned the premises, and continued when Corning took over the site.

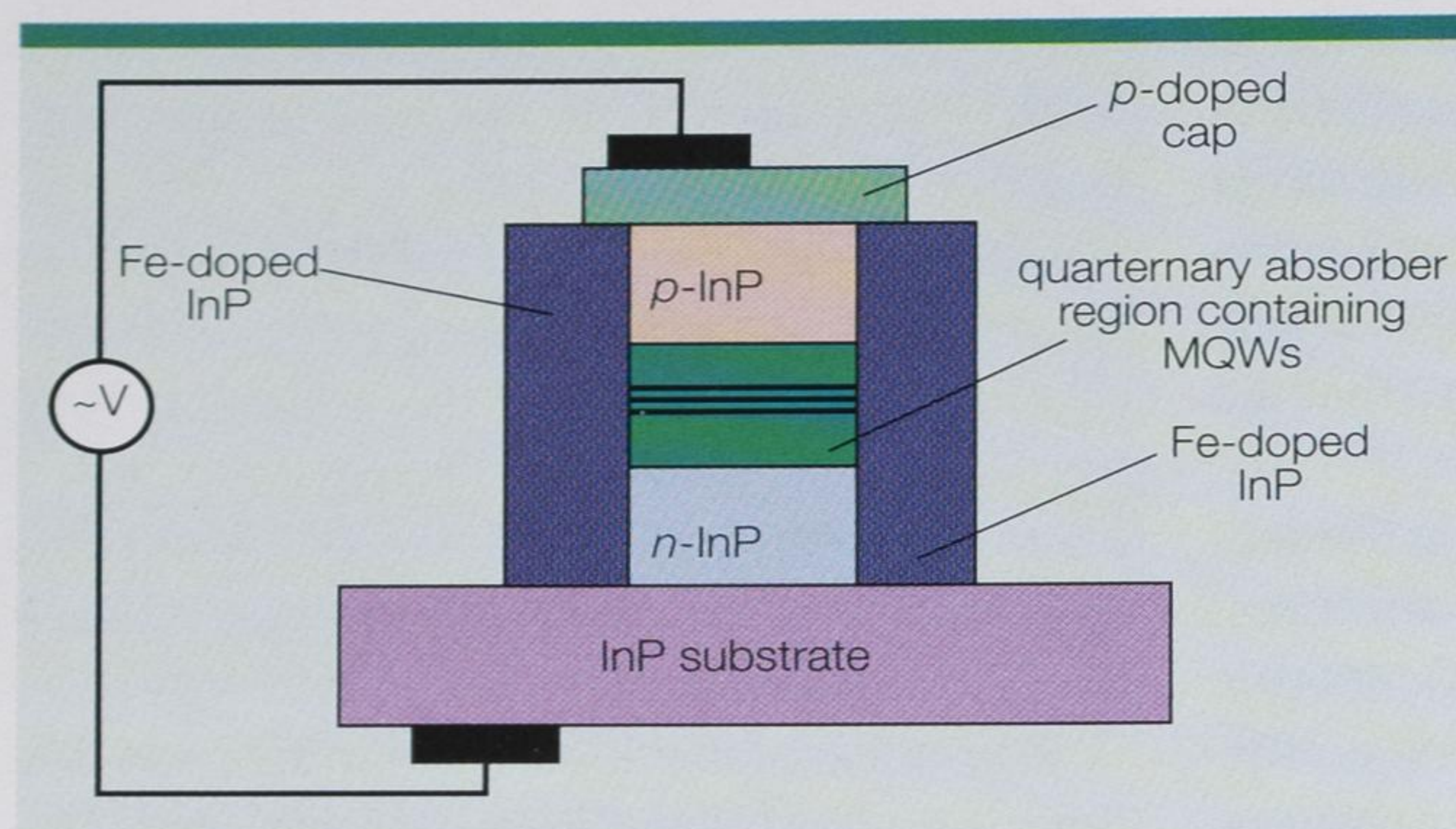
Today, however, CIP's facility is owned by the East of England Development Agency. Fitted out with £40 million (\$74 million) of inherited high-tech equipment, these facilities are used by the not-for-profit research organization to develop products for both industry and academia. The firm has released its EAMs partly in a bid to raise its profile and stimulate collaboration with industrial partners. The components themselves have useful characteristics, including low-voltage operation, high optical throughput and high-power handling.

The key attribute of EAMs – devices which are analogous with camera shutters – is that they generate short optical pulses at frequencies unattainable by laser modulation. Since they do not emit light, they are used in conjunction with a continuous-wave laser. Applying an electric field across the device enables rapid switching, thereby circumventing the slower electron-hole recombination process. Dave Moodie, CIP's EAM specialist, said: "The speed is fundamentally limited by the uncertainty principle", implying that the devices could operate in the terahertz regime.

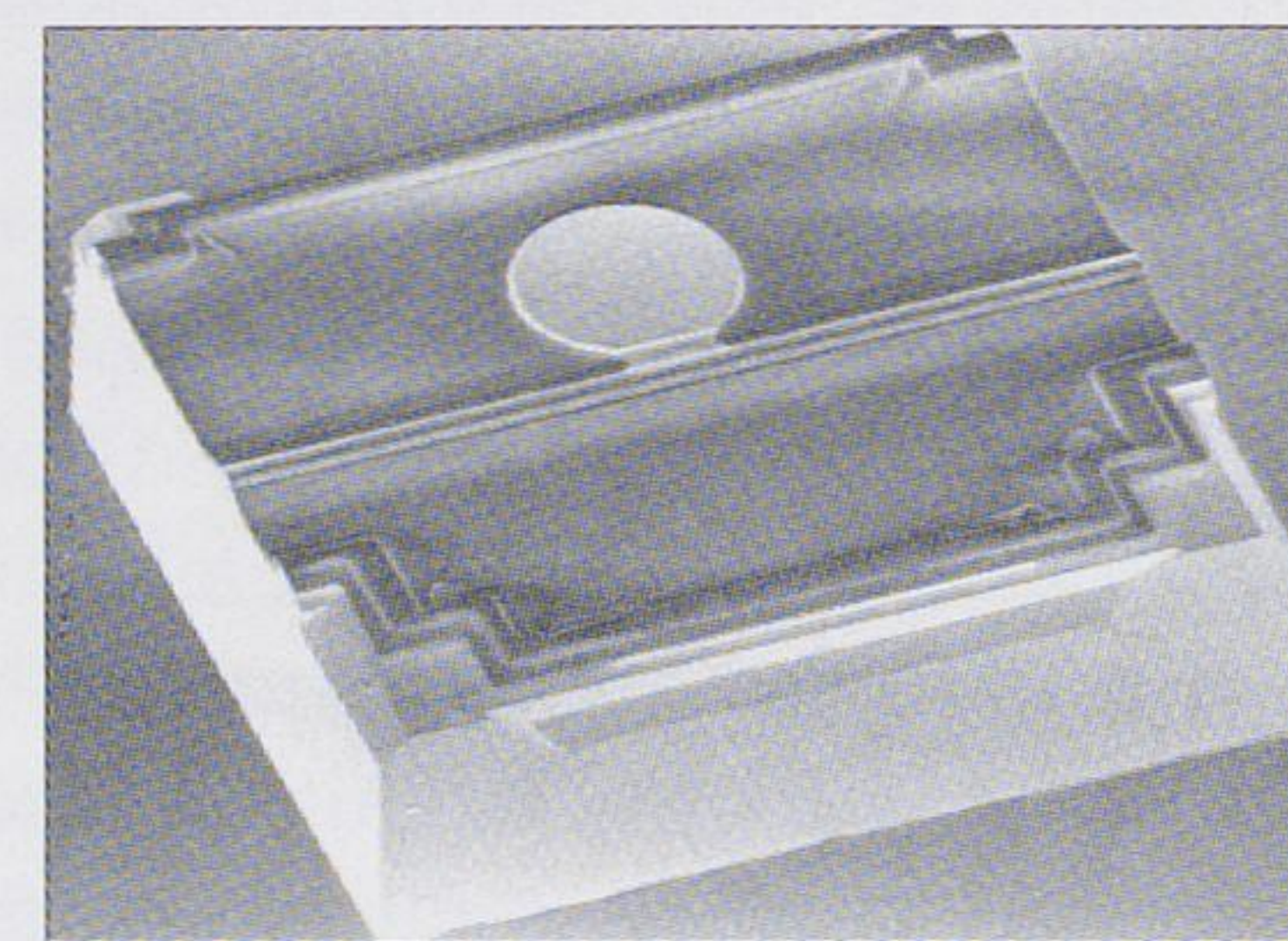
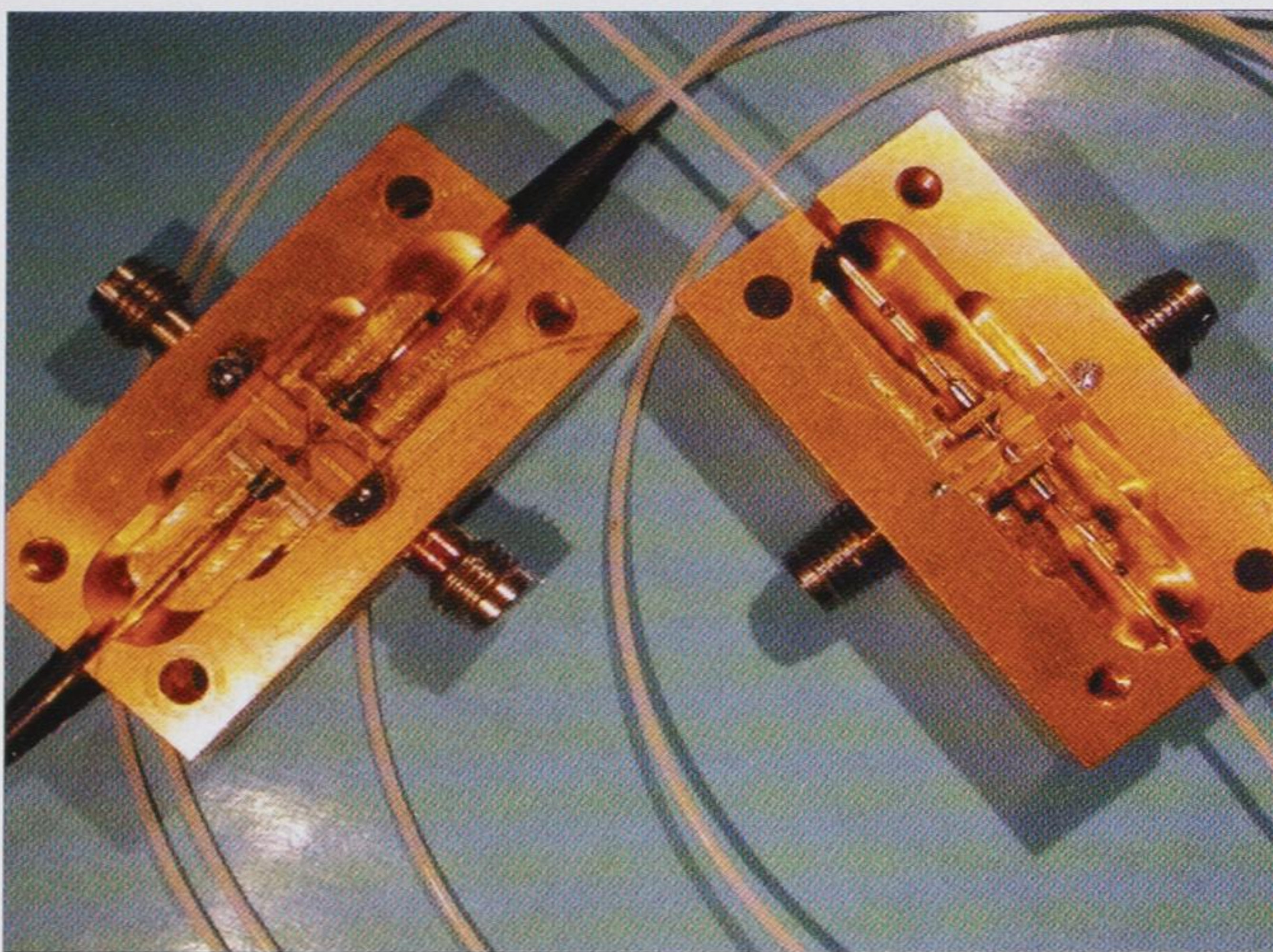
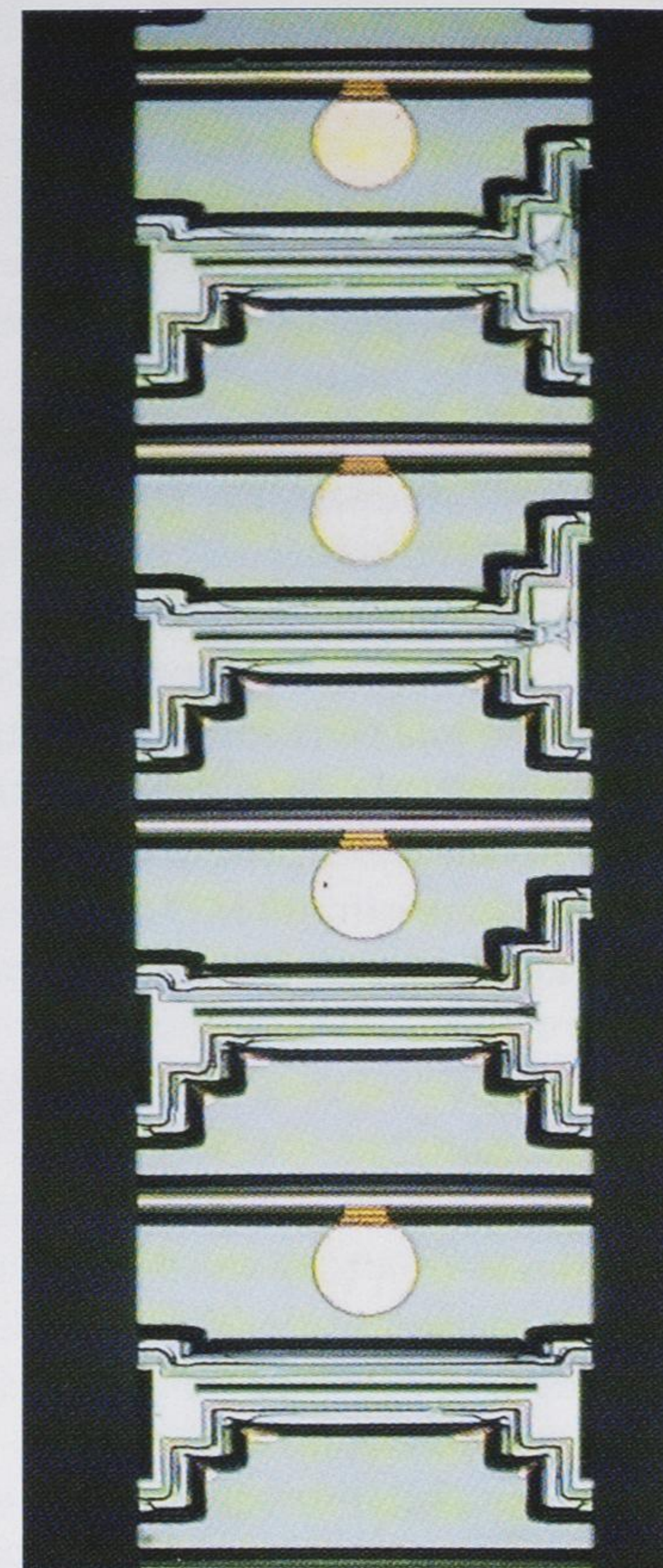
CIP's EAMs can be used in either single-mode or dense-wavelength division multiplexing communications. The devices consist of an intrinsically doped absorber region of less than 1 μm thick, sandwiched between *p*- and *n*-doped InP layers (figure 1). The "camera shutter" is triggered by applying only about 3 V across the device.

Within the absorbing region is a multi-quantum well structure. An electric field alters the wavefunctions of electrons and holes within the wells, thereby shifting the absorption spectrum of the device and blocking the light output. Moodie says that a benefit of using a quantum well structure – which creates a well-resolved exciton spectral absorption edge that can be seen at room temperature – is a greater change in absorption with volt-

The renowned BT Photonics Technology Research Centre in the UK is now occupied by R&D outfit The Centre for Integrated Photonics. **Richard Stevenson** finds out what the start-up plans to do with its intellectual-property and wafer-processing-equipment inheritance from BT and Corning.



