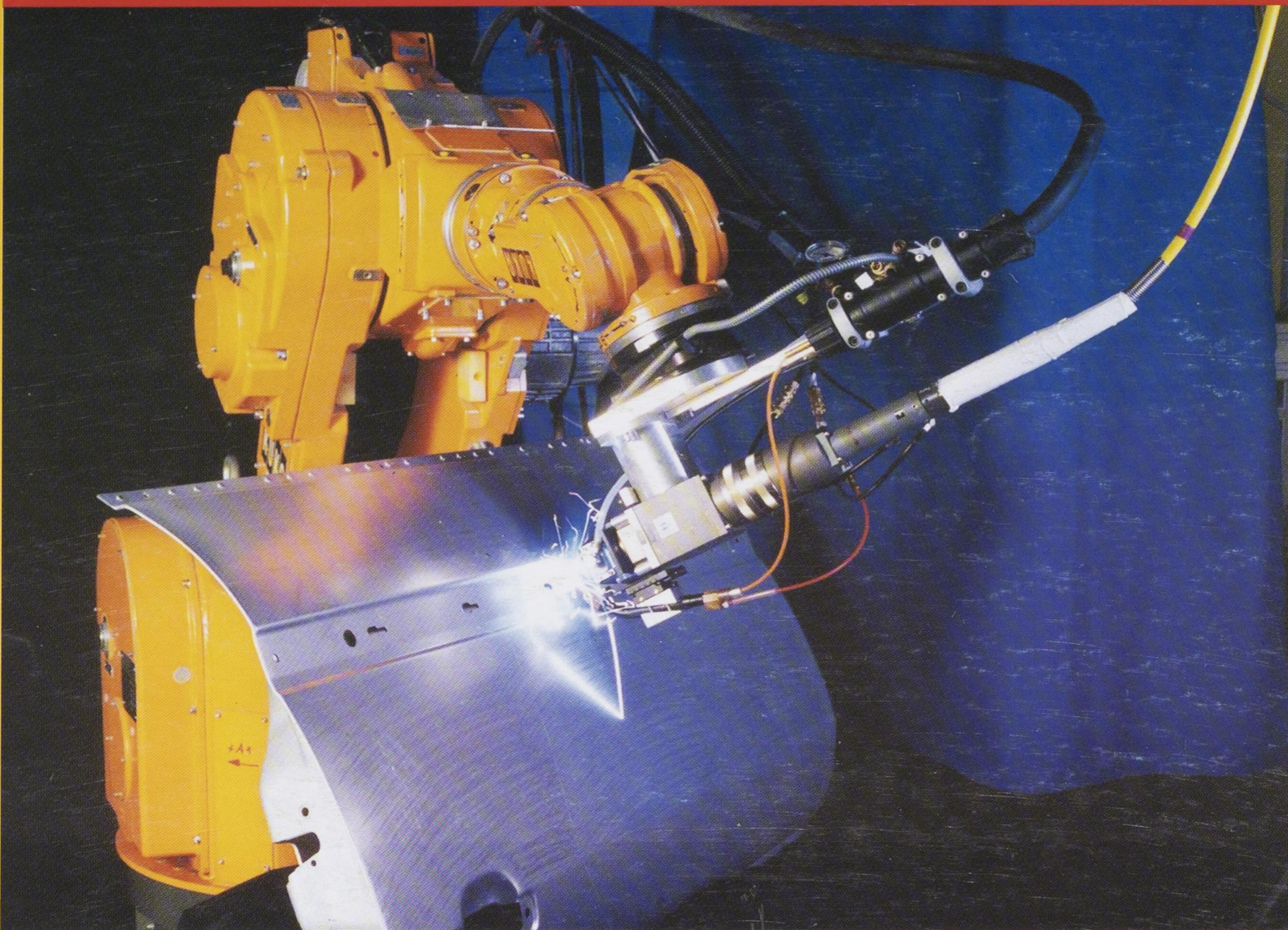


COMPOUND SEMICONDUCTOR

Three-Fives and Silicon Heterostructures

June 2005 Volume 11 Number 5



HIGH-POWER LASER DIODES **Efficiency drive set to** **boost laser reliability**

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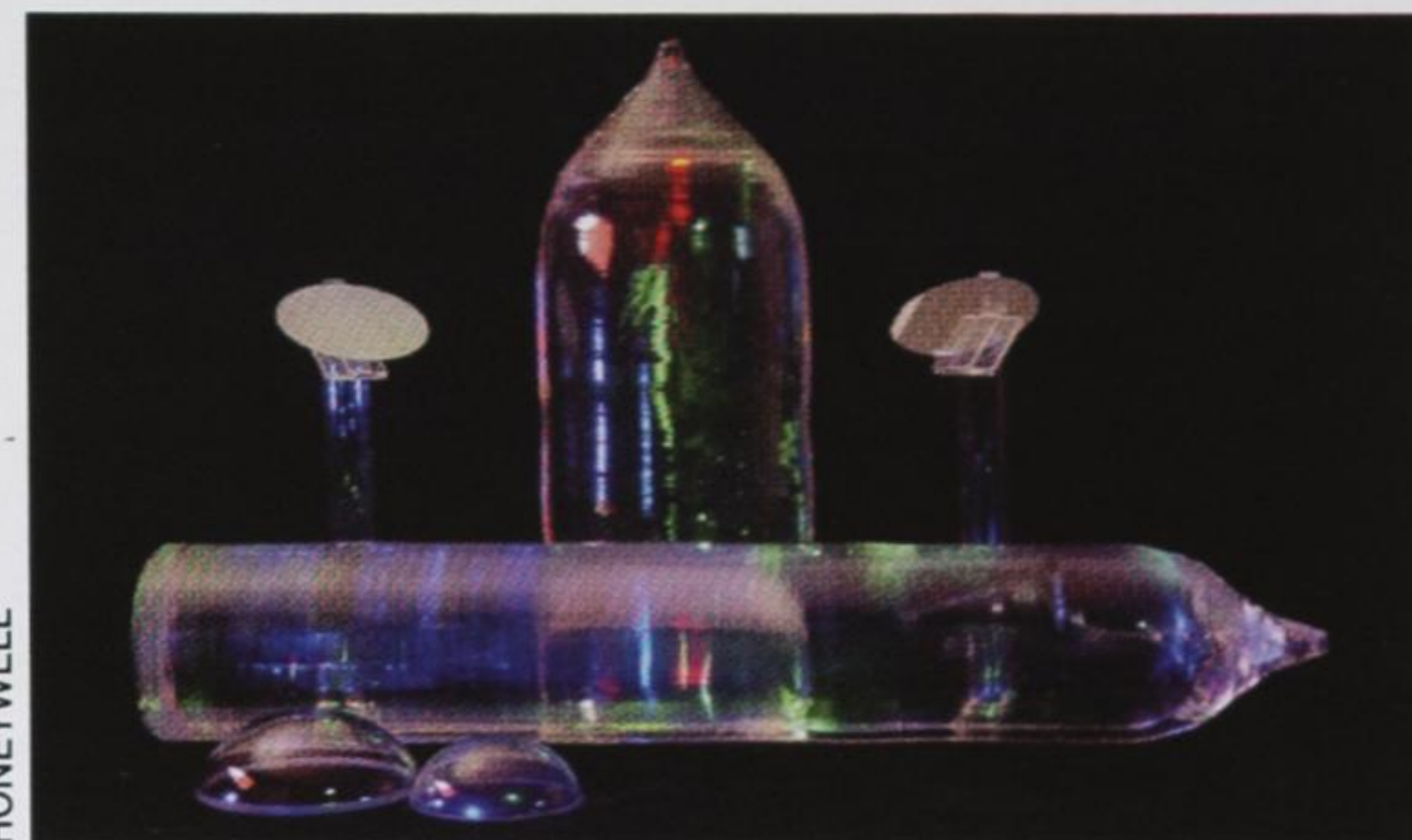
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Editorial

Get behind MIT's roadmap



When the Massachusetts Institute of Technology (MIT) kicked off its communications technology roadmap (CTR) program in 2000, it couldn't have foreseen the upheaval that was about to unfold in the optical communications industry. Five years on, and it comes as no surprise to learn that the sector is in dire need of restructuring.

The recommendations from the various CTR working groups emerged last month at the Microphotonics Industry Consortium's spring meeting, many of which call for a radical rethink of the fiber-optic component industry.

In the keynote talk, MIT economist Jerry Hausman gave delegates a reality check, saying that anybody pinning their hopes on the industry being rescued by the roll-out of fiber access to residential customers would be placing "a multibillion dollar bet with significant uncertainty". According to Hausman, that's a bet that's not worth risking, since the demand for photonic components from telecom sector alone will not be enough to return the industry to health.