Clockwise from above. Fig. 1. CIP's electro-absorption modulator (EAM) operates at up to 40 Gbit/s and uses an applied voltage to change the optical transmission properties of its quantum well region. Fig. 2. EAMs are grown on 2 inch InP substrates. A bar of devices (right) is separated into individual components (bottom right), which can be tested bare, or evaluated when housed in internally produced packaging (below).



age and therefore a lower operating voltage.

To transmit high-frequency optical signals, light is coupled into and out of the EAM. High optical throughput is essential for commercial devices, and so waveguiding is implemented in two dimensions. The difference in refractive index between the absorber region and the *n*- and *p*-doped InP layers introduces optical confinement in the growth direction, while

confinement perpendicular to this axis is achieved by mesa etching followed by regrowth of high-index material. CIP's design involves fabricating a relatively tall, narrow mesa, followed by planarization of a regrown, current-blocking, Fe-doped, InP layer using PCl_3 . This approach differs from most other EAM manufacturers, which use shorter mesas and need to regrow dielectric layers.

ns to exploit famed history

The Centre for Integrated Photonics

CIP's site at Adastral Park, Ipswich, has a strong pedigree in optoelectronic component development. It was where BT did pioneering research – including production of the world's first monomode optical fibers; it was part of the collaboration that developed erbium-doped fiber amplifiers; and it was also instrumental in the development of InP-based buried heterostructure lasers. After BT sold the site to Corning in 2000, the US company invested heavily in equipment until it eventually departed in 2003.

CIP was set up on 1 January 2004 as an open-access laboratory offering services to both industry and academia. Owned by the East of England Development Agency, CIP is a not-for-profit organization, and any income it generates is reinvested in its facilities.

A third of its funding comes from UK grants, another third from contract work, commercial activities, and consultancy, with the remainder from European Union grants and international contracts.

CIP's areas of expertise include InP growth, structure definition in planar silica and silicon, thin optical coating deposition, prototype packaging and optical testing. Applications for these technologies include biophotonics, optical communications, RF/microwave sensing and terahertz-wave generation.

Today CIP has a staff of about 30, most of whom have held positions at BT, Agilent Technologies, or Corning. Between them the staff have a combined experience in the photonics industry of more than 500 years.



Moodie says that CIP's design has the advantage of distributing optical absorption more gradually along the EAM's length, which improves optical power handling. The optical mode between the EAM and the optical fiber is also better matched, thereby reducing coupling losses and resulting in low device insertion losses (typically < 4.5 dB in the low-loss stage). A further advantage of this design

is the lower electrical capacitance per unit length, allowing fabrication of high-speed (40 Gbit/s) EAMs. The end result is uncompensated 40 Gbit/s transmission in the 1550 nm waveband over distances of up to 100 km, a feat that usually requires an additional optical amplifier.

Size is everything

The size of the EAMs also gives them a competitive edge – tens of thousands of millimeter-sized devices can be produced from a 2 inch InP wafer. "Size is becoming a huge issue," said Moodie, who believes that established lithium niobate-based EAMs are too bulky to compete in tomorrow's market-place.

CIP is targeting a range of applications with its high-speed EAMs, including optical modulators for low-chirp 10 Gbit/s systems, 40 Gbit/s transmission, optical sampling and demultiplexing for 160 Gbit/s optical time division multiplexing, and as compact optical-pulse sources. The devices could also be suitable for more exotic networks, for instance providing RF-to-optical conversion in military, medical and sensor applications.

According to Moodie's colleague Alastair Poustie, who investigates EAM performance, CIP is also able to produce variants of the device with application-specific characteristics designed to operate "anywhere across the InP band". Poustie acknowledges that CIP requires a partner for the large-volume manufacture of EAMs, because although chip production can be carried out in-house, packaging would have to be undertaken elsewhere. The firm, which can integrate EAMs with other optoelectronics, will also consider other agreements, such as licensing its process.

The cycle time for CIP to manufacture its EAMs is currently around two weeks, though CIP's III-V growth specialist Michael Robertson says this could be speeded up by introducing some automation.

The range of growth, processing, and test equipment that CIP owns, with a total value of £40 million, is truly outstanding when one considers its size. EAM material growth is carried out by MOCVD on an Aixtron 2400G3 system with an 8 x 2 inch platform, with the current focus on proof of concept, rather than manufacturing issues. As Robertson pointed out: "Everything was writ-

ten off by Corning when it was sold to CIP, so we don't suffer from capital depreciation. That's why we can afford to have a multimillion pound kit running one wafer per day."

However, using a multiwafer reactor does at least demonstrate that the EAM growth process is applicable to large-scale production, says Robertson. Although the subsequent over-growth step – depositing an iron-doped semi-insulating InP layer – is performed on one of three 2 inch single-wafer horizontal reactors inherited from BT, he says that there is no reason, in principle, why the Aixtron reactor cannot be used for over-growths.

CIP's epiwafers can be evaluated in-house using X-ray diffraction, room-temperature photoluminescence mapping, electrochemical carrier concentration profiling, and an advanced form of ellipsometry. Wet etching is carried out in a dedicated room that's designed for flexibility, and CIP can perform dry etching and metallization through either a sputtering technique using an RF plasma source, or electron beam evaporation.

To improve EAM performance, oxide-based films containing more than 100 layers and with a total thickness of 7 µm are applied to the facets of EAM chips by plasma-ion-assisted deposition. These coatings increase the optical coupling into the device by reducing reflectivity from 30 to ≥ 0.1 %. Film-thickness control is maintained through a combination of optical monitoring and feedback from 12 quartz-crystal oscillators.

A dedicated test and measurement room is used to examine bare and packaged devices at various temperatures. Robertson explains that most of the testing, coined "red flag testing", aims to determine whether any major changes are occurring within the material, such as the movement of dopants. Packaging the bare EAMs chips can be done in CIP's small mechanical workshop, which also has cleaving, scribing and polishing facilities.

CIP intends to release more optical components in 2005, and recently launched a family of 40 Gbit/s semiconductor optical amplifiers. The company is aiming to become a sustainable commercial enterprise in the next three to four years, and so any income generated through interaction with commercial device manufacturers will be crucial in its quest for economic independence. ●



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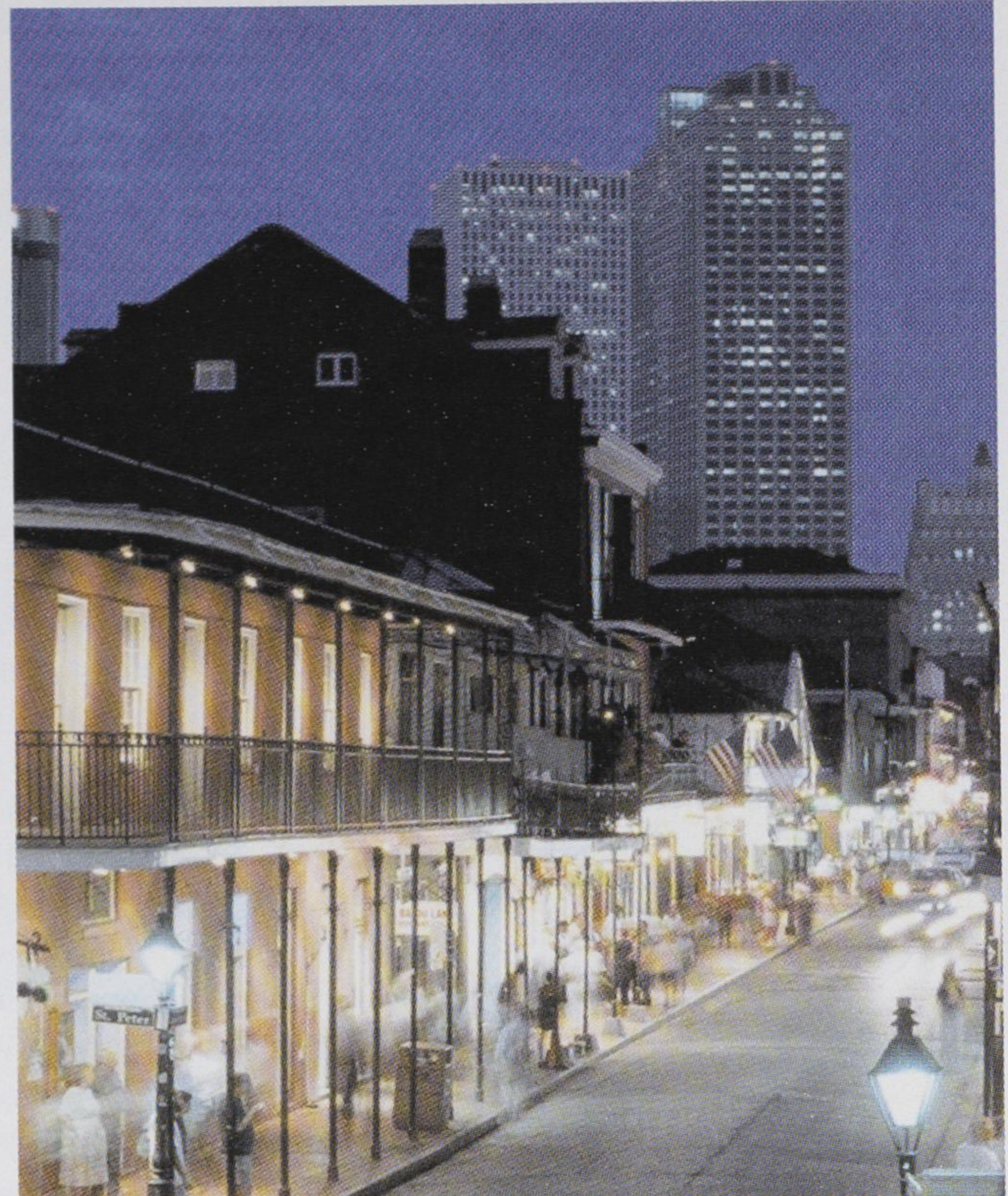
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- Mark Rosker, DARPA, provides an overview of wide bandgap technologies for microwave and millimeter-wave applications.
- Chuck Weitzel, Freescale Semiconductor, will present performance comparisons for GaAs, SiGe, LDMOS, GaN and related technologies.
- Sean McGrath, Philips Semiconductors, provides an overview on benchmarking of achievements and relative market opportunities in wide bandgap technologies.
- Herbert Bennett, U.S. National Institute of Standards and Technology, will discuss the role of compound semiconductors in the context of the 2003 International Technology Roadmap for Semiconductors (ITRS).
- Asif Anwar, Strategy Analytics, will give an overview of the CS supply chain and CS market share gain opportunities.



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X-band radar is set to reap benefits of GaN technology

Complex US military projects, such as the development of unmanned air-combat systems, demand an investment in high-technology equipment and a likely role for a range of III-V devices. **Yvonne Carts-Powell** describes some recent progress that has been made with GaN transistors.

The impressive speed and power handling of GaN has been evident for some years, and the potential of transistors based on the material is sufficiently promising that the US military and others are funding their development. Now, GaN transistors aimed at uses in future high-performance millimeter-wave (MMW) military communications links and X-band radar are being reported by a number of groups.

The US military employs RF transmitters and receivers for a plethora of applications, which include all-weather radar, surveillance, reconnaissance, electronic attack and communications systems. However, power amplifiers (PAs) in many systems still use vacuum tubes. As recently as last year, the US Navy was still funding research to improve this technology, in particular for high-data-rate communications and high-power, high-frequency radar applications.

An ideal PA is small, light, cheap, reliable and efficient, and it should provide high power densities, transmit across a wide range of bandwidths and operate in a broad range of temperatures. Wide-bandgap semiconductor electronics can provide power amplification (and low-noise amplification) with the potential advantages of being more compact, robust and longer-lived than vacuum tubes. Before solid-state electronics can replace vacuum tubes, however, the technology must be optimized and shown to be manufacturable. Material quality and process technology will dictate device performance.

GaAs and silicon PAs are already being used in some of these military systems, but GaN (along with SiC) can potentially operate from VHF through X-band frequencies while providing higher breakdown voltage, better thermal conductivity and wider transmission bandwidths than conventional devices are able to offer. GaN transistors that are the same size as GaAs devices can operate at higher powers with higher impedance.

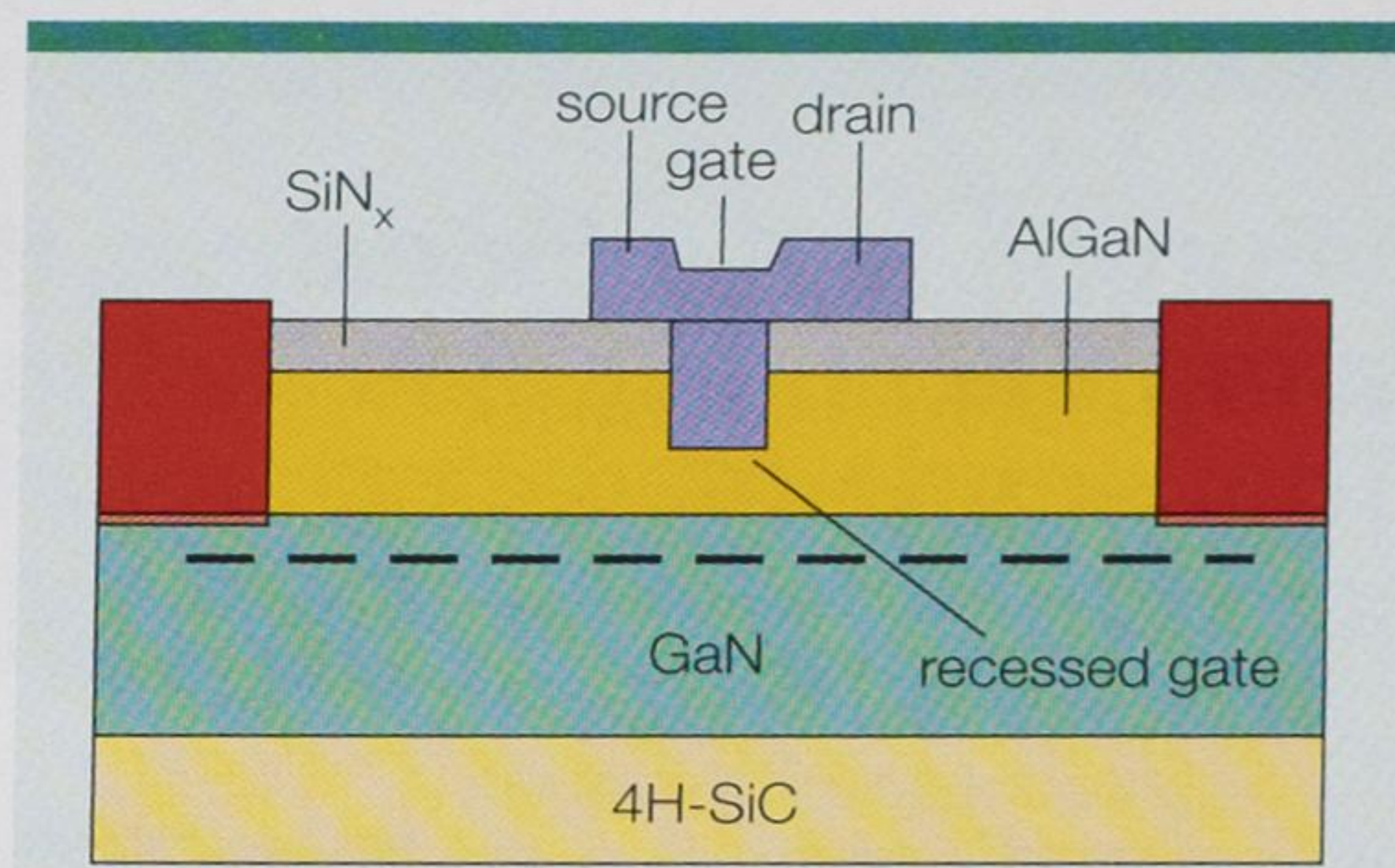


Fig. 1. This AlGaIn/GaN HEMT made by HRL provides high power density and high frequencies at the same time.

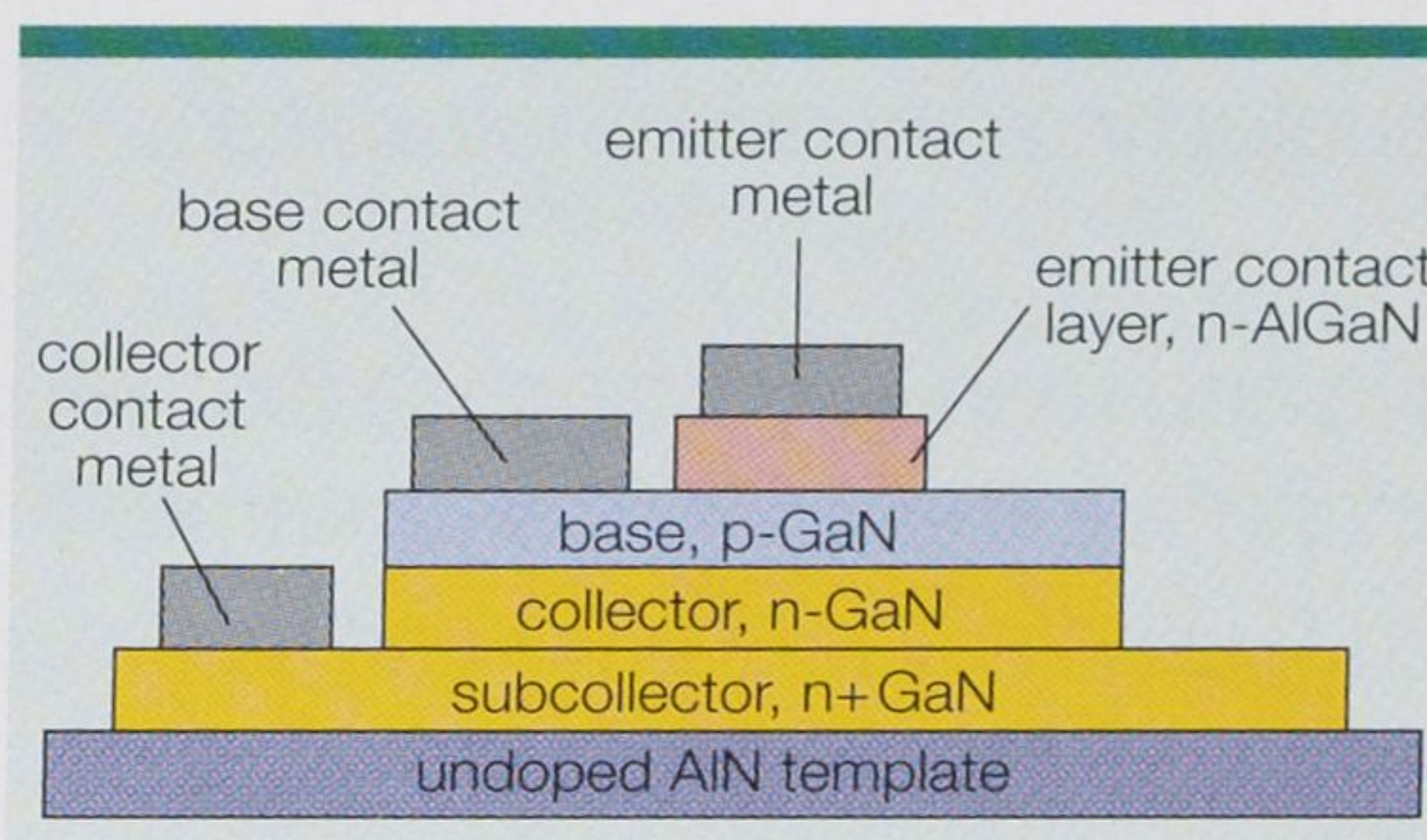


Fig. 2. US firms working with the Air Force and Boston University proposed this design for an AlGaIn/GaN HBT for X-band radar.

Within the field of RF applications, MMW communications links and X-band radar are two major areas of interest. Strategic military communications systems range from 7 to 44 GHz and beyond. Some of these will be space-borne, in which case high efficiency, reliability and low weight are all crucial. Radar traditionally requires very high pulse powers in the microwave bands from UHF to X-band (8–12 GHz) and beyond, and it includes a variety of ground, air, ship and mobile platform installations.

Signal quality is paramount

Millimeter-wave AlGaIn/GaN HEMTs have been developed with an emphasis on both output signal quality and linearity, and the US Navy is now in the process of testing the life-

times of GaN HEMTs and MMICs.

Military systems that use active aperture antenna arrays need a linear amplifier behind each antenna element, and GaN is well suited to provide that amplifier for many of these communications and radar systems. The US Navy has also funded the development of high-power broadband AlGaIn HEMT amplifiers that emit tens of watts of power at many frequencies for use as electronic decoys.

GaN's competitors can't keep up

Other materials, including GaAs and SiC, cannot measure up to GaN's ability to provide high power and high frequency at the same time. GaN's wide bandgap of 3.4 eV, high electron saturation velocity (2.7×10^7 cm/s), low onset resistance and ability to operate at high temperatures together result in potentially high-efficiency devices. GaN can also operate at higher voltages: it has a breakdown voltage of 70 V compared with GaAs's 5 V and InP's 3 V. GaN's large bandgap also makes it much less susceptible to radiation damage, which provides an additional benefit for satellite systems.

Satellite-based communications transceivers need efficient, robust and reliable transistors that can act as power amplifiers at MMW frequencies. Jeong-Sun Moon at HRL Laboratories in Malibu, CA, who presented a paper entitled "Deep-submicron gate-recessed and field-plated AlGaIn/GaN HFETs for millimeter wave applications" at the MRS Fall 2004 meeting in Boston last December, believes that GaN devices compare well to GaAs for Ka-band and even higher-frequency communications equipment. "Current GaAs power HEMT technology is hitting a wall trying to deliver high power and high efficiency at the same time," he said. "GaN may overcome [GaAs] and move beyond it."

In his talk, Moon said that PAs based on GaAs PHEMTs could produce less than 6 W of output power in the Ka-band with a power-

The logo for SEMICON Europa 2005 is positioned on the left side of the page. It features the word "SEMICON" in large, white, stylized letters, with "Europa 2005" in blue script below it. The background of the logo is a collage of images: a group of men in business suits, a modern building with a glass facade, and a large flagpole with many flags flying.

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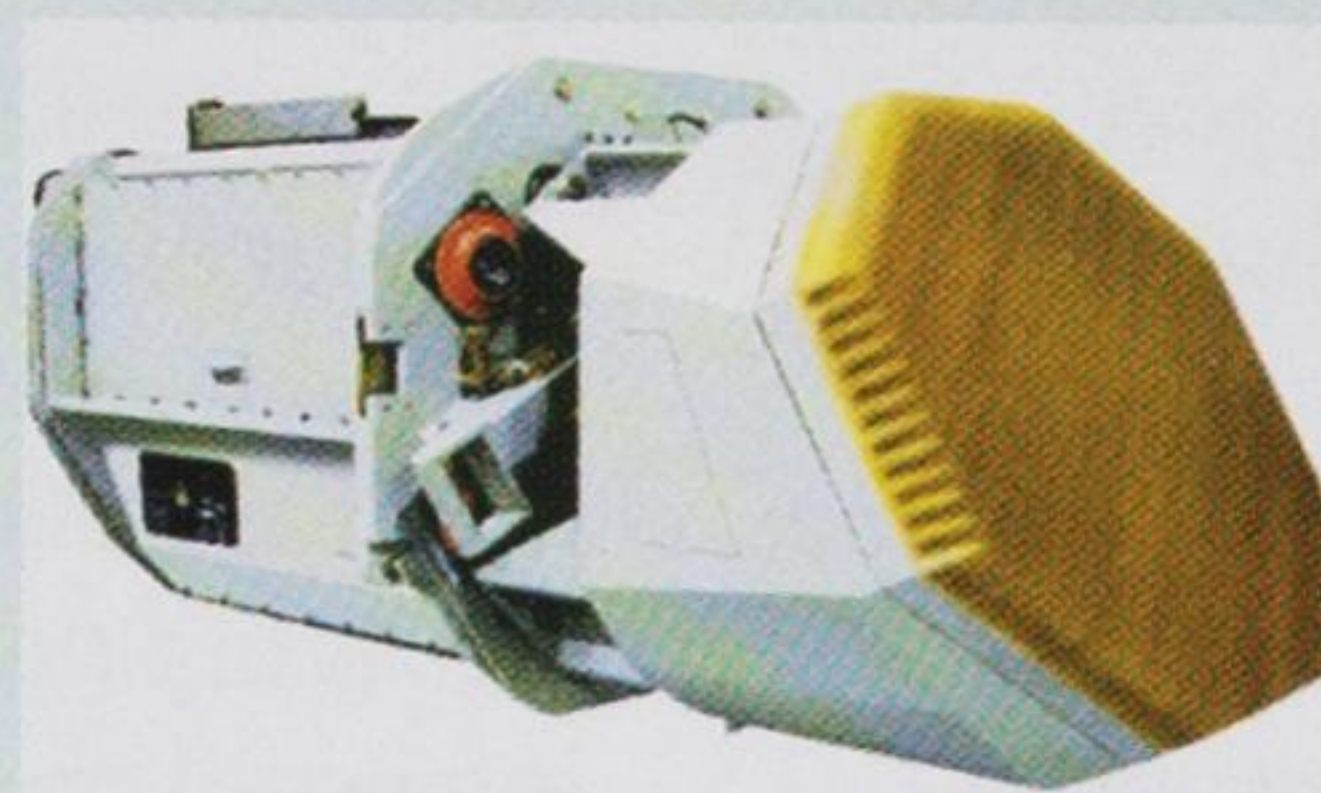
By Michael Hatcher

DARPA is leading the US Department of Defense effort to develop the Joint-Unmanned Combat Air Systems (J-UCAS) project, a high-technology program that may end up using a variety of III-V technologies. The effort actually involves two programs, called X-45 and X-47. These are being led by Boeing and Northrop Grumman respectively, and each is funded to the tune of around \$1 billion.

The basic idea behind the projects is to demonstrate full-scale aircraft that are able to fly themselves without the aid of a pilot or navigator and to carry out tasks such as electronic attacks, surveillance and precision strikes.

A wealth of technological development is required to get the aircraft ready for 2007, when flight demonstrations are scheduled to begin.

One of the critical technologies under development for J-UCAS is X-band communications. Raytheon is building the antenna technology for X-band thin radar aperture (XTRA), which employs arrays of devices to transmit



Raytheon's APG-79 advanced radar system (left; part blurred, at the request of the US Army), which uses GaAs devices, is set to be installed on 415 Super Hornet (above). Unmanned aircraft being developed under J-UCAS (bottom left) may also use this radar technology.

and receive signals at around 8 GHz.

In December 2004, Boeing's X-45 vehicle completed a flight test where control of a demonstration aircraft was switched via UHF satellite communication from the Edwards Air Force Base in California to a Boeing facility in Seattle and back again.

The transmit/receive modules that may end up being used by unmanned

aircraft are also being developed for fighter aircraft, including the F-15 and F/A-18 Super Hornet.

In January of this year, Raytheon delivered, ahead of schedule, the first of an expected 415 advanced array systems for the Super Hornet aircraft. Raytheon confirmed that the active electronically scanned array (AESA) system, which is also known as APG-79, uses GaAs devices.

added efficiency (PAE) of about 23%. High-voltage GaAs FETs have shown better credentials with 1.5 W/mm power density, but so far the frequency performances have been limited. The MMW communications application could use more power but, equally important, it could also use higher efficiencies. GaN HEMTs have the potential to operate at power densities 10 times as high as those that GaAs PHEMT devices can cope with.

The efficiencies and power of GaN transistors have been increasing steadily. Also at the MRS meeting, Moon described GaN HFETs operating at 10 GHz with an output

power density of 11 W/mm and a PAE of 50% at $V_{ds} = 30$ V. At 30 GHz in the Ka band the same device produced a power density of 5.7 W/mm, with a PAE of 45% at $V_{ds} = 20$ V – better than the best reported GaAs PHEMTs.

Less circuit protection required

These GaN devices have other advantages too, including high-temperature operation, and they do not require as much off-chip circuit protection as GaAs transistors. Using GaN instead, those protective circuits could be eliminated for weight and cost savings. In addition, the ability of the GaN transistors

to handle higher voltages may allow the systems to use fewer transistors in total.

Moon also described efforts to optimize AlGaIn/GaN-based HFETs. Conventional T-gated HFETs operating at high frequencies showed a power output much lower than theoretically possible, which could be attributed to high field-induced trapping under high voltages and high RF power operation. The HRL team has also produced AlGaIn/GaN HFETs optimized in a deep submicron field-plated and gate-recessed layout in order to operate the devices at higher frequencies than the X-band (i.e. in the K, Ka, Q and V bands) with high power and high efficiency.

X-band bipolar transistors

There is some precedent for this design, with recessed gates and field plating employed to increase power performance at low GHz frequencies. The HRL group therefore made an AlGaIn/GaN HFET on a SiC substrate with a recessed gate (figure 1). The gate foot dimension ranges from 0.23 to 0.14 μm , with a recessed depth of 10 nm. The gate-recessed and field-plated devices showed a source-drain saturation current density (I_{dss}) of 0.7 A/mm with a pinch-off voltage of -2 V. The measured extrinsic transconductance was as high as 600 mS/mm – comparable to that of GaAs PHEMTs. The output power density and PAE of gate-recessed and field-plated AlGaIn/GaN HFETs were almost twice those of baseline planar AlGaIn/GaN HFETs.

In the meantime, GaN bipolar transistors are being developed through a collaboration between Photronix of Waltham, MA; Solid State Scientific in Hollis, NH; Boston University; and the Air Force Research Laboratory. The team is researching GaN *n-p-n* transistors for use in X-band radar transceivers (figure 2).

Although AlGaIn/GaN FETs look promising, bipolar transistors offer several inherent advantages over FETs, explained William F Stacey from Photronix. Bipolar transistors are normally “off” devices that ought to provide more uniform threshold voltages, higher linearity and higher current densities than FETs. This is particularly attractive for applications that need ultrawide bandwidth, high linearity and high power.

At the Fall MRS Meeting, Stacey described the team's progress. It has received SBIR Phase 2 funding to develop the GaN bipolar transistor but is yet to report success. The group has, however, made two back-to-back *p-n* diodes on an AlN substrate, plus a GaN

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homojunction transistor on a SiC substrate.

These diodes were made by growing multi-layer GaN films onto 1 cm² AlN templates. The AlN layer sits atop a sapphire substrate, but Solid State Scientific, which supplied these materials, plans to provide AlN detached from the substrate. This unconventional AlN substrate is more compatible with GaN than either sapphire or SiC in a number of ways: the crystal structure, lattice size, thermal expansion, thermal conductivity and chemical properties are well matched. If large, uniform AlN substrates can be made cost-effectively, they could provide a substrate for high-quality GaN epitaxy (see *Compound Semiconductor* October 2004 p27).

At Boston University, researchers have optimized MBE growth to produce diodes that have the qualities that the transistor will need. Mesas were etched using inductively coupled plasma, and novel wafer processing techniques provided good uniformity as well as control of the etch depth.