Despite improving sales, many fiber-optic component vendors remain wildly unprofitable. One problem is that the normal rule of economies of scale, exploited so effectively in the silicon industry, simply doesn't apply to photonics. Why not? Too many technical specifications, and the fact that the cost of components is dictated largely by their testing and packaging requirements, rather than by the pure manufacturing cost.

The solution? More standards, the use of global testing platforms, yet more consolidation, and shifting manufacturing to China will all help. But these will not solve the underlying problem. Crucially, the industry must downsize, find non-telecom applications to boost demand, and collaborate.

Greater collaboration will improve the alignment of the whole supply chain. This should lead to better manufacturing tools, better relationships between companies and a healthier industry altogether. MIT's photonics roadmap could be the first step towards this. The III-V industry should take note and get behind it.

Michael Hatcher

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Photonics roadmap urges collaboration

A wide-ranging effort coordinated by the Massachusetts Institute of Technology (MIT) to produce a roadmap for the photonics industry has highlighted a number of major issues that the III-V community must address.

Lionel Kimerling, the director of MIT's Microphotonics Center and one of the driving forces behind the communications technology roadmap (CTR) program, told *Compound Semiconductor* that the telecommunications industry alone would not be able to support the investment that is required to develop the technologies that will be needed for future photonics applications.

Kimerling said that, although the photonic components market is recovering, losses are rising along with increasing revenue, meaning that the current manufacturing model is unsustainable. With the three major InP photonics suppliers each still able to handle four times the current global demand for devices, more consolidation is inevitable, he added.

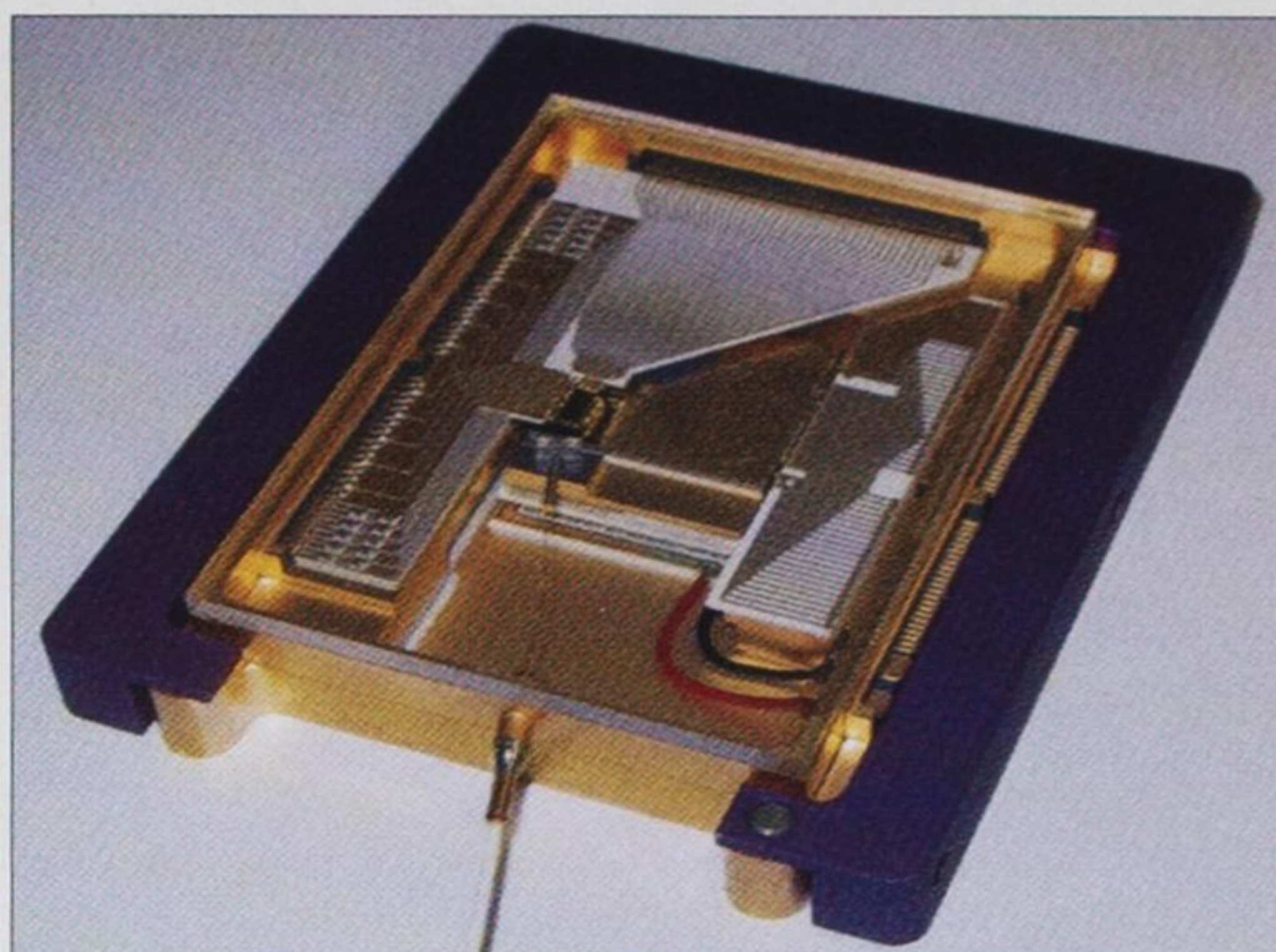
But even consolidating the manufacturing base will be insufficient on its own. In what Kimerling described as "a real eye-opener" for the industry, an analysis by MIT economics professor Jerry Hausman showed that packaging and testing amounted to 80–90% of the total cost of photonics components.

So even if chips can be made much more cheaply, the overall effect on cost may not be that great. Instead, developments such as the establishment of a global test procedure for individual components could be more beneficial to the industry.

Another significant problem identified is that there is currently no market driver of sufficient volume for the InP manufacturing industry to be profitable. The CTR's III-V working group concluded: "For telecommunications to fully realize the cost benefits of an integrated InP technology, this traditional market may have to 'piggyback' on emerging high-volume markets."

And although the report concludes that the optical components industry stands at the threshold of a major expansion, it also identifies a need to restructure business procedures that will allow it to operate profitably over the next three decades.

Part of that restructuring will demand far greater cross-industry collaboration within the III-V photonics community. Speaking at the consortium's spring meeting held at MIT, where the roadmap conclusions were



This 100 Gb/s DWDM transmitter made by US company Infinera demonstrates the high level of photonic integration that is identified as a key element of the future photonics industry as defined in MIT's communications technology roadmap. It features 10 distributed feedback (DFB) lasers, modulators, variable optical attenuators, power monitors and optical multiplexing on a single InP die.

"Taking advantage of developments in high-volume markets may be the only path for economical III-V integration in telecom."

III-V WORKING GROUP OF THE COMMUNICATIONS TECHNOLOGY ROADMAP

unveiled, III-V working group co-chairmen Rick Clayton and Tom Dudley drew up a "plan of attack" that identified a number of measures that could be implemented to address key challenges.

Achieving economies of scale in InP is an issue at the forefront of many manufacturers' plans, and Clayton said that companies should consider pooling their resources. This would help to consolidate manufacturing volume, allow collaborative efforts on critical process technologies and result in more efficient spending on process development.

But fostering that collaborative spirit will inevitably be a major challenge. While Kimerling says that he has detected the beginning of a consensus across the industry to collaborate more freely, he admits that this is only hap-

pening slowly, with firms still wary about any loss of intellectual property that might result.

For compound semiconductor chip manufacturers, the implications of the proposed changes could be enormous, with Kimerling believing that there will be a major shift in the III-V photonics manufacturing base over the next 10 years. One of two options must be followed, concluded the report.

The first is to move to an outsourced manufacturing model, since the amount of revenue available to individual firms will not allow for profitable support of an internal fabrication facility. The second option is for further large-scale consolidation among current suppliers.

In one of many recommendations, it was concluded that an industry effort to develop standard manufacturing processes and design rules for III-V technology is now required. The III-V working group also reported that the integration of photonics and electronics on InP is limited currently by the lack of fabs that are capable of producing large-scale optoelectronic chips in the material.

While much of the existing InP capacity, for example, is focused on 2 and 3 inch processing, these larger chips will need to be made on 4 inch wafers, said the III-V working group. Since the move to 4 inch manufacturing is currently an unviable option for cash-strapped photonics companies, one solution could be to design products that can be made using standard processes originally developed for InP microelectronics, it added.