The resulting diodes showed stable device characteristics over 20–475 °C, and two promising attributes in particular: a long-term

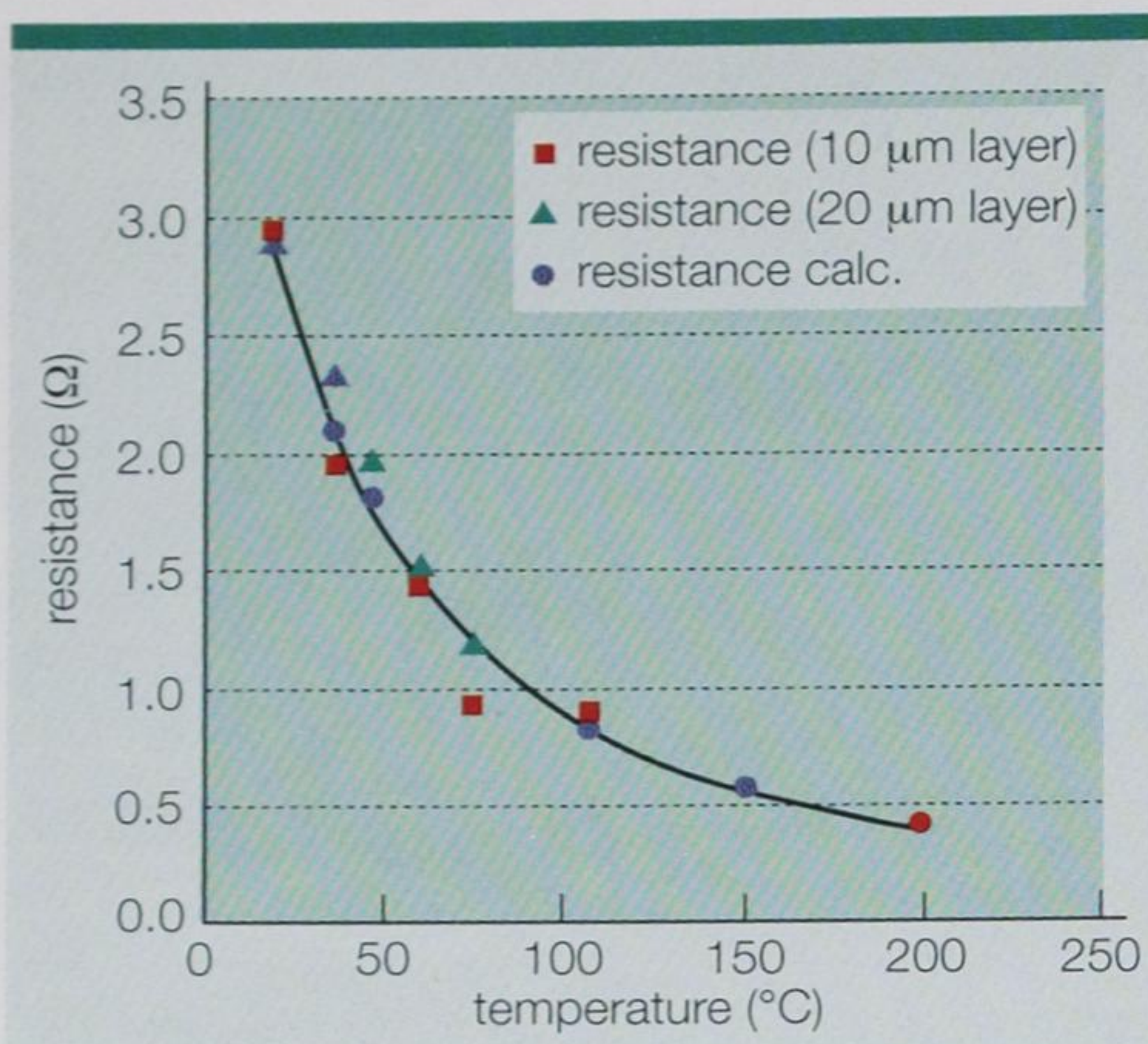


Fig. 3. As the temperature increases in a GaN diode, the resistance of the *p*-doped base layer drops, Photronix researchers discovered. They hope to construct an *n-p-n* transistor that increases in efficiency as it heats up. Red and green points represent experimental measurements while the curve shows theoretical values.

stability at high current densities (in contrast with the behavior of SiC bipolar devices) and a *p* layer resistivity that decreased with

increasing temperature (figure 3).

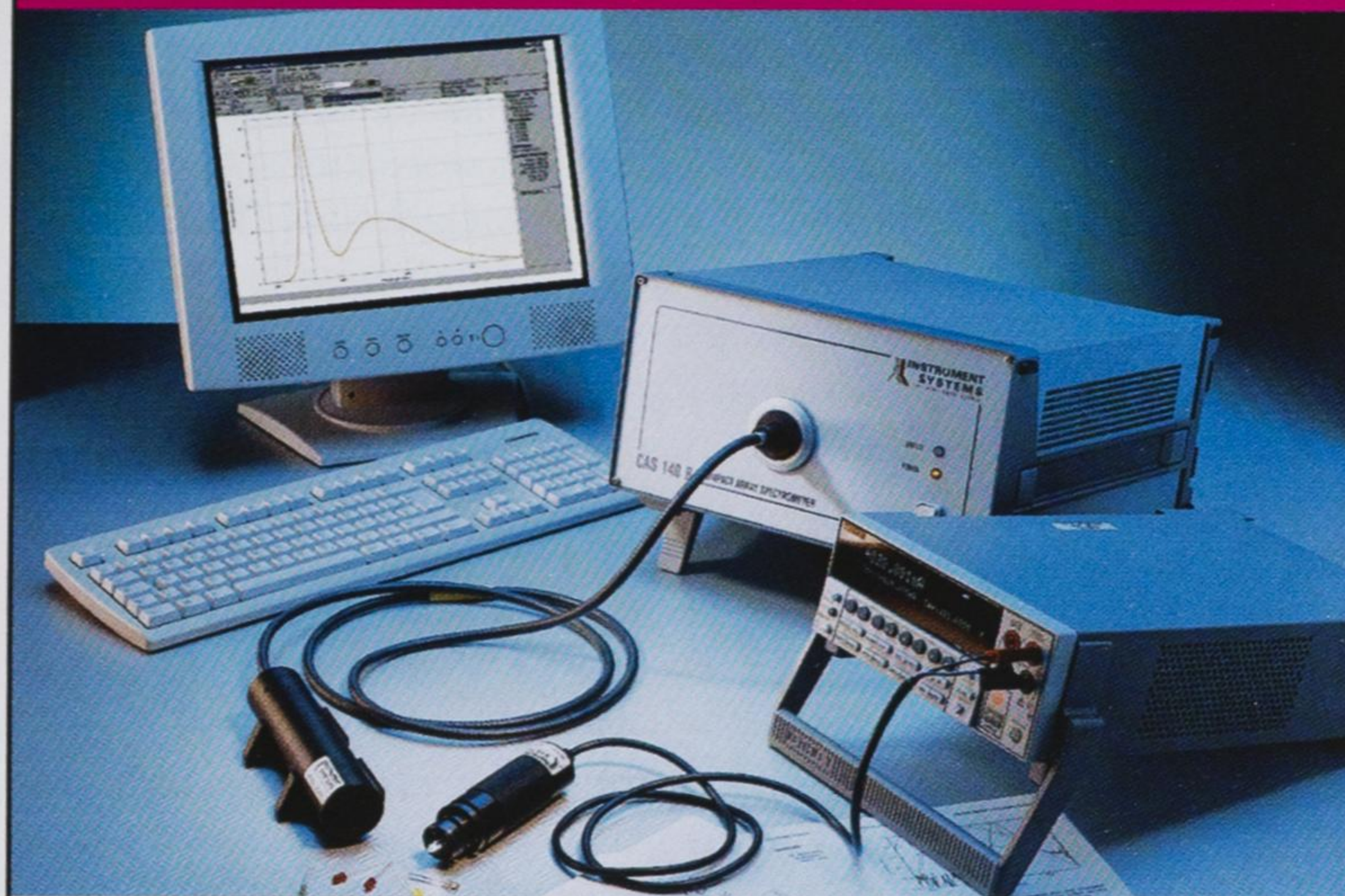
Good conductivity in the *p* layer is important, and difficult to achieve, says Phil Lamarre, president of Photronix. The resistivity characteristics mean that the diode (and eventually the transistor) becomes more efficient at elevated temperatures. "You want to run it hot," Stacey explained.

The latter may be important, because the majority of the waste heat in a transceiver module is generated from the power-output stage. As a result, many devices in use now require large cooling systems. If the *n-p-n* transistor retains this resistivity drop, then system designers may be able to eliminate the cooling systems, thus making the transceivers smaller and perhaps less expensive.

When it comes to military applications, the benefits of GaN transistors are clear, and this is driving their development. If manufacturing problems can be overcome, both X-band radar and MMW links featuring the technology look likely to emerge.

Yvonne Carts-Powell is a freelance technology journalist based in Boston, MA.

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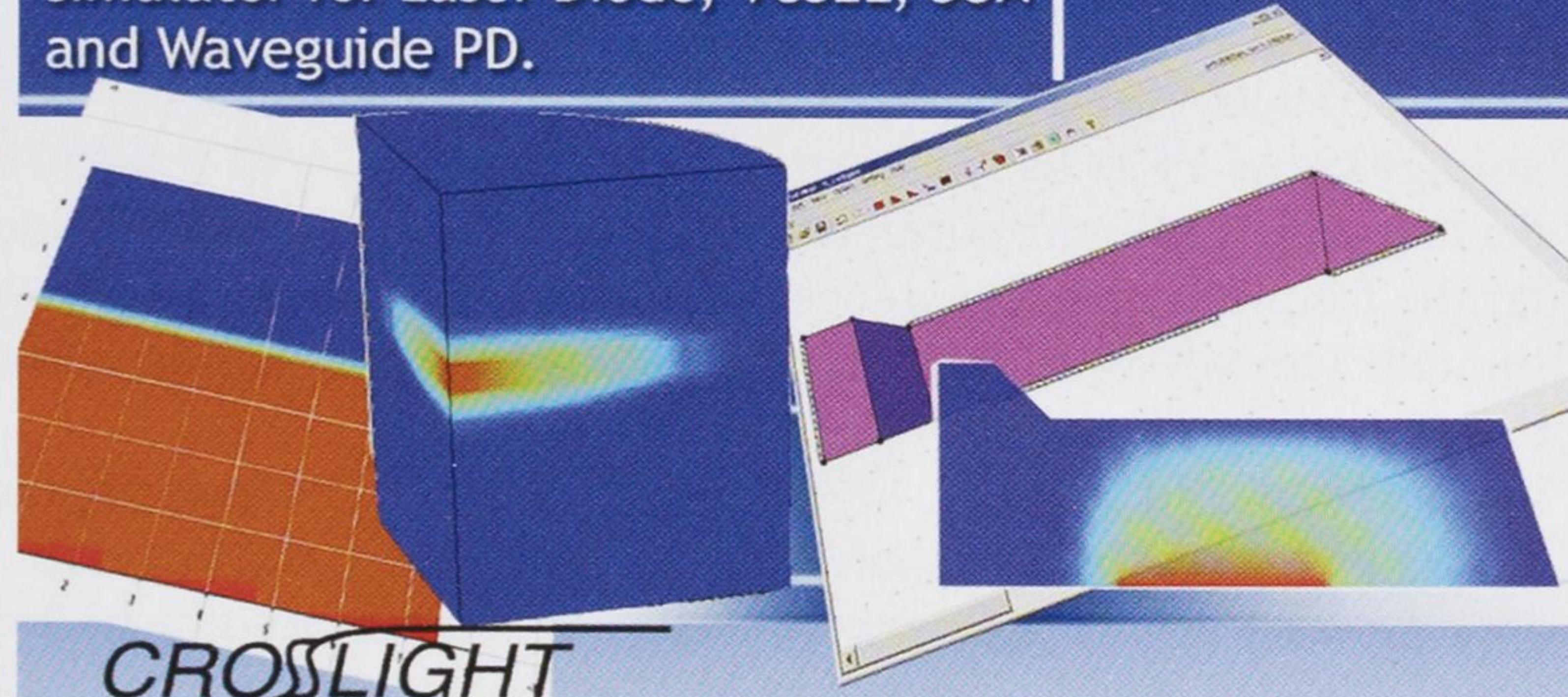
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Additional pipework opens up transistor applications for SiC

Peter Wellmann, from the University of Erlangen, Germany, describes a new approach to silicon carbide substrate growth that could improve LED and Schottky-diode performance, as well as pave the way for new devices, such as insulated-gate bipolar transistors for power applications.

Commercial applications for silicon carbide (SiC) substrates are dominated by blue and white LEDs produced on 6H-SiC and high-voltage Schottky diodes grown on 4H-SiC. No other mass-produced devices currently benefit from SiC's intrinsic properties (high breakdown voltage, thermal conductivity and electron-saturation velocity), but this could change if improvements can be made to the material's doping uniformity and the range of dopants available.

Modified physical vapor transport (MPVT), an alternative method for bulk wafer growth, could be the answer. This approach has produced aluminum-doped substrates that are suitable for insulated-gate bipolar transistors (IGBTs) – devices that could be used in electrical power converters and power circuits for the control of higher-power electrical motors.

The MPVT process could also increase the yield of 4H-SiC substrates through polytype control, and may lead to heavily phosphorus-doped substrates that reduce substrate resistance, thereby enabling the production of low-power-loss Schottky diodes.

Commercial limitations

Bulk single crystals of SiC that provide substrates for industrial device fabrication are usually grown by a seeded-sublimation technique, referred to as either physical vapor transport (PVT) or the modified Lely technique. The process involves sublimating SiC powder at high temperatures ($T > 2000^\circ\text{C}$), followed by recrystallization on a slightly cooler single-crystal SiC seed (figure 1a).

It is a method that was used by current market leader Cree in the early 1990s to produce the first commercial 1 inch substrates. Today the same approach produces industry-standard 2 and 3 inch wafers (see Allen *et al.* 2003), and it will also be used to fabricate the 4 inch wafers that will enter the market in the near future.

The majority of SiC substrates manufactured require *n*-type doping. Nitrogen gas is

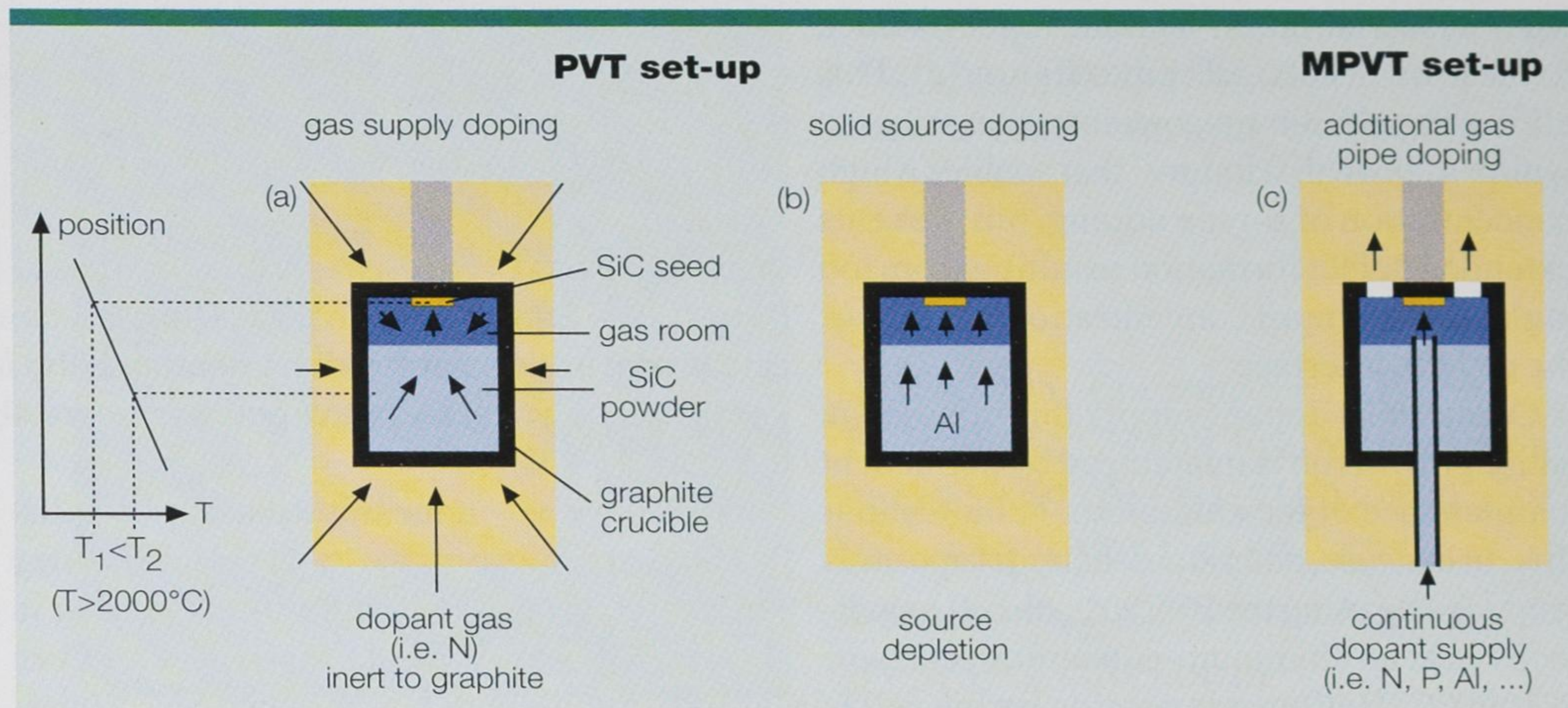


Fig. 1. (a) and (b) The conventional approach to silicon carbide crystal growth – PVT – hinders gas-phase control and prevents the growth of aluminum-doped SiC crystals with uniform doping profiles. (c) MPVT uses an additional gas pipe to fine-tune the gas-phase composition. This method achieves vastly improved aluminum-doping profiles in SiC.

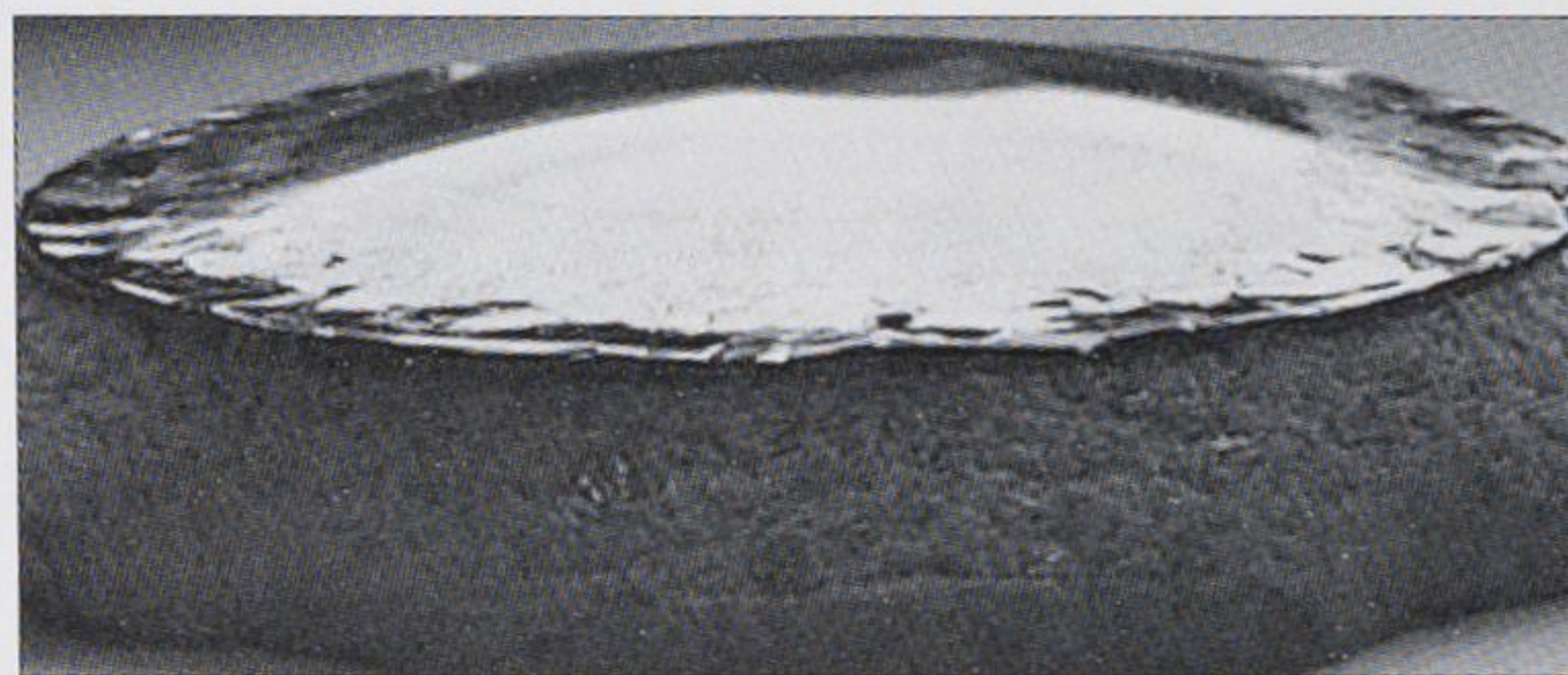


Fig. 2. High-quality aluminum *p*-type doped SiC crystals produced by the MPVT process are suitable for applications such as insulated-gate bipolar transistors.

the most common *n*-type donor and, because it does not react with graphite, it can be supplied to the SiC crystal-growth interface through a slightly porous graphite crucible.

However, one drawback of this quasi-closed-graphite-crucible approach is a lack of direct control of the gas-phase composition, which depends on parameters such as the crucible temperature, and the temperature gradient in the growth system. This is a major disadvantage: to produce high-quality crystals with a low defect concentration requires a well-defined supply of the dopant species.

Although control of dopant feeding is well developed for nitrogen, this is not the case for reactive elements such as phosphorus (*n*-dopant) and aluminum (*p*-dopant). The growth of aluminum-doped material by PVT involves adding aluminum to the source material (figure 1b). During the initial crystal-growth seeding process, growth defects are formed, caused by the far higher partial pressure of aluminum compared with the silicon- and carbon-containing gas species. As the growth continues, an undesirable dramatic fall in aluminum concentration occurs due to source depletion, leading to lower dopant concentration. We measured a 50-fold variation between the head and tail of the crystal.

Additional pipework

At Erlangen, we have demonstrated a modified growth set-up that uses an additional gas pipe to fine-tune the gas-phase composition (figure 1c, see Wellmann *et al.* 2005). This approach, funded under WE2107/3 from the Deutsche Forschungsgemeinschaft, has produced the first SiC wafers suitable for high-

power IGBT device applications: aluminum-doped *p*-type substrates with a specific resistivity of only 0.1 Ωcm .

The MPVT set-up combines all of the benefits of conventional PVT, such as inexpensive source materials and a well-developed industrial-growth process, with the advantages of chemical vapor deposition (CVD), such as control of the gas-phase composition. The approach is also unaffected by the additional gas flux, with even the addition of propane or silane producing no change to a CVD process.

To grow aluminum-doped substrates by MPVT, an aluminum–helium vapor is added to the growth cell via a pipe (figure 1c). This allows the aluminum concentration to be set within a “growth window” that enables a high concentration of *p*-type doping, but prevents extended defect formation resulting from too high an aluminum concentration in front of the growth interface.

Continuous dopant supply throughout the entire growth run is guaranteed by permanent maintenance of the aluminum–helium vapor flux. In our case, aluminum–helium vapor was produced by using the PVT growth cell to indirectly heat an aluminum-containing reservoir to 1000°C. Helium gas passing by the cell is enriched with aluminum vapor and the mixture is transported into the growth cell. One inherent advantage of using aluminum vapor instead of trimethyl aluminum is the absence of hydrogen species, which can passivate acceptors.

MPVT has produced aluminum-doped SiC wafers with an aluminum concentration of $1.3 \times 10^{20} \text{ cm}^{-3}$ and a room-temperature hole conductivity concentration of $2 \times 10^{19} \text{ cm}^{-3}$. This difference in density arises from incomplete thermal activation as opposed to electrical activation of the acceptors. Variation in charge-carrier concentration across the wafer is less than 10%, thereby providing further proof that the gas inlet does not alter PVT growth conditions. The material’s specific resistivity is 0.1–0.2 Ωcm , a value low enough for us to enter a regime where devices can be produced without exhibiting a large voltage drop across the substrate.

Encouragingly, initial structural characterization studies suggest that defect densities in aluminum *p*-type doped SiC are comparable to nitrogen *n*-type doped SiC. Increased concentrations of *p*-type doping did not produce an adverse contribution to the overall dislocation density, although there were some indications of variation in the dominant dislocation type, i.e. threading versus screw dislocation. To our surprise, in our *p*-type

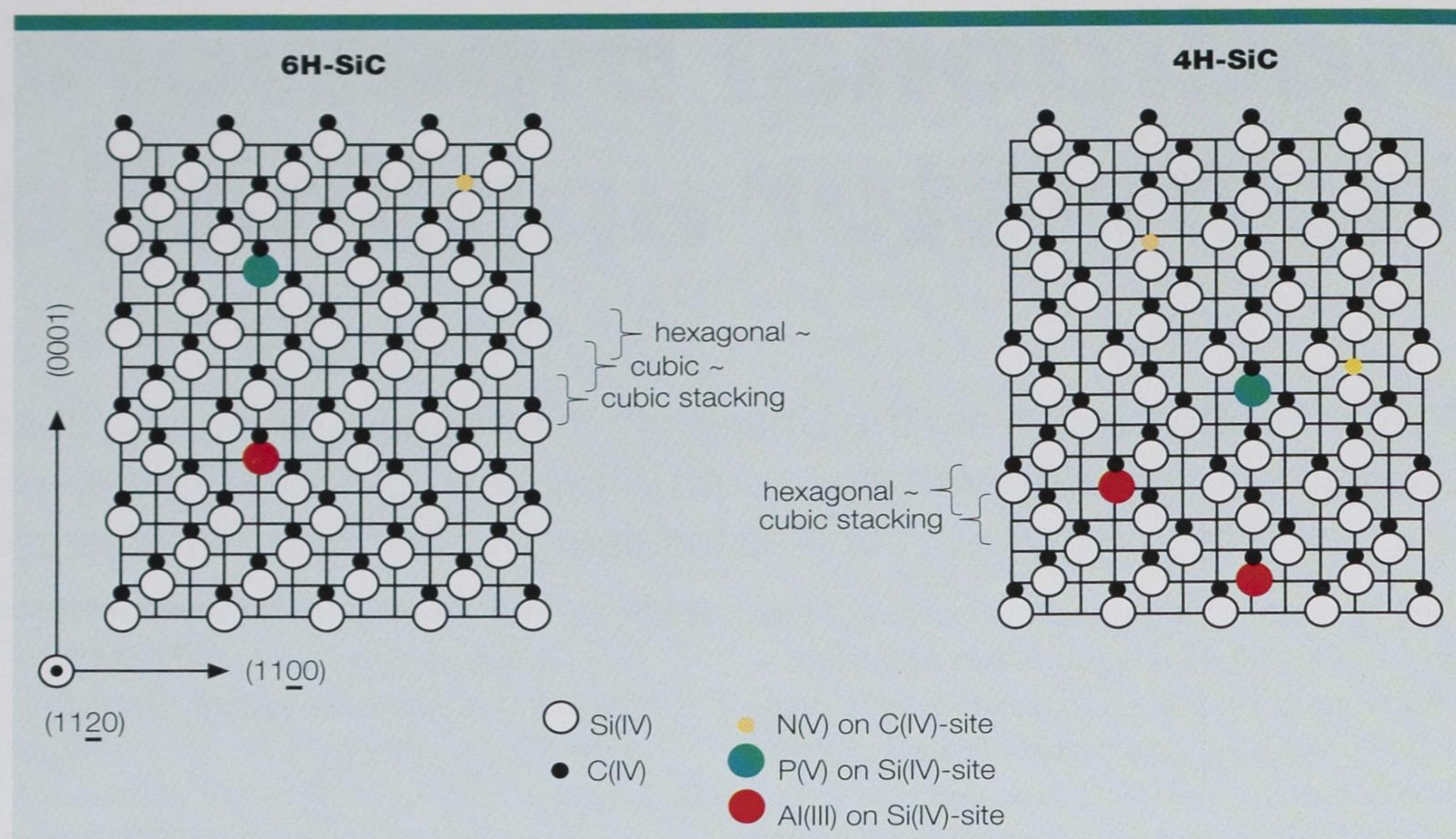


Fig. 3. The Erlangen team hopes that the carbon: silicon ratio can determine the SiC polytype; under carbon-rich conditions the formation of the more hexagonal-like 4H-SiC is expected. Polytype control could improve 4H-SiC substrate production yield.

material we saw none of the basal plane dislocations prevalent in *n*-type SiC. This may indicate that the stacking faults existing in *n*-type SiC may be less pronounced or even absent in aluminum *p*-type doped SiC, a question we are addressing in our current research.

Phosphorus versus nitrogen

Recent ion-implantation studies have shown that phosphorus exhibits a chemical solubility in SiC that is 10 times as great as that of nitrogen, the standard donor species (see Schmid *et al.* 2004). However, at typical SiC bulk-crystal-growth temperatures of above 2000°C there is no phosphorus dopant source compatible with the SiC sublimation process that occurs in a closed-graphite crucible. The MPVT growth set-up, in contrast, opens up the possibility of using the standard phosphorous dopant phosphine.

In trials we used 3–10% phosphine diluted in helium for *in situ* phosphorus doping. The highest dopant density achieved so far is $1.3 \times 10^{18} \text{ cm}^{-3}$, demonstrating that phosphorus doping of SiC is compatible with MPVT. At present there is no indication of a kinetically driven incorporation limit, suggesting that much higher doping levels are achievable. This regime would make phosphorus a strong candidate for doping commercial SiC bulk crystals, with the higher doping level reducing substrate resistance and leading to devices with lower power loss.

Another potential use for MPVT is the control of SiC double-layer stacking through

adjustments in the carbon:silicon ratio (figure 3). Two stacking sequences are possible along the *c*-axis: cubic stacking in a silicon-rich environment and hexagonal stacking in a carbon-dominated atmosphere. Growth with more silane and/or propane present may control the deposited SiC polytype, because 4H-SiC and 6H-SiC differ in their sequence of cubic and hexagonal SiC double layer stacking. 4H-SiC has a periodic repetition of a hexagonal and a cubic SiC double layer, while 6H-SiC is built up of one hexagonal and two cubic SiC double layers. We expect the addition of propane to form the more hexagonal-like 4H-SiC polytype, which could, consequently, increase the substrate yield during 4H-SiC production.

With control of the polytype a possibility with MPVT, alongside well-controlled aluminum doping of substrates for IGBT applications, it may not be too long before today’s SiC manufacturers consider adding further gas flow to existing crystal-growth reactors. ●

Further reading

- S Allen *et al.* 2003 *Compound Semiconductor* September p25.
- F Schmid *et al.* 2004. *Appl. Phys. Lett.* **84** p3064.
- P J Wellmann *et al.* 2005 *Mater. Sci. Forum* **483–485** p25–30.

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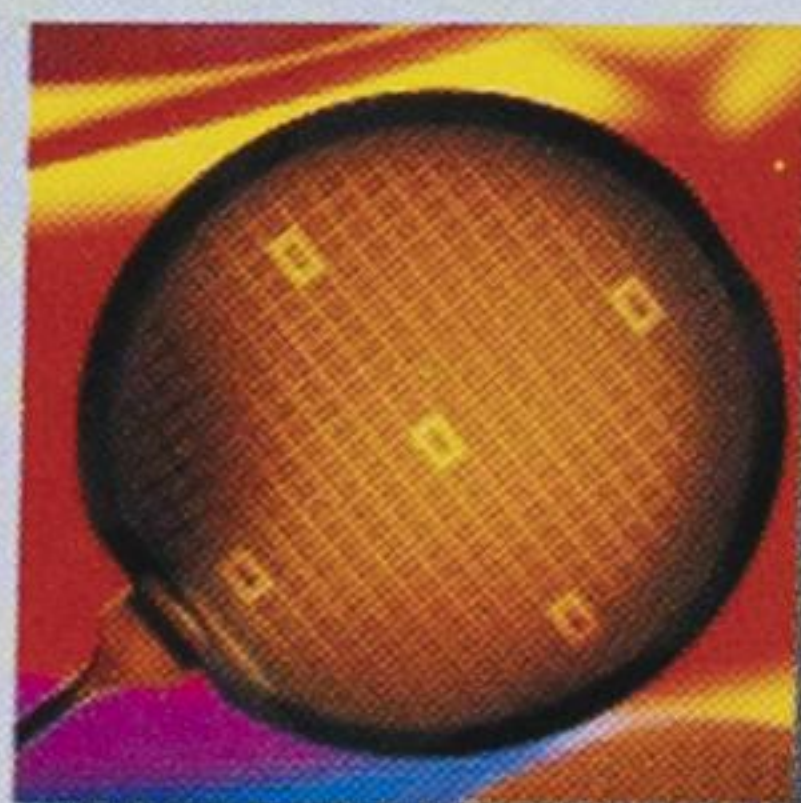
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Nichia marches on, Nakamura licks wounds and pays lawyers

“The court considered that the invention of the blue LED was made a success not by one person, but many people’s efforts and ideas.” That was Nichia’s reaction after it was told to pay Shuji Nakamura “only” \$8 million in compensation after the pair had their heads knocked together at the Tokyo High Court in January.