The Irish company Eblana Photonics is already working with US-based InP foundry Vitesse on just such a model, using the latter's HBT electronics process to fabricate lasers (see *Compound Semiconductor* March p23).

The III-V working group went on to identify epitaxy as a key part of the "recipe book" for any successful foundry model, whether or not it is contracted out to growth specialists.

Techniques to control material composition and doping levels across wafers will also be necessary, said the III-V working group. It added that one option to solve the problem of insufficient demand could be to find a high-volume application in a different market sector, such as photovoltaics or data storage. Processes used here could cross over into communications, it concluded: "Taking advantage of developments in high-volume markets may be the only path for economical III-V integration in telecom."

Anadigics aims to take market share with on-die transistor integration

RF chip and module manufacturer Anadigics says that it is leading the industry movement towards greater GaAs RF functionality through its integration of HBT and PHEMT devices on a single InGaP die.

The Warren, NJ, company believes that the convergence of the cellular handset with broadband wireless access is ushering in a need for increased device integration at the chip level and that its PHEMT/HBT solution offers designers the same kind of freedom that they've come to expect in silicon-based FET circuits.

Enabling greater functionality in a smaller package is a key challenge for GaAs manufacturers at the moment, and Anadigics' VP of technology, Aditya Gupta, says that the new process allows the on-die integration of power amplifier (PA) and switch functions, as well as more robust biasing circuits. The end result for handset manufacturers is longer talk-times for their products, which is something that is becoming increasingly important with the advent of battery-draining 3G applications, such as video messaging.

As if to emphasize this, wireless service provider Verizon is now insisting that its handset suppliers provide phones with a minimum talk time of 200 minutes, a demand that Gupta says that Anadigics' technology can meet.

While Anadigics believes that it is the first company to develop and implement into vol-

ume production a commercially viable PHEMT/HBT process, other GaAs manufacturers, such as TriQuint Semiconductor and Agilent Technologies, are pursuing alternative integration paths (see *Compound Semiconductor* May p18 and p21).

Anadigics has used the process since 2003. Its AWT6137 PA module, launched in March last year, was the first volume product to exploit PHEMT/HBT integration. Although Gupta admits that the integration technology is unlikely to see Anadigics dislodge RF Micro Devices or Skyworks Solutions as the leading suppliers of GSM PAs, there are signs that it is attracting some gains in market share.

In perhaps the clearest indication yet of the acceptance of the technology, Samsung, the third-ranked cell-phone supplier with a global market share of 12.6% last year, is to use Anadigics AWT6562 modules based on the high-efficiency low-power (HELP) product line in a 3G phone. Reacting to that, and another recent design win in Samsung's CDMA phone line-up, market analyst Asif Anwar of Strategy Analytics said: "The latest contract with Samsung demonstrates that Anadigics is making inroads into the GSM platform."

And there should be more to follow, according to Anadigics, who said: "We're currently engaged with more handset manufacturers than ever before."



Samsung is to use Anadigics power amplifier modules in a new 3G phone.

Anwar echoed the feeling that the PHEMT/HBT technology platform is unlikely to create a major shift in the cellular PA business: "Anadigics has stolen a march on its competitors by integrating a PHEMT/HBT process, and has demonstrated the viability of the process in commercially available products targeting both CDMA and GSM platforms," said the analyst. "On the other hand, and based on the information available, we don't see this development leading to a major shift in cellular handset PA market share."

Ultimately the integration strategies of all of the GaAs manufacturers should result in modules that offer greater functionality for suppliers of all kinds of wireless terminals. For Anadigics, the best prospects look likely to come from the WiMAX area, where an incumbent market leader is yet to be established in terms of PA supply.

Anadigics believes that it has the technology to become that market leader as WiMAX connectivity gathers momentum. Strategy Analytics predicts a market of more than 20 million WiMAX subscriber terminals and base stations per year in 2009.

Sony confirms GaN lasers will feature in Playstation 3 console

Consumer electronics giant and diode laser manufacturer Sony has announced the launch of its forthcoming games console, the Playstation 3, which will feature Blu-ray Disc (BD) data storage technology.

Sony, which has allied with blue-laser pioneer Nichia in the development of optical heads that will be used in the next-generation storage medium, says that it will launch the console at the Electronic Entertainment Expo, which takes place in May 2006.

The games sector will offer a big potential market for blue lasers based on GaN. For example, Sony has sold nearly 200 million of its previous-generations of Playstations.

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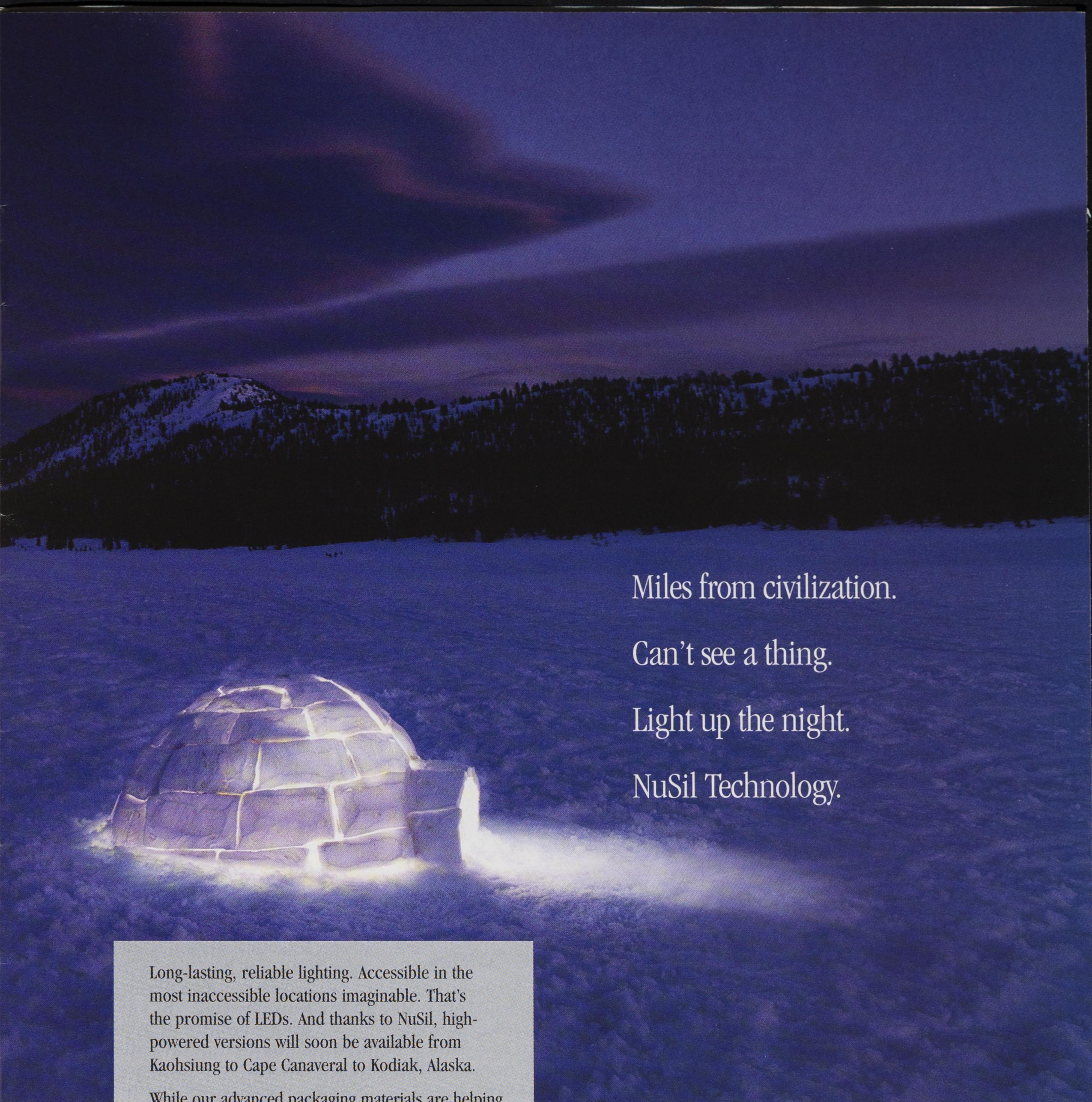
Sony is using its hugely successful Playstation games platform to help launch the Blu-ray Disc data storage format that uses GaN-based blue laser technology.

through the BD-ROM discs will enable delivery of graphics in full high-definition quality.