After a despondent Nakamura jetted back to Santa Barbara, CA, his home for the past five years, to lick his wounds, *Compound Semiconductor* asked what plans he had for the money. Nakamura revealed the inevitable: “After paying taxes and my lawyers, \$8 million has become a small amount of money,” he admitted. Ah yes, the lawyers.

Despite Nichia’s lingering reservations about the final agreement – the company contends that the court still awarded Nakamura too much, and that the 1997 start date of an interest calculation adding 20% to the initial \$6 million settlement was incorrect – it was in every other way the victor in this dispute.

So when it came to the crunch, the Tokyo judge fell on the side of corporate Japan, leaving Nakamura to curse what he sees as the continued exploitation of employees who in many cases regard the firm that they work for to be more important than their own family. He also questioned the effect that it might have on future generations of engineers: “A professional baseball player earns \$6 million a year, but that’s what I receive for my entire career in research,” lamented Nakamura.

Nichia saw the decision simply as a vindication of the risk it had taken when it decided to mass-manufacture blue LEDs. “In the settlement, we think that the court acknowledged the fact that only the firm, and not the employee, takes the risk of funding research and development,” it said in a statement.

Of course, Nakamura would argue that he carried out the crucial research against the wishes of his bosses at the time.

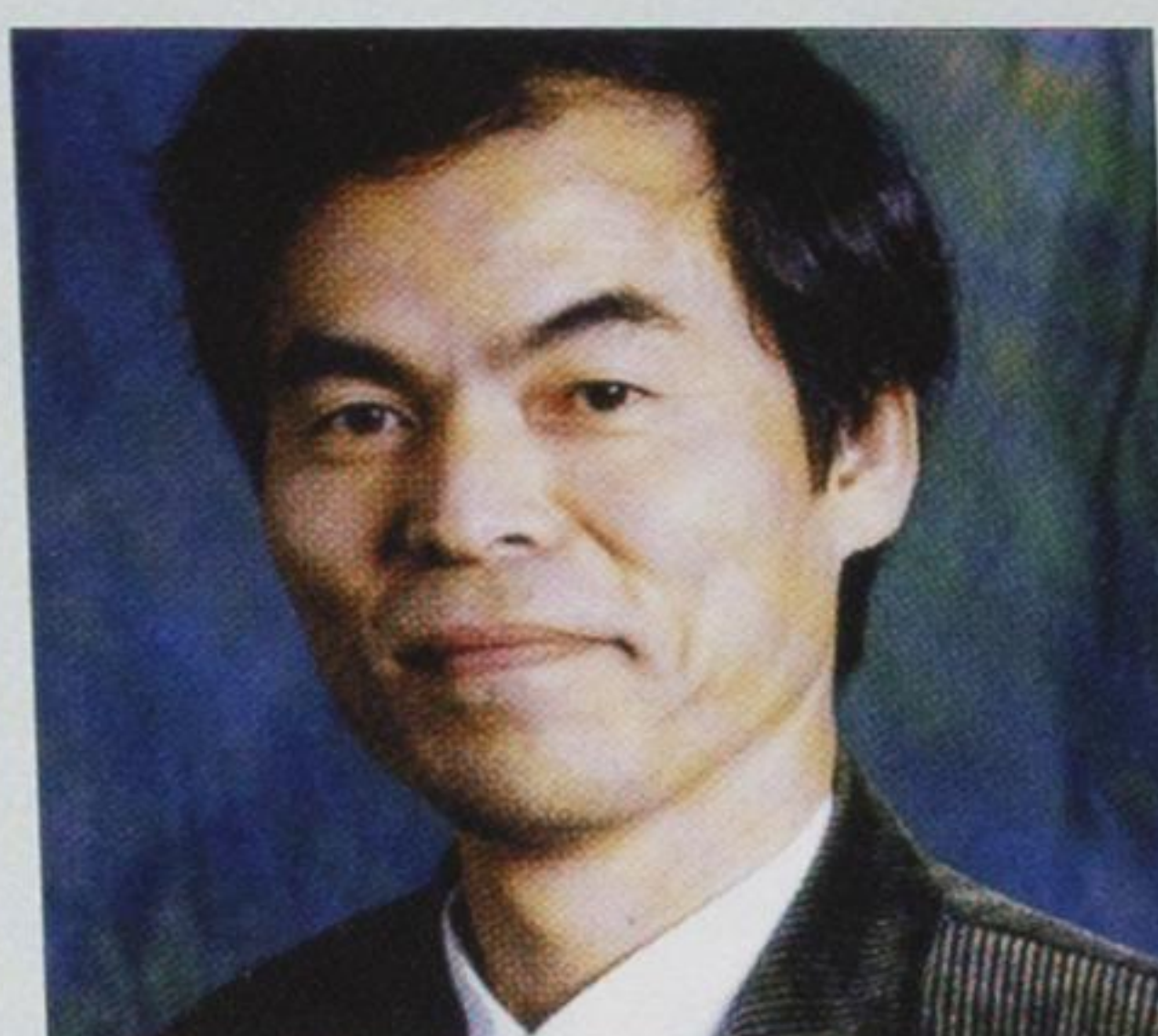
In Japan, the degree of compensation is calculated by looking at the amount of “extra” profit that a company has made thanks to an invention by one of its employees. The precedent that had already been set before the Nichia case is for the inventor to receive 5%

After a legal battle spanning nearly four years, Nichia has finally claimed victory over its former employee Shuji Nakamura.

Michael Hatcher looks back at the famous blue-LED case and assesses the reaction of the two protagonists.

Timeline

- **Early 1990s** Nakamura and colleagues at Nichia report blue LEDs based on GaN.
- **December 1999** Nakamura leaves Nichia for the US, where he becomes a professor at UCSB and an advisor to Nichia’s rival Cree.
- **December 2000** Nichia files lawsuit against Nakamura over alleged leaking of trade secrets.



- **August 2001** Nakamura launches damages claim for ¥2 billion (\$19 million) against Nichia over blue

LED invention.

- **September 2002** Tokyo court rules that although Nakamura does not own key patents, he is eligible for compensation.
- **February 2004** Tokyo district court awards Nakamura \$189 million; Nichia appeals.
- **January 2005** Nakamura and Nichia agree to settle for \$8 million at Tokyo high court.

of that “extra” profit, and the court seems to have accepted this, calculating that the company contributed 95% to the development.

But Nakamura didn’t get his 5%. The difficulty for the judge was that, thanks to the phenomenal success of its blue LEDs, Nichia’s “extra” profit was enormous – an estimated \$2 billion through 2004. Nakamura’s 5% would therefore have meant a huge pay-out.

As a result, believes Nakamura, the high court judge decided to cap his compensation at \$6 million, for fear of damaging Nichia’s future growth. The decision also took into account Nichia’s profit from extensive cross-licensing contracts, and reduced Nakamura’s contribution accordingly. However, Nichia maintains that a single researcher cannot be entirely responsible for such a major technological breakthrough.

If Nakamura had received a much larger payout, what signal would it have sent out to Japanese industry? Imagine you were about to build a fab to manufacture millions of laser chips for next-generation DVD applications. If the court had sided with Nakamura over blue LEDs, the precedent would be set in

favor of employees, and any firm thinking about making a new product in high volume would have to take on board additional risk. In short, it may stifle the industry.

So on goes Nichia, cranking out its blue and white LEDs at an absurd profit margin that must make chief executives around the globe turn green with envy, safe in the knowledge that no court will be taking that profit away. “We are relieved to have finished the dispute, as all employees who were involved in the case can now concentrate on and return to their essential business,” said Nichia.

Back in his UCSB lab, Nakamura may well be wishing that he’d taken up baseball instead of materials technology. But, in the end, while you can’t help but feel sorry for the researcher – at least, as sorry as one could ever feel for a resident of Santa Barbara – the judge had no option but to side with Nichia.

What do you think? Did the Tokyo High Court make the right decision, or should Nakamura have received more compensation? Write to the editor with your view on the case (e-mail: michael.hatcher@iop.org).

Agilent sets out its consumer vision for future profitability

Increasing its market share in power amplifiers and creating opportunities for its daughter company Lumileds are two of the strategies that Agilent's semiconductor product group will use as it looks to increase revenue from consumer electronics applications. **Michael Hatcher** reports.

Agilent Technologies is a rare bird: a chip manufacturer that is targeting a whole range of III-V applications, including fiber-optic communications, power LEDs (through its part-subsi-dary Lumileds) and GaAs-based RF components.

Considering the breadth of chip technologies developed and manufactured by the California-based company – which is also the leading supplier of silicon CMOS imaging chips with an 18% market share – its profile in the public consciousness is virtually non-existent, and certainly nothing like that of its parent company, Hewlett-Packard (HP).

Agilent feels that this is especially true when it comes to its semiconductor operation. At January's annual gadget-fest in Las Vegas, the International Consumer Electronics Show (CES), executives from the company's semiconductor product group (SPG) were at pains to raise Agilent's profile.

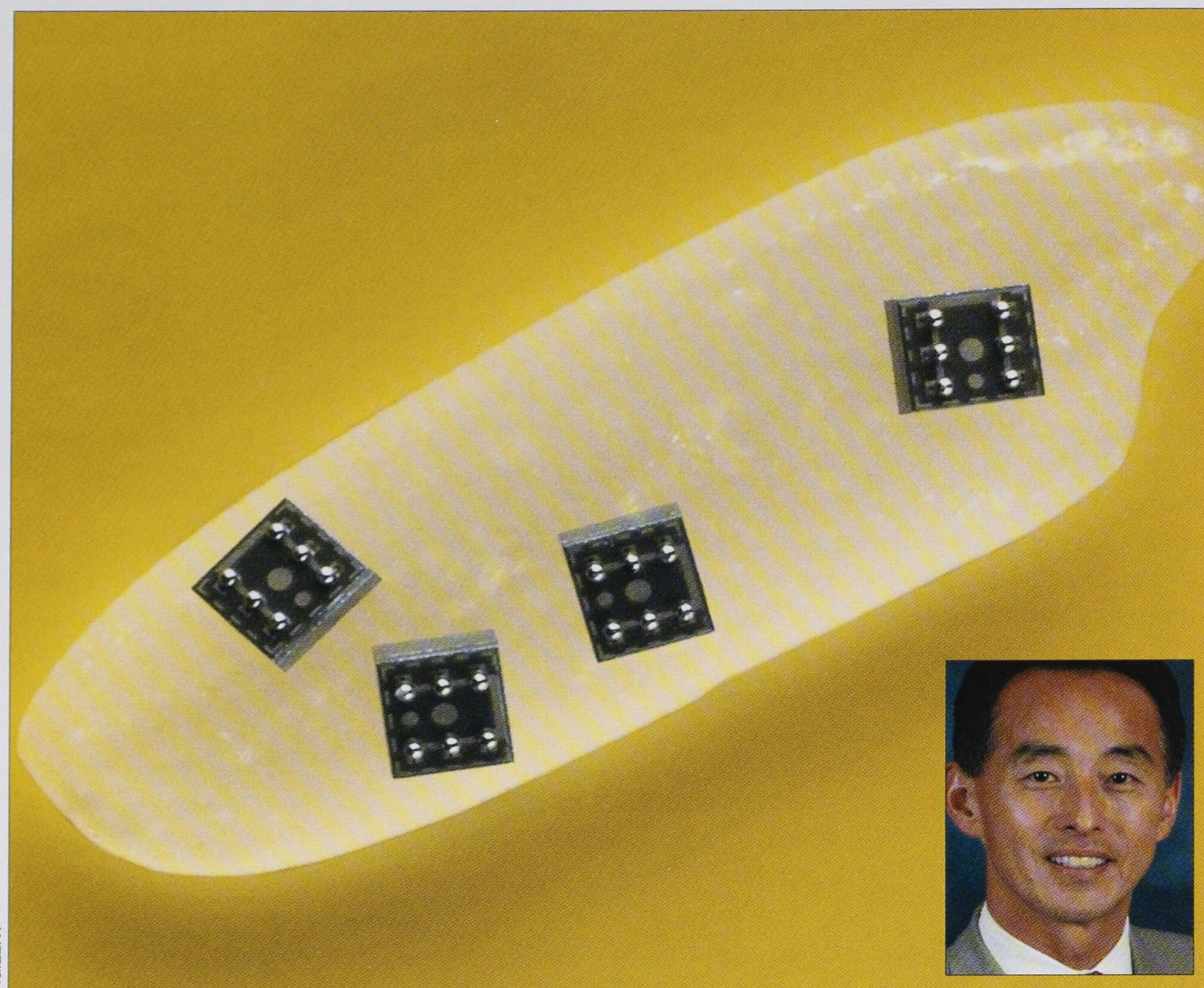
While Young Sohn, CEO of Agilent's SPG, said that the group regards itself as "unknown" in the consumer electronics field, it is clear that this market is going to be critical to the operation's future growth and profitability.

Turning the corner

Just a couple of years after Agilent was spun off from HP in the boom of 1999, the SPG suddenly found itself in a much tougher business environment than it might have expected. Now with around 6000 employees – some 24% fewer than in 2001 – Agilent SPG has cut costs drastically and, after turning a corner in 2003, has been profitable for the past 18 months.

Expertise in analog chips, and in particular optoelectronic components, is the foundation of the business, which is now preparing itself for rapid growth. With revenue of \$1.7 billion in 2004, Sohn and colleagues have set themselves a stiff challenge: to drive sales up to \$3 billion by 2008. To do this, the company will need to take market share from its competitors across the entire range of applications.

While fiber-optic communications is one



Four of Agilent's film bulk acoustic-resonator filters sit on a single grain of rice. These MEMS devices are used in combination with the company's E-PHEMT chips to increase the talk time of cell-phone handsets. Inset: Young Sohn, CEO of Agilent's semiconductor product group, is focusing the business on consumer electronics applications.

area where Agilent has traditionally been very strong, the company clearly sees consumer electronics as the way forward. Sohn's view is that the phenomenal progress made in digital electronics in recent years means that the spotlight has now swung back onto analog devices used in imaging, display and information-transfer applications.

The RF and microwave sector is probably Agilent's weakest application area, where the company ranks itself ninth among global suppliers, and has a market share of only a few percent in what Sohn admitted was a very tough market. This does of course give the

company plenty of scope to steal market share from its rivals, and Agilent's recent move to acquire the Korean power-amplifier (PA) module specialist Wavics will have sent out a signal of intent to the rest of the industry (see p9). Wavics is a fabless company based in Seoul whose PA modules are said to reduce battery drain in cell-phone handsets.

On the technological front, Agilent reckons that its E-PHEMTs, detailed in these pages in May 2004, will challenge HBT chips. The key advantage, it says, is that of extended talk time allowed by PAs based on the technology. The high linearity of the devices makes them

particularly good for the more complex front-end electronics used in more advanced cell phones. E-PHEMTs are manufactured at Agilent's 6 inch GaAs fab in Fort Collins, CO, and the company has recently released E-PHEMT FETs for base-station applications.

But with its dominant position in CMOS imagers, the camera cell phone is Agilent's core strength, and now its daughter company, Lumileds, is looking to exploit this leadership as the camera's performance improves. That's because the more pixels there are in an imaging chip, the more light is required to generate sufficient illumination for taking high-quality photos. Xenon lamps currently provide the flash function in such phones, however Lumileds has worked hard on improving the brightness of its white LEDs.

Having developed the chip design to support a junction current of around 1 A, Lumileds believes that it is well on the way to making its LEDs competitive with xenon lamps. And because imaging and illumination technology go hand-in-hand, Lumileds has a straightforward route into the market through Agilent's existing leadership position in handsets.

Camera flash was one of many power-LED markets identified by Mike Holt, CEO of Lumileds, during Agilent's vision summit at the CES. He also pointed to automotive applications as a large existing market for red power LEDs in products such as high-mount stop lights. Despite the 50 million new cars sold every year, however, Holt said that this sector had "kind of plateaued", with the relatively high cost of the technology still proving to be a barrier for introduction in vehicles that are made in very high volumes.