Meanwhile, Sony's chief competitors in the

gaming world – Microsoft and Nintendo – said that they will not be using GaN laser technology in their next-generation consoles. However, both Nintendo's system and Microsoft's Xbox 360 will feature regular DVD storage that uses red lasers.

Next-generation DVD using GaN-based lasers is expected to become fully commercial by the end of 2005. Although the two rival industry groups developing the technology – one led by Sony and Matsushita Electric, the other by the high-definition DVD industry group that includes laser makers Toshiba, Sanyo and NEC – have recently been involved in talks to unify the two standards, no agreement has yet been reached.



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WiMAX spending will rocket, says TIA

Wireless industry spending on infrastructure required to deploy the emerging WiMAX standard in the US will rocket from just \$15 million recorded last year to \$290 million in 2008. That's according to an analysis of the market by the Telecommunications Industry Association (TIA), based in Arlington, VA.

WiMAX is a broadband-wireless-access technology that uses a fixed, outdoor-mounted antenna similar to a small satellite dish to provide a broadband connection with users that are up to 50 km away.

Operating in the 2–11 GHz window, WiMAX could offer a sizeable market oppor-

tunity to GaAs-based chip manufacturers in the future. Warren, NJ, firm Anadigics says that it has received a volume order for its InGaP HBT power amplifiers to be used in WiMAX applications, while the top silicon-chip manufacturer Intel is known to be very keen on the technology.

In its 2005 market review and forecast, the TIA says that it expects WiMAX-infrastructure revenue to increase "dramatically" in the next few years. "With the Wi-Fi and WiMAX markets expanding rapidly, we will begin to see more demand for mobile broadband and broadband connectivity," said TIA president

Matthew Flanigan. "It is likely that both markets will stimulate the overall broadband sector to the benefit of all technologies."

Although it will eventually be mobile, WiMAX will never achieve the nationwide coverage of a cellular network, says the TIA in its report. Initial shipments of WiMAX equipment will be for backhaul applications, connecting hot spots with the Internet, it adds.

According to the industry group's report, the WiMAX-infrastructure market in the US will be worth \$115 million this year, rising to \$180 million in 2006, \$230 million in 2007 and \$290 million in 2008.

Nokia raises its 2005 cell-phone forecast

Number-one cell-phone manufacturer Nokia has revised its forecast for the 2005 handset market following a strong start to the year.

The Finland-based firm, which had a handset market share of about 31% in 2004, is now expecting 15% growth this year, despite seeing some weakness in the market for 3G handsets. If correct, that would see the overall market grow from 643 million units last year to 740 million units in 2005. In an earlier forecast, Nokia expected global unit volumes to increase by only 10%.

Nokia is seeing its fastest growth in China, which has now become its number-one single market for mobile devices.

On the down side, Nokia saw shipments slide in the Americas, with North American volumes down 33% annually. Nokia says that operator migration from TDMA, traditionally a strong Nokia sector, to GSM and CDMA protocols, has been the chief reason for this.

In the first quarter of 2005, Nokia sold 53.8 million mobile devices, representing a year-on-year rise of 20%. As would be expected in the extremely seasonal mobile-device market, that volume was down 19% on the previous quarter.

Sales in China alone surged 69% compared with the equivalent period in 2004, reaching 7.1 million units.

On the financial side, Nokia's revenue from cell-phone sales in the first quarter of 2005 increased 11% compared with the same period last year to reach €4.5 billion (\$5.9 billion). However, operating profit for the division dropped 16% to €869 million.



GIGABEAM

Broadband-wireless-access provider GigaBeam is to use Endwave's modules in commercial deployments of gigabit radio links operating in the E-band at 70–80 GHz. The first of these links is in operation at Trump Place, downtown Manhattan, enabling residents in the block to receive fiber-equivalent wireless access, including quadruple-play services: high-speed data, voice/video over IP, high-definition TV and video-on-demand. Ed Keible, president and CEO of Endwave, said: "As these high millimeter-wave frequencies demand innovative technology solutions and the precision and repeatability of automated manufacturing, [our] expertise makes us uniquely positioned to serve as the leading subsystem supplier to E-Band radio OEMs."

Telesat buys Ka-band terminals to deliver broadband access

One of the world's leading satellite operators has signed a deal to buy terminals that use GaAs MMICs to provide broadband communication services to consumers. The US company Viasat will supply Telesat with its DOCSIS-for-satellite terminals, which operate in the Ka-band at 26–40 GHz.

And Viasat will be incorporating satellite modems and Ka-band transceivers based on GaAs MMICs made by its Arizona-based subsidiary US Monolithics as a key element in these terminals.

Viasat says that its terminals use a networking technology that efficiently exploits the available satellite bandwidth. This ought

to result in cheaper services for consumers.

Telesat, a Canadian company that in 1972 launched the first domestic commercial-communications satellite to be deployed in a geostationary orbit, had already chosen Viasat to supply the critical technology for the Anik 2 satellite just over a year ago.

"Telesat is committed to using the best technologies available to bring affordable broadband services to consumers," said Dave Lahey, the satellite operator's vice-president of business development. "Viasat's terminals will help Telesat deliver a superior satellite broadband service that can help make the digital divide a thing of the past," he continued.

Viasat says that Telesat's multiyear purchase order will bring the number of its DOCSIS terminals that are on order around the world to almost 200,000 units, thus establishing the technology as a serious alternative for broadband access.

SiGe reference design shapes up for WiMAX

Fujitsu Microelectronics America and SiGe Semiconductor have collaborated on a 3.5 GHz reference design for WiMAX equipment.

The design – based on Fujitsu's new system-on-chip baseband, which is combined with SiGe Semiconductor's RF transceiver chipset – will now be submitted to the WiMAX Forum industry group for certification.

Providing a complete RF chain, the reference design is said to deliver high-intensity signals, produce low noise and have a tuning range of between 3.3 and 3.8 GHz. It allows simultaneous broadband access to high-speed voice, data and video services.

SiGe Semiconductor has also released a new RF front-end module that allows simultaneous transmission and reception of wireless LAN and cellular signals.

"Our new modules are the industry's only truly integrated WLAN front-end solutions for cellular handsets," said Andrew Parolin, SiGe Semiconductor's director of wireless data products. "With these devices, we are addressing the fast-growing market opportu-



The SiGe/Fujitsu WiMAX reference design will provide an easy integration path to broadband wireless communication at 3.5 GHz, according to the two companies.

nity created by the widespread adoption of WLAN, and consumer desire for increased cellular feature integration."

Skyworks is confident of a strong finish to 2005

RFIC and module maker Skyworks Solutions says that cell-phone handset sales will accelerate in the second half of 2005 as the consumer uptake of 3G technology gathers pace after a slow start.

Registering a 4% year-on-year increase in quarterly revenue in the seasonally weak post-holiday period, the Woburn, MA, company predicts that between 725 million and 750 million handsets will be sold in 2005.

Despite the slower-than-expected initial uptake of 3G products, Skyworks' CEO David Aldrich says that the penetration of top-tier phone vendors such as Motorola and Nokia into China will more than compensate.

A key target for the firm is to increase the gross margin on its products as it simultaneously looks to build dollar content per phone through the integration of different functions.

One example of this is Skyworks' progress with Sony Ericsson, which the GaAs IC manufacturer now boasts as a 10% customer, along with Samsung and Motorola. Previously, Skyworks supplied Sony Ericsson with power amplifiers at a cost of \$1.50 per unit,

but the handset maker has now switched to using a front-end module that sells for \$2 but which reduces the phone's overall bill of materials.

Skyworks is also focusing on integrating new filter technology, specifically bulk acoustic wave (BAW) filters, in future products. Estimating that 2.3 billion filters were used in cell-phones in 2004, Aldrich says that he expects the market share of BAW devices – currently very small – to rise dramatically as advanced, multiband phones proliferate.

Having recently invested in increasing HBT capacity at its Newbury Park facility, Skyworks is also looking to reduce GaAs-wafer costs with a view to improving margins.

As a result of the expected second-half bounce and improved margins, Skyworks is expecting its operating profit to increase by 25% sequentially.

For the quarter that ended April 1, Skyworks' net profit came in at \$1.2 million, compared with a net profit of \$13.9 million in the prior quarter and a net loss of \$9.4 million in the equivalent period last year.

Frost report presses for RF-chip scaling

Increasing deployment of multimode and multiband wireless handsets developed for the latest wireless-communications standards is set to spark demand for RF semiconductors.

That's according to analyst firm Frost & Sullivan, which has just issued a report on the RF semiconductor market in handsets. It says that the value of the sector is set to grow from \$5.34 billion in 2004 to \$8.27 billion in 2008.

Frost & Sullivan's figures include all RF semiconductors used in handsets – both GaAs- and silicon-based – specifically referring to RF switches and filters, duplexers, power amplifiers and transceivers.

"The swelling number of wireless standards, coupled with the co-existence of many standards in any region, necessitates multimode and multiband handsets, [for which] there is a corresponding hike in the number of RF components that go into a handset," said Frost & Sullivan analyst Deepa Doraiswamy. "Additional filters have to be added in the front-end to serve multiple frequencies. It will ultimately increase the dollar value of RF semiconductors."

Device integration and scalability are two key aspects that RFIC manufacturers must concentrate on, the report urges.

"RF semiconductor firms will have to design devices that improve the overall performance of the RF section in handsets and support the creation of single-chip radios and the integration of RF and baseband," said Doraiswamy.

The analyst adds that many companies have begun to invest heavily in developing the process technologies required to cope with the increasing pace at which handset designs evolve: "The design cycles of handsets could shrink further. RF semiconductor manufacturers need to develop scalable solutions with advanced power control features and interfaces to varied functionality."

Doraiswamy adds that with the filter and switch markets almost saturated, it is the power amplifier and RF transceiver applications that offer more scope for technologically innovative start-up companies.

"An emerging company with a ground-breaking technology can make significant inroads into these markets, provided that the gestation period for its technology is short."

● Frost & Sullivan's *Strategic Analysis of World Handset RF Semiconductor Markets* is available at www.frost.com.

Osram files a white-LED lawsuit against Citizen

By Tim Whitaker

Japanese LED maker Citizen Electronics is facing a lawsuit filed by its German competitor Osram Opto Semiconductors.

The complaint concerns Osram's patented color-conversion technology for white LEDs, which is used in applications including display backlighting in cell-phones and car radios.

Developed by Osram in the mid-to-late 1990s, the technology in question uses a phosphor to convert blue emission from InGaN chips into white light. Osram claims to have been the first manufacturer to launch the white single-chip LED commercially.

The situation is complicated because Citizen makes white LEDs using technology licensed from Nichia, under an agreement reached in 2002. Later that year Nichia and Osram signed a cross-licensing agreement, allowing them access to each other's technology, but this doesn't cover third-party access.

In June 2004 Nichia issued a statement aimed at its competitors that signed licensing agreements with Osram in relation to white LEDs. Nichia was keen to stress that, despite the cross-license agreement between Nichia

and Osram, a license granted to a third party under Osram's patents does not imply a license under Nichia's patents.

In the latest lawsuit, Osram claims that Citizen continues to infringe its patents by importing, selling and offering certain white LEDs in Germany. Osram intends to obtain a restraining order and is applying for compensation. The company has also taken similar action against an LED distributor, which has since declared that it will not distribute Citizen products that infringe Osram's patents.

Osram issued similar warnings to Malaysian LED manufacturer Dominant and its distributors in Germany, France and Taiwan on the basis of the patent infringements last year. However, Dominant now claims that the International Trade Commission has cleared it of any wrong doing, freeing the company to sell white LEDs globally.

"Our objective in taking legal action against Citizen is to prevent unauthorized use of our technology," stated Osram CEO Rüdiger Müller.

Tim Whitaker is Editor of LEDs Magazine.

LED spin-off propels Kopin into profit

Kopin Corporation, the Taunton, MA, supplier of HBT epiwafers, reports a net profit of \$1.2 million in its latest financial quarter.

Although the company's \$18.9 million revenue was down on the figure posted in the equivalent period last year, the decision to shelve its LED manufacturing activities has improved its bottom-line performance.

A year ago Kopin reported a net loss of

\$3.4 million on revenue of \$22.4 million. However, spinning out its LED manufacturing business as part of Taiwan-based joint venture KO-BRITE appears to have saved Kopin more than \$5 million in operating costs during the last quarter.

The company also registered a reimbursement of \$0.65 million for providing KO-BRITE with training and R&D expertise.

In brief

- US-based LED manufacturer **Lumileds** has improved the performance of its Luxeon I LED for all InGaN colors (white, blue, cyan, green and royal blue) while maintaining their cost. White LED emission has increased from 31 to 45 lm. Other colors are said to have similar improvements, all without increasing the package or chip size. It has also released red, red-orange and amber Luxeon III

LEDs that deliver 110, 140 and 190 lm.

- **Color Kinetics** has used Cree's high-brightness XLamp 7090 LED series in several of its next-generation architectural and entertainment lighting products. Color Kinetics vice-president of engineering, Fritz Morgan, said that the company chose Cree's XLamp because of its intensity gains, tight color and intensity binning, and ease of use in the manufacturing processes.

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Cree licenses patents to a trio of firms in Far East

By Tim Whitaker

Cree has licensed its white LED patent (US patent 6,600,175) to Japanese firms Stanley Electric and Rohm, as well as Cotco Holdings from Hong Kong.

The license gives manufacturers the right to sell white LEDs incorporating Cree's LED chips. Cree is currently in discussions with other potential partners to license this patent, and it says that it hopes to announce further licensing arrangements later this year.

The patent in question was also licensed to Nichia earlier this year. Originally filed in 1996 by Advanced Technology Materials Inc (ATMI), the patent was not granted until 2003 and was only acquired by Cree when the company took over ATMI's GaN epitaxy and substrates business last year.

The patent covers any solid-state device coupled with a down-converting light-emitting medium, and it specifically refers to the

production of white light by combining a monochromatic blue or UV LED with a fluorescent organic and/or inorganic material in a polymeric matrix.

"These additional licenses further reinforce the importance of this patent and the increasing awareness and respect for intellectual property in the industry," said Cree's general manager of optoelectronics, Scott Schwab.

● Cree's CEO and president, Chuck Swoboda, has been elected as chairman of the company's board of directors following the resignation of F Neal Hunter.

As one of Cree's original founders, Hunter had been chairman for the past 10 years, during which time Cree became a major manufacturer of SiC-based LED chips and microelectronic devices. Hunter was also Cree CEO from 1994 to 2001.

Tim Whitaker is Editor of LEDs magazine.



Osram says that its Ostar Lighting LED is the brightest semiconductor light source that it has ever released. The white-emitting 3 x 1 cm package is claimed to produce more than 200 lm at 700 mA and to last for more than 50 000 hours. The device differs from most white-light LEDs, says Osram, because the yellow converting material is incorporated directly on the chip and not in the encapsulation material. The German company claims that this modification means that its latest LED can deliver pure white, which remains constant from all viewing angles and does not create colored shadows at the edges.

Nichia: 'further IP actions are needed'

By Tim Whitaker

Nichia says that it will accelerate its patent enforcement against blue/white LEDs that infringe its intellectual property rights.

The Japanese firm claims that, although it has taken a series of legal actions against certain LED manufacturers to protect its patented technology, it "believes that its rights are not necessarily respected by certain companies in the industry".

"Intellectual property has been an important issue for Nichia, and its importance will not be diminishing in the future," said Noboru Tazaki, executive vice-president of Nichia Corporation. "We are serious in protecting our rights, as well as business of our customers and our licensing partners."

According to the company, some distributors are now marketing products with labels indicating that they contain Nichia LEDs, and Nichia is not currently enforcing its LED patents against those labeled products.

Nichia is considering additional legal action in several countries, and will commence if an infringement is found and the threat is "not tolerable".