Lumileds now has a partnership with its other parent company – Philips – that is focused on developing more LED-based lighting systems for automotive use.

Rebirth of Trinitron

Holt identified two key consumer applications in Las Vegas: illuminators for personal handheld projectors; and backlights for large LCD televisions. 450 Luxeon emitters provide the backlight for Sony's top-of-the-range Qualia televisions, and Holt did his best to wow the CES delegates with the dazzling color reproduction that the technology provides. He said

that Sony believes that the technology will be the "rebirth of Trinitron".

Trinitron is the advanced cathode-ray-tube technology developed at Sony that led to the company's dominance of the television market in the 1980s. The latest high-spec LCD televisions featuring the three-color LED backlights are only available in Japan at present, but Holt hinted that Sony might release the televisions in the US shortly.

While many of the applications it is focused on lie in the future, Lumileds is already enjoying rude financial health. According to Philips, the joint venture made a profit of \$62 million from total sales of \$280 million in fiscal 2004. That represents a 43% year-on-year growth in line with the expansion of the overall high-brightness LED market.

Meanwhile, Agilent Labs – the R&D facility that is charged with coming up with the SPG's next-generation products – has some innovative ideas in the pipeline. These include an LED-based eyeball-tracking system that is designed to monitor and warn drowsy drivers, and a range of fiber-optic systems, including a prototype 500 Gbit/s optical "engine".

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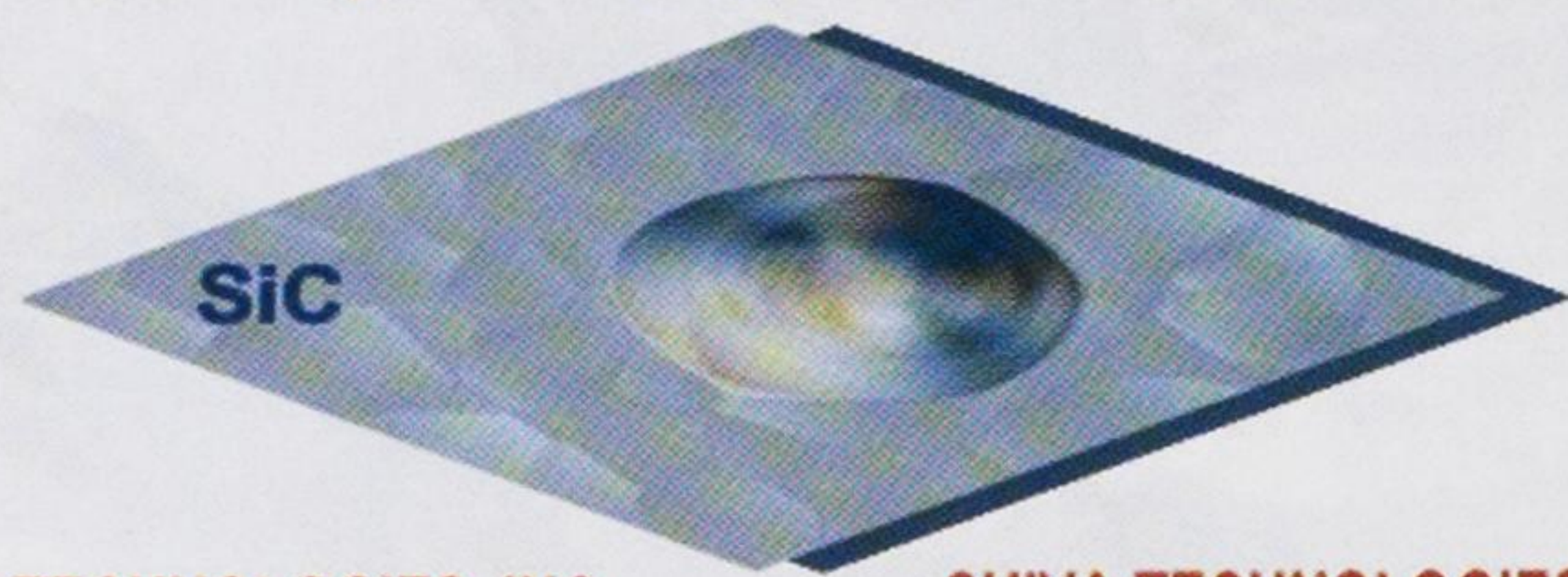
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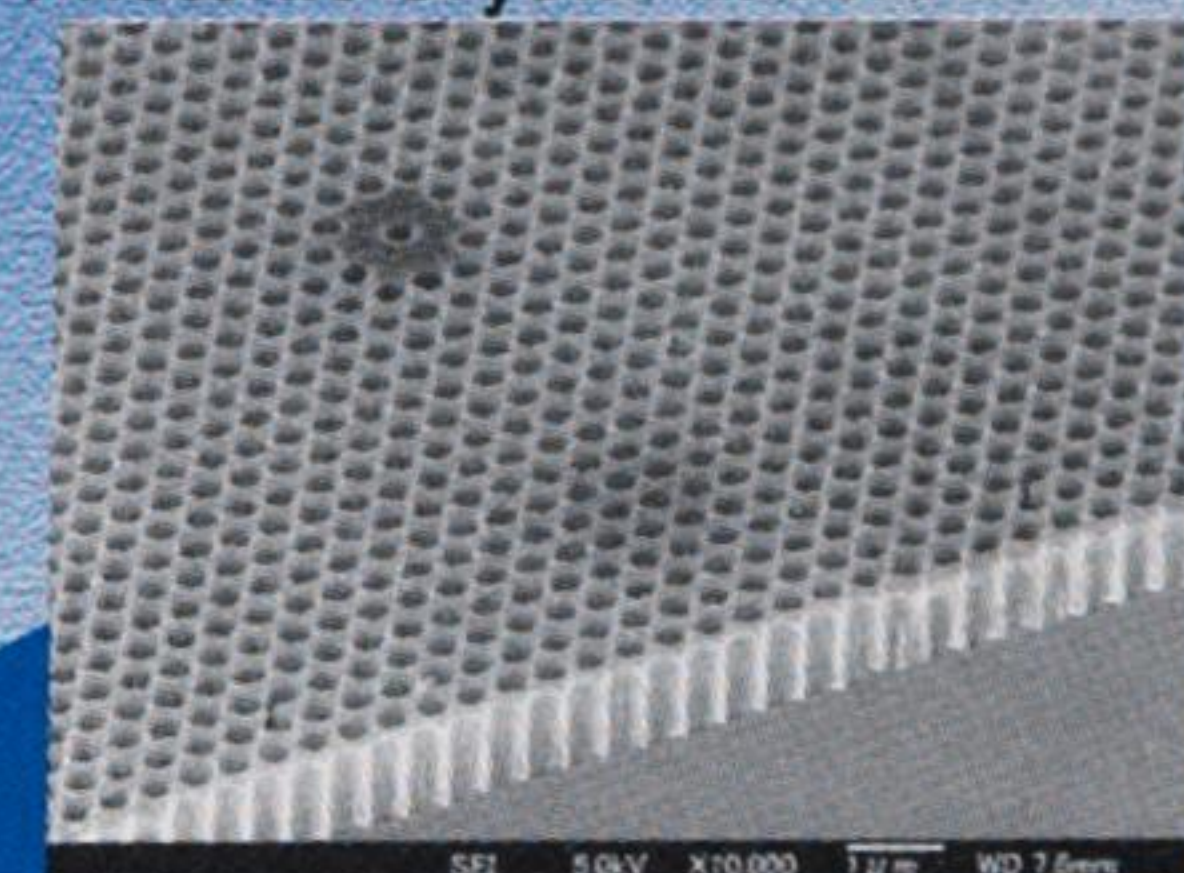


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Kopin wins two patents covering GaAsInN HBT wafer technology

Kopin has received two US patents covering advanced wafer technology for next-generation cell-phone power amplifiers (PAs).

Patents 6,847,060 and 6,750,480 cover so-called GAIN-HBT technology, which is based on the quarternary material system GaAsInN.

According to the Taunton, MA, wafer supplier, the physics of the material will enable greater flexibility in transistor design, something that will become crucial as PAs used in cell phones are increasingly required to run at higher frequencies and duty cycles.

Applications such as mobile video will put current PA technology under pressure as data rates increase, and Kopin believes that its technology could be implemented without the usual difficulties associated with a new material.

"The changes in transistor structure can be rendered transparent to the circuit-fabrication process, lowering the technological barriers for implementation," said Roger Welser,

Kopin's director of GaAs HBT technology.

Welser led the Kopin team that engineered the GAIN-HBT structure by introducing indium and nitrogen into the 50 nm base layer of a GaAs wafer. The more complex material increases the transistor's frequency range and improves its temperature stability, while simultaneously reducing operating voltage.

Patent 6,750,480 covers basic GAIN-HBT device technology, while 6,847,060 describes an enhanced transistor that contains graded compositions of the four constituent elements.

"GAIN-HBT transistor wafers provide improvements in all key areas of mobile appliances: performance, battery life, integration and durability," said Kopin's CEO John Fan.

"Although the base layer is only 200 atomic layers thick and composed of four elements in varying compositions, production control allows reproducible growth of these transistors for maximum performance advantages."

IQE order book grows

UK-based epiwafer supplier IQE says that, despite a near-term drop in revenue, its order book is now at its highest level for two years.

Wireless applications are showing strongest, with the company having already begun volume shipments to a US-based RF-component maker that decided to close down its own wafer-manufacturing facility.

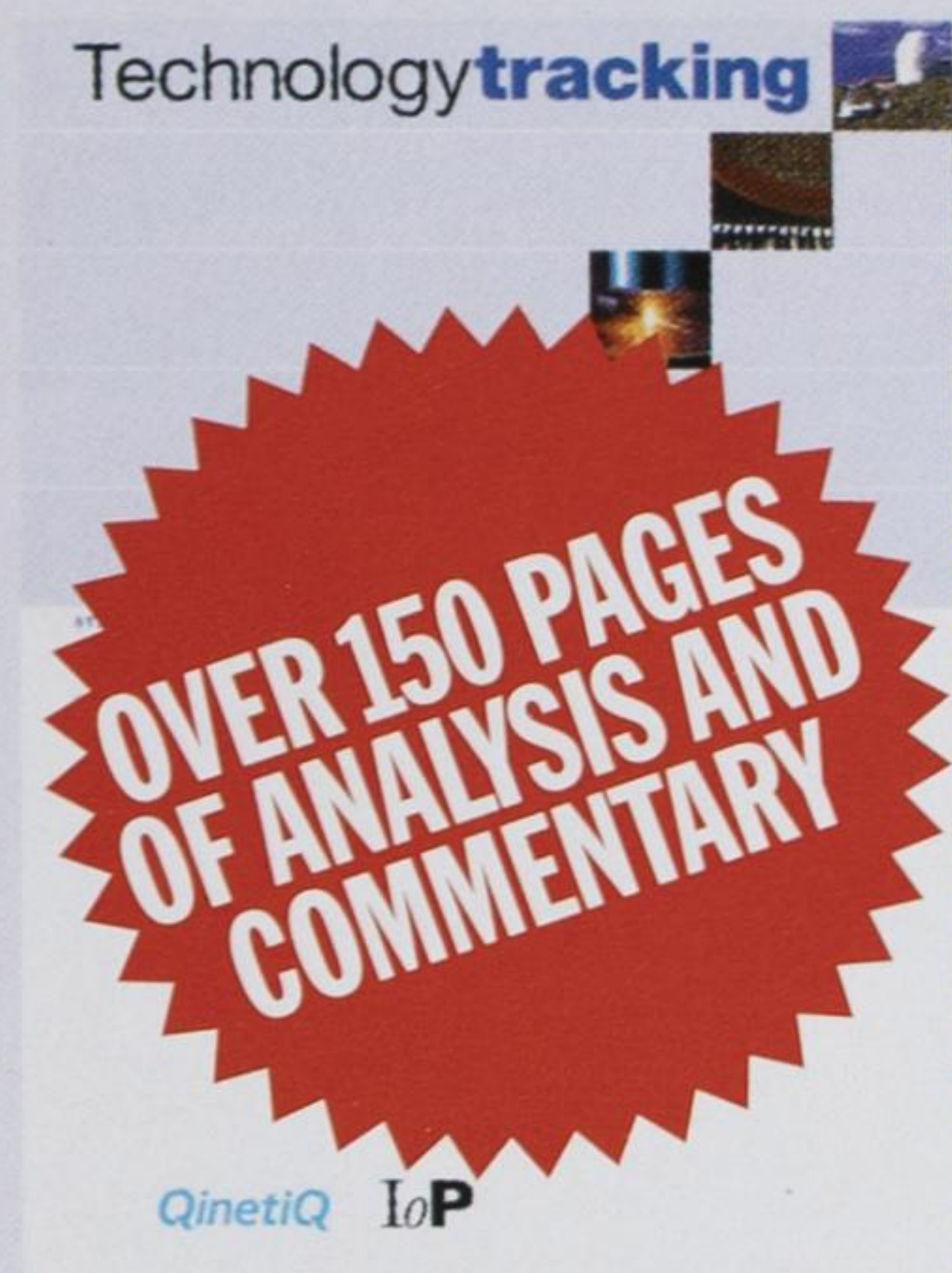
With more business from Asian customers and US government contractors too, IQE says that its wireless unit will be profitable by the end of its fiscal first half, June 30.

In optoelectronics the picture is mixed, with some weakness in optical-storage applications and a flat HB-LED market offset by improving business in telecom and industrial laser applications.

Overall, the firm expects to report 2004 revenue of at least £15.3 million (\$28.9 million). That is slightly down on the 2003 figure, when IQE's revenue came in at £18.8 million. The company says that a weak third quarter and a weak US dollar have combined to produce the drop.

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Gallium sales help AXT cut loss by half

Substrate supplier AXT says that customers are starting to order its 4 inch GaAs substrates now that it has managed to iron out problems with material quality.

The Fremont-based company made the announcement as it attempted to draw a line under what has been a tumultuous fiscal 2004 in its full-year financial results. After a year in which it faced a shareholder lawsuit; took a sales hit due to non-compliance with product-testing procedures that led to a boardroom reshuffle; paid a \$1.4 million charge following litigation by rival substrate supplier Sumitomo Electric Industries; and laid off 50 employees, AXT reported a net loss of \$13.6 million.

That bottom-line figure contrasts with a net loss of \$26.7 million in the previous year. At \$35.5 million, overall revenue came in just slightly up on 2003 sales.

"We made significant quality improvements in our 4 and 6 inch GaAs substrates," said interim CEO Don Tatzin. "Samples of 4 inch-diameter substrates sent to several customers that were processed using our new cleaning equipment appear to be largely haze-free, similar to our 2 and 3 inch substrates."

Tatzin adds that the company has recently won a number of orders for 4 inch products from customers who had steered clear of AXT for several months: "We believe that this indi-

cates a turnaround is at hand if we can maintain high quality."

In its most recent quarter, however, sales to LED-manufacturing customers declined in what AXT called a seasonal fluctuation, although the decline was partially offset by increased sales of gallium. AXT made a net loss of \$2.3 million on revenue of \$7.6 million in the three months up to December 31, 2004.

Despite the improving picture regarding substrate orders, the company forecast revenue in the current quarter to be flat, resulting in a net loss of around \$3.2 million. AXT plans to expand its joint-venture activity in China in a bid to return to profitability in 2005.

In brief

- Despite posting a year-on-year fall in revenue of 22% in 2004, **Riber** starts 2005 with an order backlog worth €9.9 million (\$12.9 million), almost double the €5 million on the books at the beginning of the previous year.

The French supplier of MBE equipment recorded €13.5 million sales for fiscal 2004, comprising three production machines netting €3.8 million, 10 research machines contributing €5.9 million, and accessories and spare parts adding

€3.7 million. Year-on-year sales increased by 14% in Europe, but fell by 62% in Asia and 16% in North America.

- Oxford Instruments Plasma Technology**

has made the first sale of its new Clusterlab600 MBE system to the National Changhua University of Education (NCUE), Taiwan. NCUE will use the Clusterlab600 tool to grow GaN films and epitaxial layers for laser diodes, including DVD lasers and VCSELs, as well as for InGaN- and AlGaIn-based LED

devices. Other intended applications include spintronics, with the growth of epitaxial Mn-doped GaN/InGaIn films.