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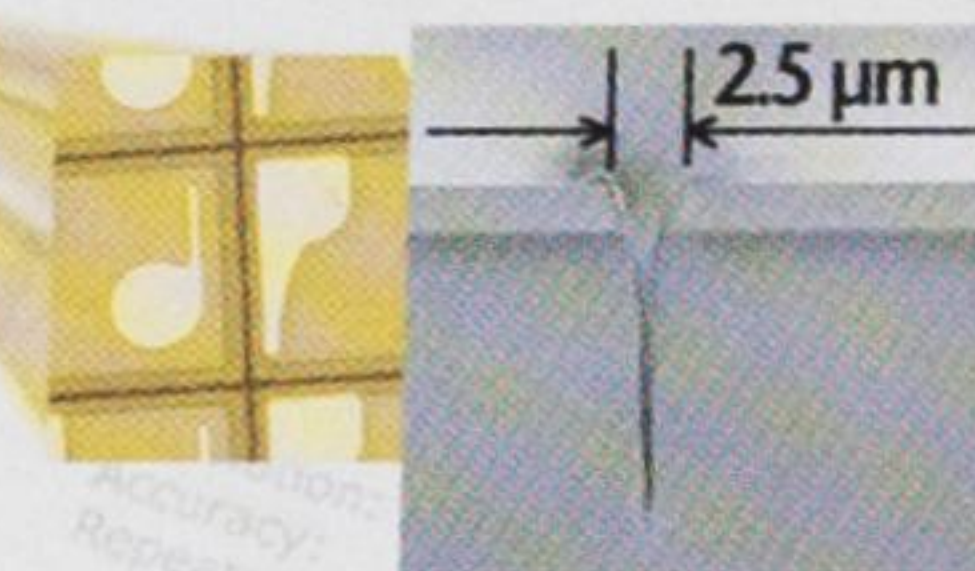
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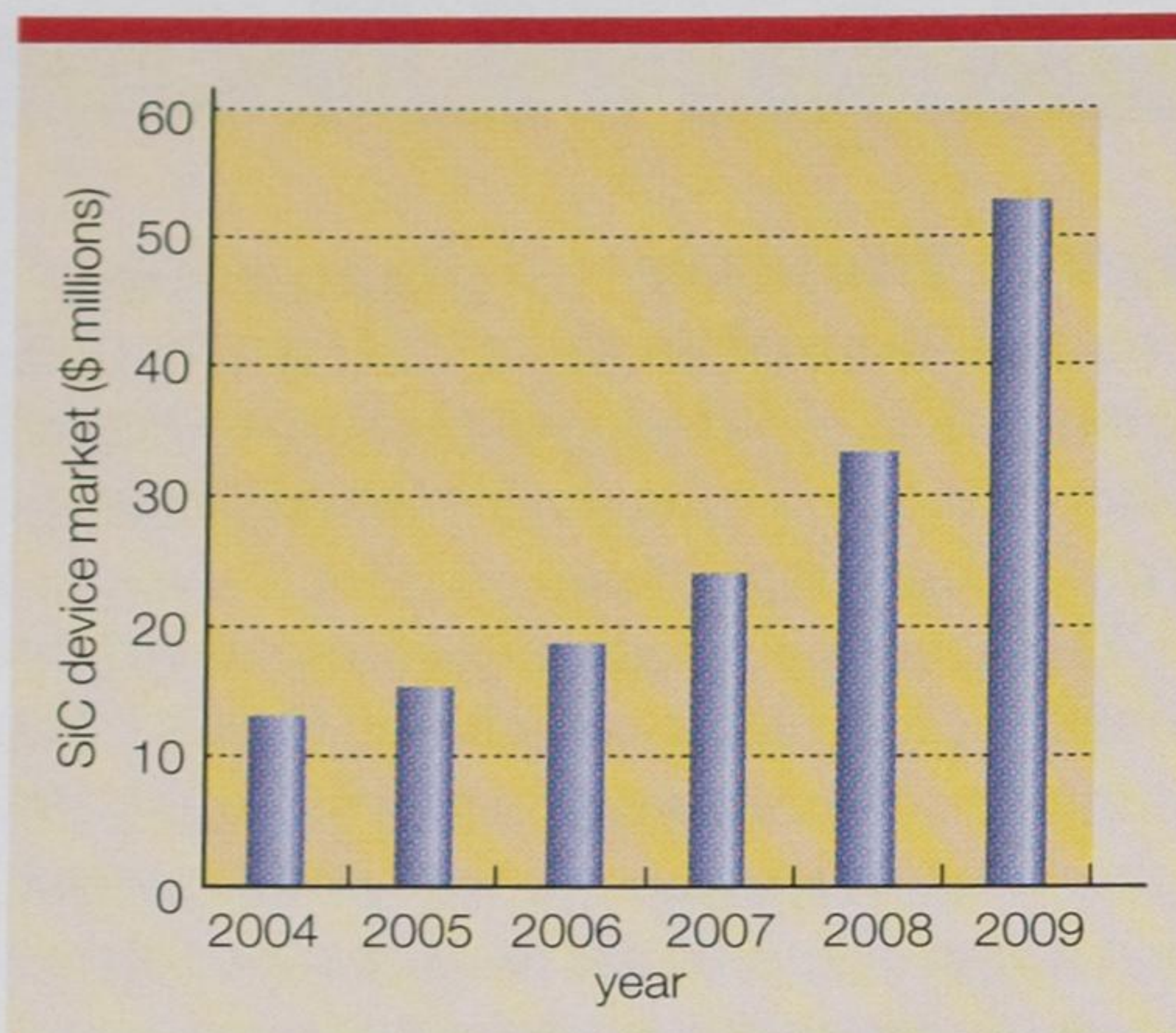
SiC electronics market set to quadruple by 2009

The SiC electronic device market will be worth more than \$50 million by 2009, according to a report by German market analyst Wicht Technologie Consulting (WTC).

The Munich-based firm says that although almost 80% of SiC substrates will be used for high-brightness blue, green and white LED manufacture by then, "fresh" markets will emerge for a new generation of energy-efficient, high-performance diodes and transistors used in power supplies and electric motors.

The company predicts that the global market for SiC Schottky diodes and transistors will increase from \$13 million in 2004 to more than \$53 million in 2009 at a compound annual growth rate of 32%.

WTC senior research analyst Olivier Nowak explains that the attractions of SiC Schottky diodes over their silicon counterparts – far lower losses when operated in forward bias and higher-temperature operation – result in smaller, more efficient power supplies. The market for replacement power sup-



SOURCE: WTC

There are big opportunities for SiC device makers in power circuit management, says the market research firm WTC.

plies that could contain SiC diodes is worth several billion dollars. He added that if these devices were used in conjunction with SiC MOSFETs, then 10-fold improvements in energy savings would be possible.

Despite the intrinsic advantages of SiC over silicon, Nowak says that commercial SiC-based products have so far been limited to Schottky diodes and MESFET RF transistors. According to his report, today's SiC Schottky diode market is headed by US company Cree, which holds a market share of 50%, and Germany-based Infineon. Cree also has a 95% share of the far smaller and less mature transistor market. Rockwell Scientific is the only other commercial supplier of SiC MESFETs.

"Materials issues with SiC substrates and supply chain deficiencies have compounded to keep prices high, especially for transistors," remarked Nowak, who added that today high-end power supplies are the only commercial application of power devices based on SiC.

WTC also expects Cree's dominance in the SiC substrate market to continue. However, it added that the Finland-based start-up Norstel, which also sells SiC substrates, will take a significant share of the relatively small European market for power device substrates.

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Emcore spin-off raises \$6 million

Emcore has spun off the development of its GaN power device technology in the form of a new firm called Velox Semiconductor.

Velox, in which Emcore holds a 20% stake, has already raised \$6 million from three venture capitalists – DCM-Doll Capital Management, SAS Investors and DFJ New England.

The firm was set up to commercialize fast, high-voltage GaN diodes for high-power electrical supply applications and is headed up by CEO Tom Hierl. Hierl previously formed Quantum Epitaxial Designs where he was CEO until the company's merger with UK-based epiwafer supplier IQE in 1999.

Emcore CTO Richard Stall is on the Velox board, and the new firm has five full-time employees. Velox will also sub-let space from Emcore, and it is expected to reduce Emcore's operating expenses by \$1.2 million per year.

Emcore CEO Reuben Richards says that the Velox spin-off will focus on the 200–600 V power diode product line, with Emcore's GaN-based RF development staying in-house.

That's because the technology and its application areas are distinct from the conventional III-V business areas, with the GaN power diode business requiring a separate distribution system that does not fit in with the rest of Emcore's product lines. "We decided that it was better off on its own," said Richards.

Richards adds that Emcore's GaN RF business is one of its most profitable and fast-growing units, with associated revenue tripling in the most recent quarter.

In its latest quarter, the Somerset, NJ, chip manufacturer reported a year-on-year revenue increase of 31% to \$30.4 million, witnessing stronger demand across its fiber-optic, photovoltaics and electronic materials businesses.

Emcore made an operating loss of \$4.9 million in the quarter, but saw its overall income boosted by a \$13.2 million earn-out due to Veeco's sales of TurboDisc MOCVD equipment. (Veeco acquired the TurboDisc division in 2003.) The net result was a profit of \$7.6 million for the quarter.

RFMD road-tests its 100 W GaN amplifiers

In its bid to challenge silicon LDMOS technology in cellular infrastructure applications, RF Micro Devices (RFMD) says that it has sampled 100 W GaN amplifiers to customers.

Speaking at the recent Piper Jaffray 7th Annual Technology Conference, CEO Bob Bruggeworth said that the technology could "change the game" in this area of the company's business, in a similar fashion to the effect that GaAs HBTs had on the cell-phone handset sector in the 1990s.

Bruggeworth also revealed that RFMD has manufactured its first GaN wafers at its Greensboro, NC, production facility, where the company makes its GaAs-based devices, after migrating this capability from its research and development fab in Charlotte.

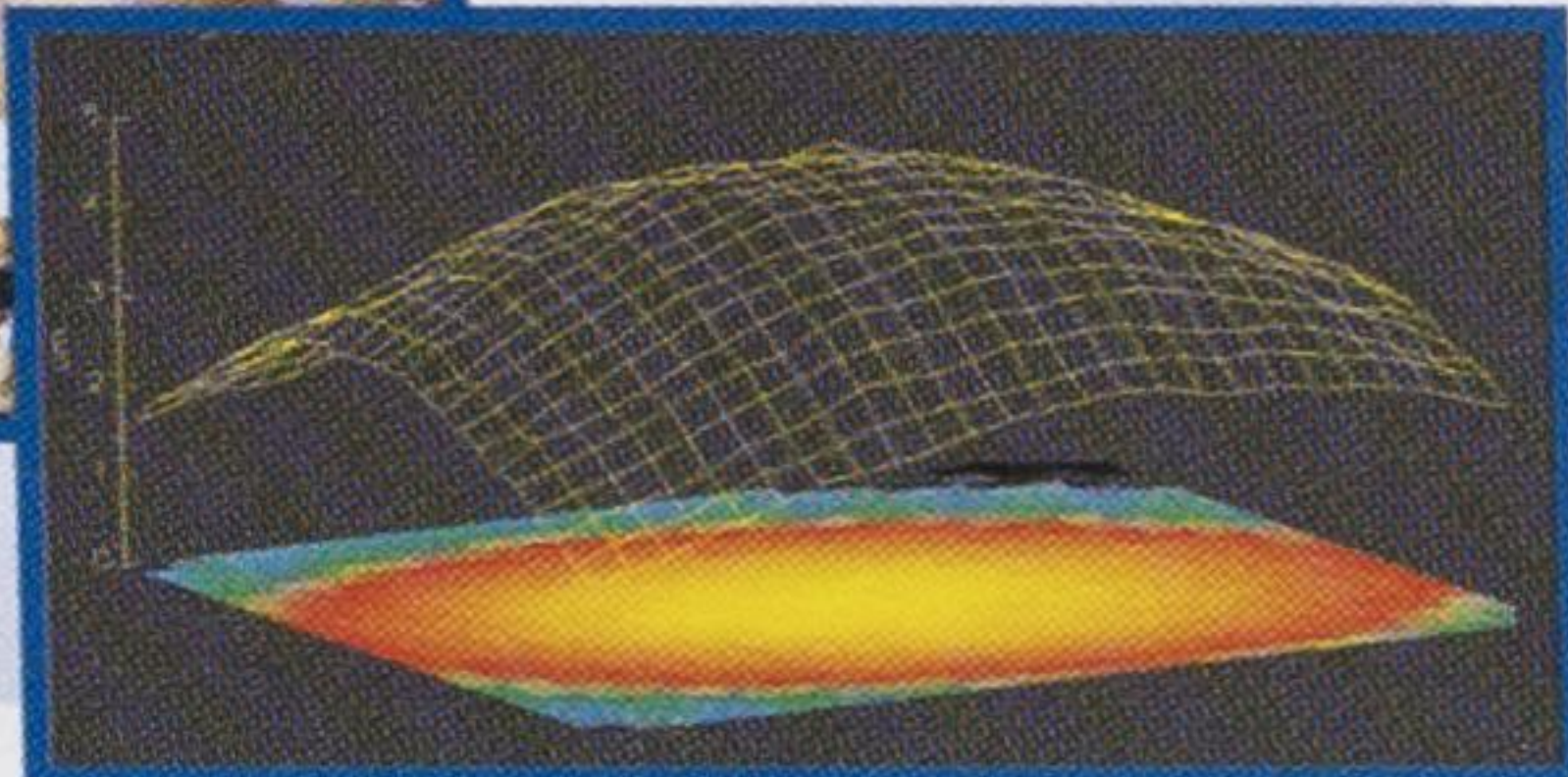
The infrastructure business, which Bruggeworth believes offers his firm an estimated \$800 million total addressable market, should also increase overall profit margins because of the high-value RFICs that are required.

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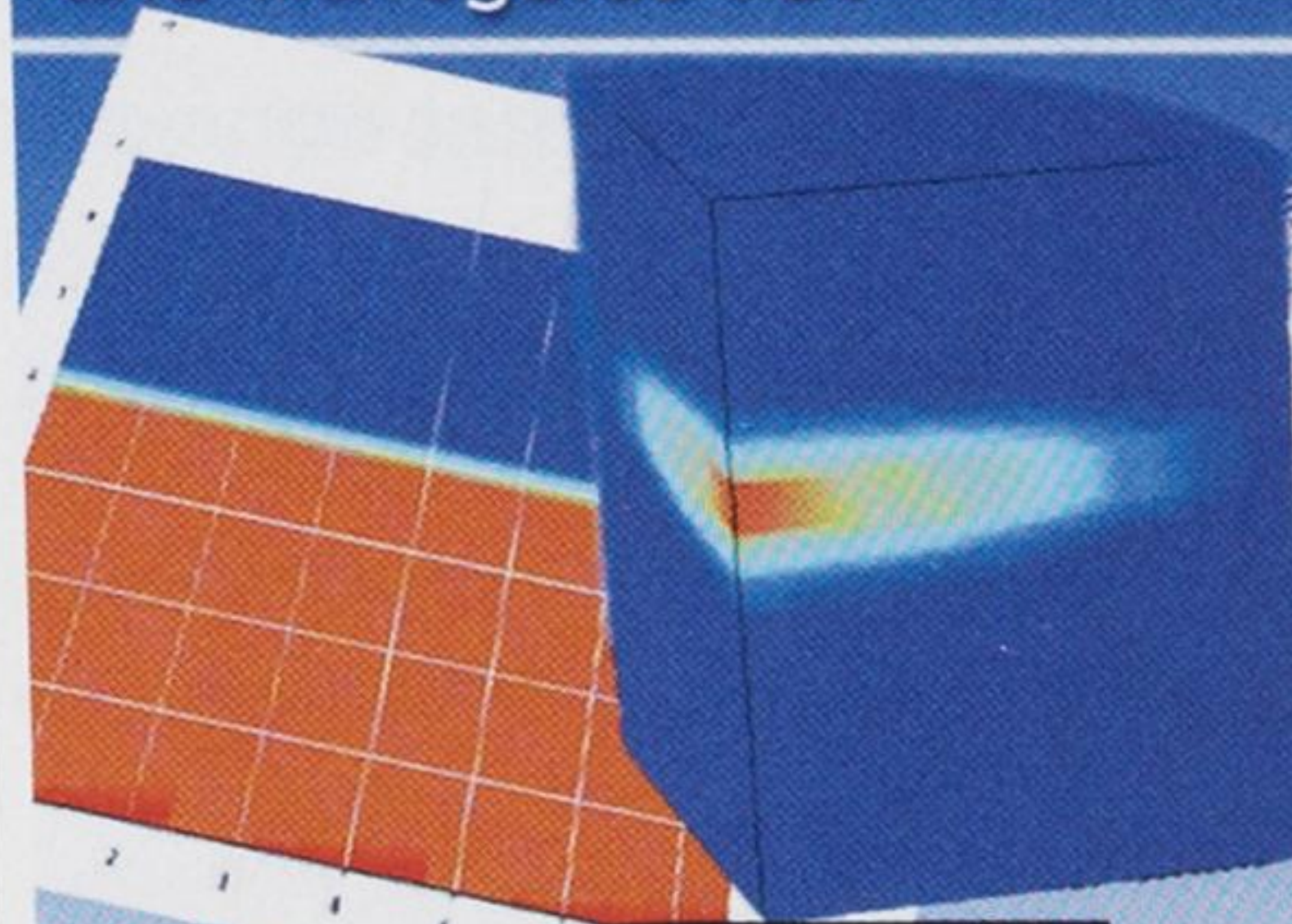
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Extended Nortel deal delays closure of Bookham's UK product-assembly plant

Faced with dwindling cash reserves, optoelectronic-chip manufacturer Bookham has been boosted by a \$100 million minimum-purchase commitment from its number-one customer, Nortel.

Reporting sales of \$49.9 million for its third quarter – a 22% year-on-year increase – Bookham says that Nortel, which accounted for 39% of its revenue in the three months up to April 2, has also relaxed some of the terms of Bookham's loan repayments.