- Lasertel** has purchased a GEN200 MBE system from Veeco Instruments to increase its capacity for the production of high-power laser diodes. The Tucson, AZ, company, which uses solid-source MBE technology to produce its lasers, says that it selected the GEN200 MBE system in part for its silicon-style, cluster-tool wafer-handling feature.

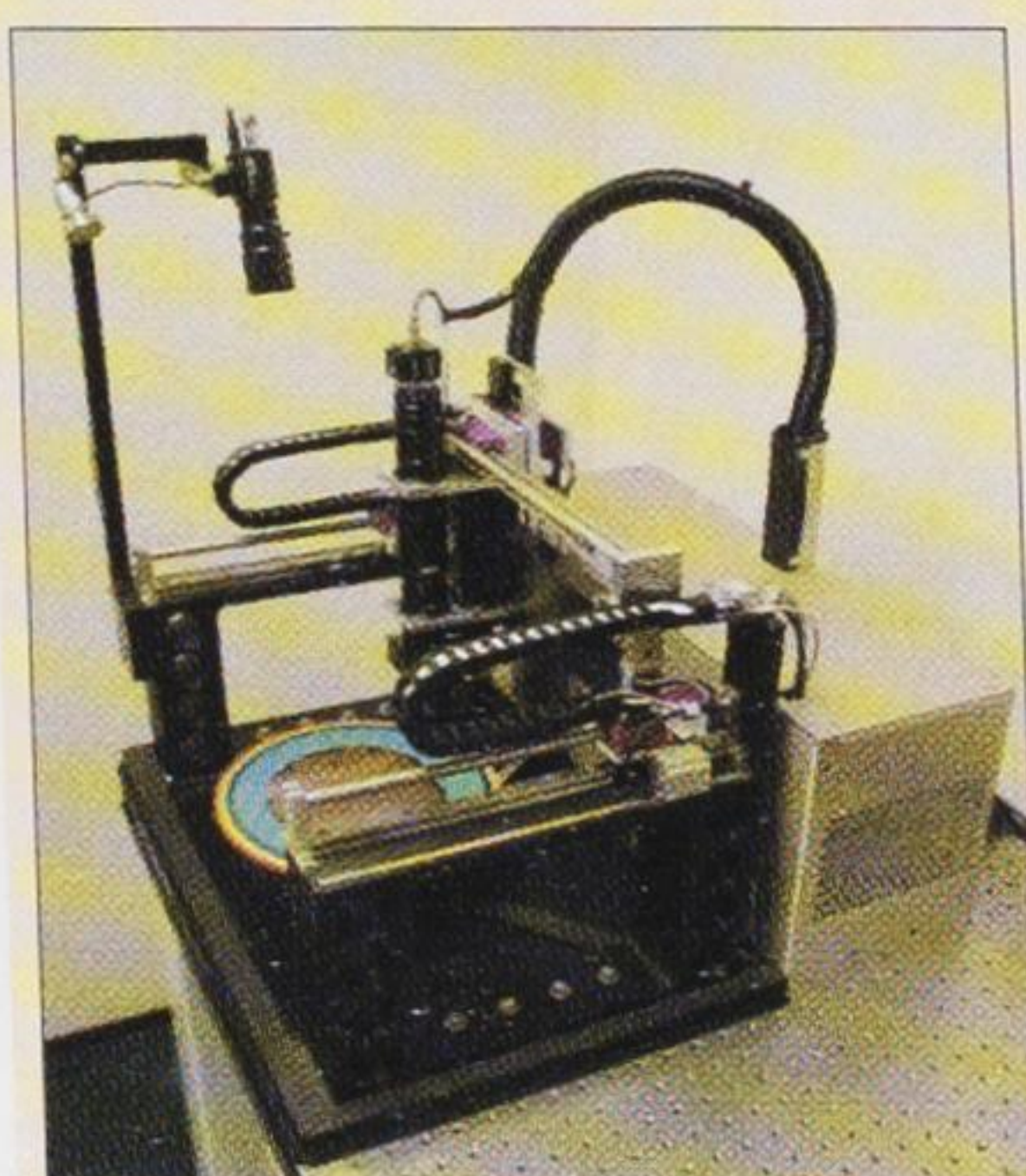
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High-precision scribe dicing

Micro Processing Technology

MPT's new High-Precision Scribe Dicing System for scribing compound semiconductors and MEMS devices incorporates a porous ceramic vacuum chuck and a scribe force feedback control system to produce scribe lines that are uniform in depth across the entire surface of the wafer. For the first time, this allows the process engineer to optimize and reproduce scribe processes to maximize dicing yield and to minimize chip-out.

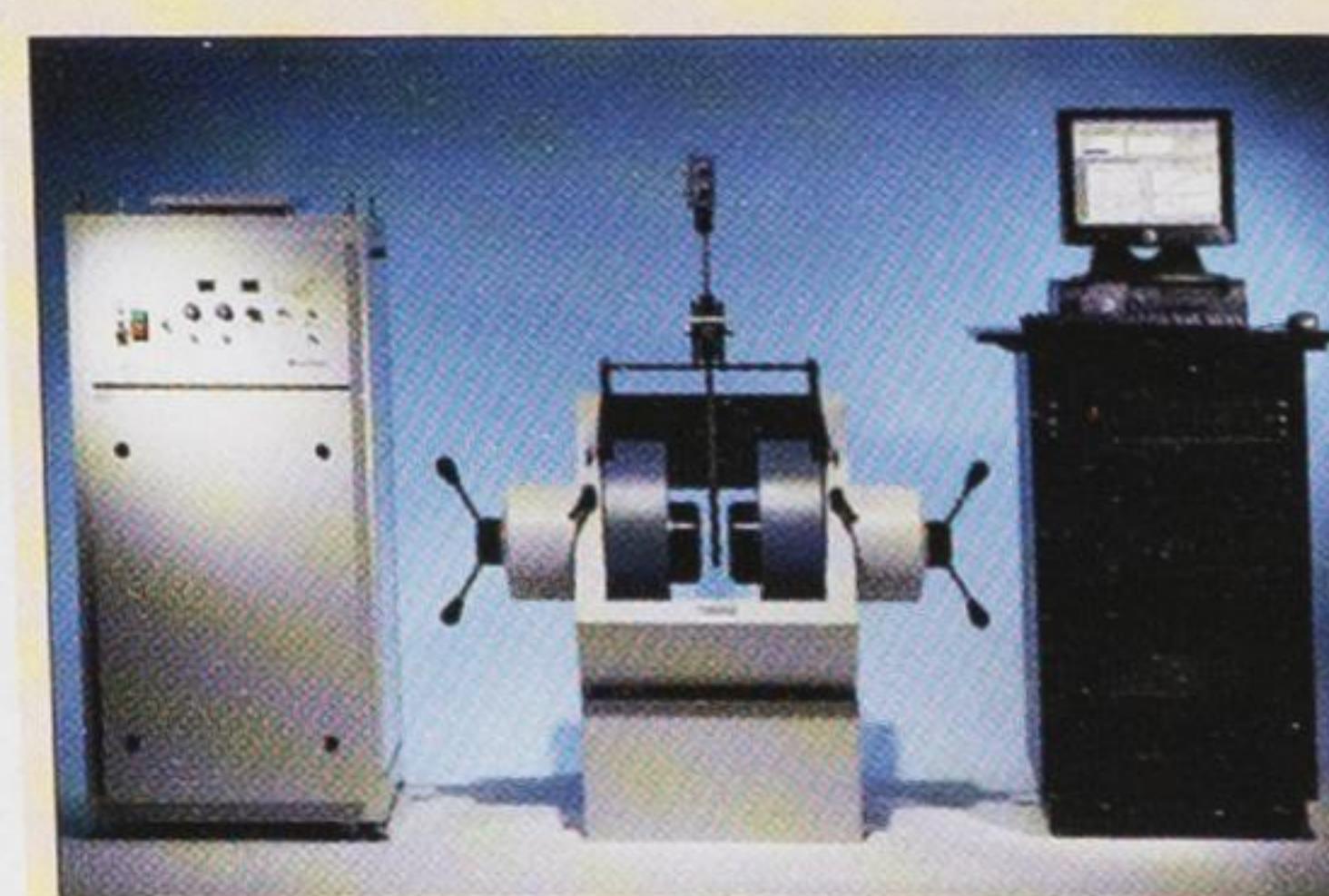


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Slowdown of phone market is a challenge for GaAs industry

As the explosive growth seen in the cell-phone market in the past two years cools off, RFIC makers need to gain market share and increase GaAs content in more advanced handsets to restore profits.



The December quarter is traditionally the strongest of the year for GaAs IC manufacturers serving the cell-phone handset market, and the final quarter of 2004 was no exception.

Headline cell-phone shipment figures from Nokia and market-research firm IC Insights confirm that phones flew off shelves in the final three months of the year. Nokia says it shipped a record 66 million units in the quarter, representing 19% annual growth.

But did that bumper phone crop translate into bumper profits for compound semiconductor chipmakers? Well, apart from Skyworks Solutions, no. While Nokia re-established its sizeable lead as the world's top cell-phone supplier, the Finnish company did this mainly through cutting the price of its phones.

And perhaps as a result of Nokia passing on that strategy to its chip suppliers, RF Micro Devices (RFMD) only broke even on revenue of \$186.9 million. Unsurprisingly for the time of year, that figure was up \$19.8 million sequentially, but well down on the same period one year ago, when RFMD posted a handy profit of \$28.2 million. In contrast, RFMD's main rival Skyworks posted record quarterly sales of \$220 million, up 26% on the previous year. At \$22.9 million, profit has doubled in the past 12 months.

Meanwhile, TriQuint Semiconductor said that it would prioritize a return to profitability in 2005 as it posted revenue of \$74.7 million in the December quarter, down both sequentially and on the prior year. However, at \$347 million, TriQuint's full-year revenue was 11% up on 2003. Somewhat indicative of the challenges facing the RFIC sector, TriQuint made a \$29.1 million loss in 2004 despite shipping a record number of components and devices.

RFIC maker Anadigics is fighting a similar battle. Although the Warren, NJ, company did increase full-year revenue by 21% to \$91.3 million in 2004, its net loss in the period was \$43.1 million.

With all market commentators expecting growth in

the cell-phone market to slow in 2005, in terms of units shipped, the outlook appears a little gloomy. Nokia is forecasting 10% overall growth, while IC Insights puts the figure at just 5%. Both agree, however, that total unit shipments will be around the 700 million mark in 2005.

According to ABI Research, prospects look even worse when it comes to base-station applications of RFICs. The New York-based market analyst recently reiterated its forecast for the sector, saying that despite the widespread 3G build-out currently in progress, power-amplifier (PA) suppliers will continue to suffer as demand from base-station constructors remains weak.

Certainly, a pessimistic view of the sector appears to have grabbed investors, with the stock values of TriQuint, Skyworks and RFMD all having slid around 20% since the turn of the year. With slowing growth and continued price erosion of around 15–20% per year in low-end products, it is clear that to be profitable suppliers will either have to improve margins on existing products, gain market share from rivals, or increase the overall dollar content that they provide per phone.

As the largest supplier of cellular PAs, RFMD expects the number of radios required in each handset to increase 30% every year as mobile devices incorporate greater functionality. In particular, multimode W-CDMA handsets will each require two PAs, says RFMD. The company believes that 40 million such handsets will ship in 2005, providing a total market opportunity of \$240 million.

Believing that it already has a "commanding" lead in EDGE and W-CDMA PAs, RFMD expects to benefit as these interfaces gain greater market share in years to come. In the December quarter, W-CDMA accounted for only 7.4% of RFMD's \$150.5 million cellular business, but the company expects to increase its dollar content from just \$2 to more than \$12 in multimode phones.

In an increasingly challenging market, chip suppliers will be hoping that next-generation handsets prove just as popular as their predecessors.

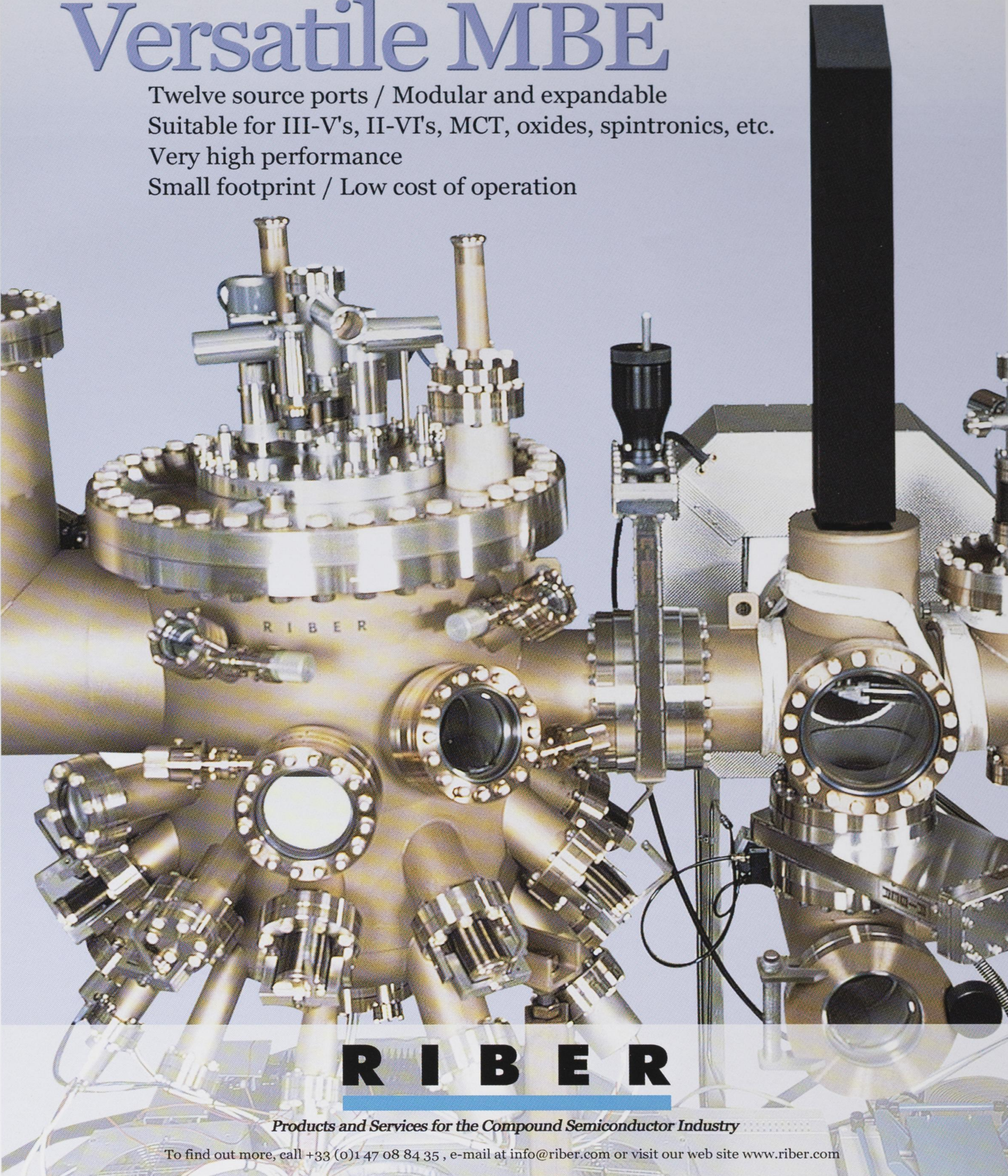
Major GaAs IC manufacturers: December 2004 quarterly results

Company	Symbol	Quarterly revenue (\$m) (year on year change, %)	Net income/loss (\$m)	Share price (\$) on Feb 14 (52-week range)
Anadigics	ANAD	22.4 (-5)	-10.3	2.56 (2.34–7.68)
RF Micro Devices	RFMD	168.9 (-12.5)	+0.6	5.72 (4.66–9.80)
Skyworks Solutions	SWKS	220 (+26)	+22.9	7.55 (6.98–12.68)
TriQuint Semiconductor	TQNT	74.7 (-16)	-29.1	3.58 (3.20–8.95)

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