Thanks to Nortel's commitment, and what Bookham CEO Giorgio Anania describes as "accelerating demand", particularly for laser transmitter components used in metropolitan communication systems, the firm gave guidance predicting a strong upturn in revenue for its next two quarters. In fact, says Anania, Bookham has been unable to meet some customer orders because of limited capacity.

And the CEO is keen to stress that the firm has widened its customer base, with key system deployer Cisco accounting for more than 10% of Bookham's revenue for the first time.

Half of the Nortel supply arrangement covers products made in Paignton, UK, that are due to be discontinued, while the remainder is for ongoing product lines that will be assembled and tested in Shenzhen, China.

Although the increased Nortel order should benefit the company overall, it does mean that Bookham will have to keep its UK assembly plant open for six months longer than it had originally expected.

That will hamper Bookham's ongoing cost-



Bookham is busy switching product lines to this Shenzhen, China, facility in a bid to cut costs, but restructuring charges and a six-month delay in the closure of the Paignton, UK, plant will put extra pressure on the company's rapidly-diminishing cash reserves.

cutting measures as the company watches its cash reserves melt away.

So despite the improving demand and visibility, Bookham still looks like it could face a cashflow problem before long unless it can raise further capital, possibly through the sale of its Paignton site. On the company's books, the site is included as an "asset held for resale" worth \$14 million.

Cash and cash equivalents now stand at \$34.5 million, down from \$69.5 million just three months ago. Bookham has also taken the opportunity to write down some of the reduced valuations of its 2004 acquisitions, with the net effect putting a further \$100 mil-

lion dent in the company's balance sheet.

The expected 15–20% increase in revenue in the current quarter, followed by a further increase of around 5% in the subsequent quarter, on top of the reduction in manufacturing costs, will inevitably slow down Bookham's cash burn.

But without some kind of financial injection, it remains to be seen whether the improving business climate will be sufficient to stave off a cash crunch. Bookham still expects to post a net loss in the next two quarters, and on top of that it will have to pay out a further \$8 million–\$12 million in costs associated with its restructuring.

Streamlined JDSU sees demand build momentum

JDS Uniphase (JDSU), which makes compound semiconductor chips that are used in optical communications applications, is to further reduce its manufacturing operations as it aims to become profitable.

According to company CEO Kevin Kennedy, 1350 positions will be removed from the payroll: 850 in North America and a further 500 in China. Cost-saving measures include the closure of a transceiver manufacturing operation in Florida, the sale of another facility in Ewing, NJ, and the divestiture of its cable-TV business.

With further streamlining of its operations in the pipeline, the company is at last seeing strengthening demand for its components that are used in optical communications. Kennedy said that JDSU's communications business made sales of \$101.7 million in the quarter that ended March 31.

That represents a 28% year-on-year increase. And with revenue in the company's other business area – commercial and consumer products – dropping sharply, the communications group was responsible for more than 60% of JDSU's revenue in the recent

quarter. As recently as last year, the split between the two business groups was even. But with the lower profit margins associated with the communications business, the company is planning to continue trimming its workforce and product offering.

On its total sales of \$166 million in the most recent quarter, JDSU made an operating loss of \$44.6 million and a net loss of \$38.6 million. The company reckons that the most recent cost-cutting measures will lead to savings of around \$20 million per quarter once fully implemented.

CyOptics raises \$24 million funding and secures supercomputer contract

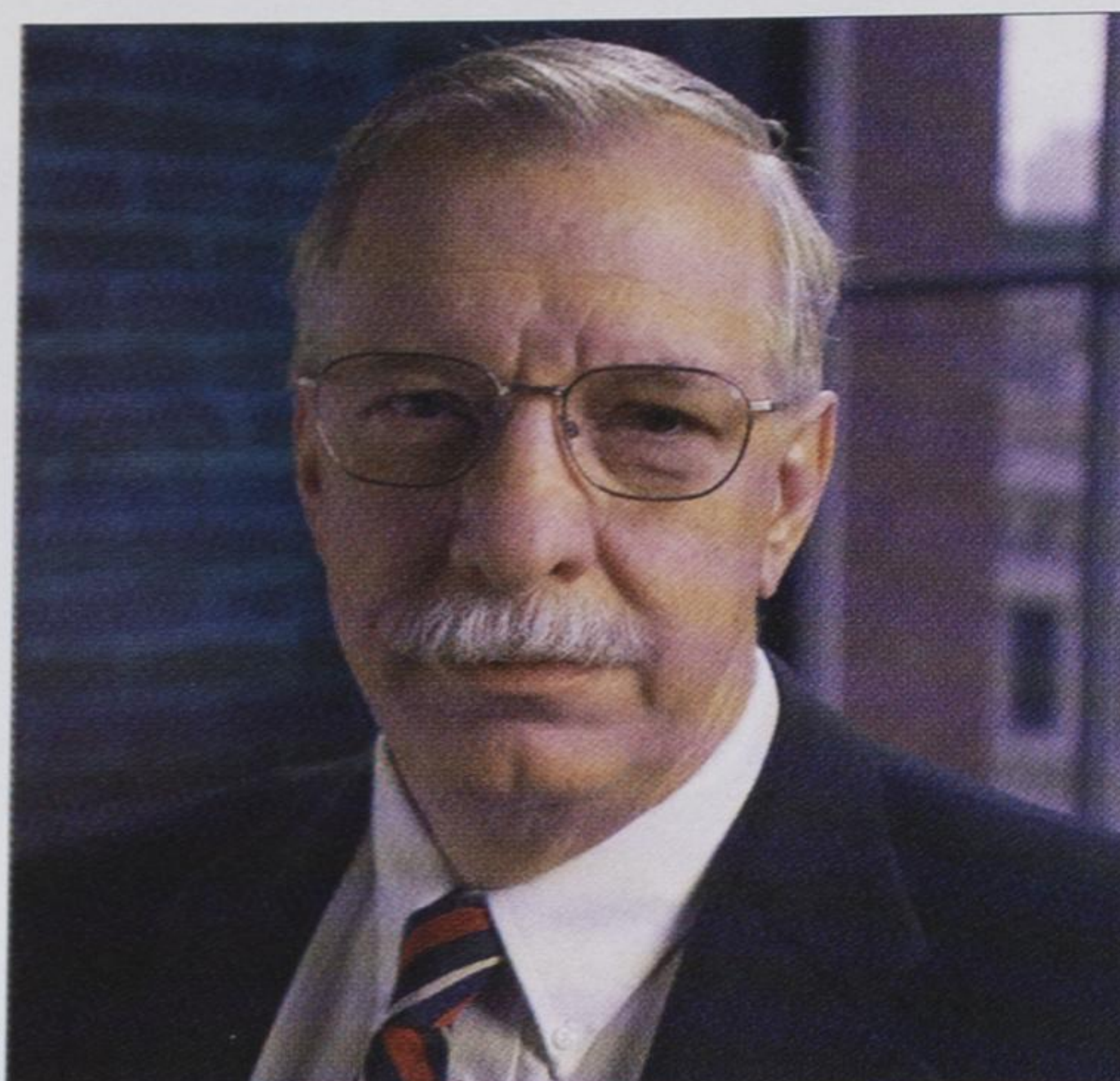
CyOptics says that it has raised \$24 million in its Series F funding round, which was completed just as the Israel-based firm finalized its acquisition of TriQuint Semiconductor's optoelectronics business.

According to CyOptics' VP of sales and marketing, Ali Abouzari, the latest funding round comprised a combination of \$16.5 million in equity investment and a \$7.5 million loan from the Comerica Bank. Other participants in the funding round included Jerusalem Venture Partners, Sprout Group, TowerBrook Capital Partners and Eurofund.

CyOptics closed its previous funding round of \$10.3 million as recently as September last year. It will now apply some of its existing device designs and packaging expertise to the former TriQuint product line.

Valued at \$23.5 million all told, the acquisition of TriQuint's optoelectronics division included an undisclosed cash transaction, while it also gave TriQuint an equity stake in CyOptics. The deal also included so-called "seller financing".

CyOptics now has two InP wafer fabs: one in Lehigh Valley, Pennsylvania, and a second in Yokneam Illit, Israel. The latter, a 7000 ft² facility, has been operational since 2002. The



Burton Smith, the chief scientist at supercomputer builder Cray, will be hoping that he can overcome the current limits of high-speed data processing by developing optical interconnects featuring InP-based lasers made by CyOptics.

company now plans to consolidate volume device production at the Lehigh Valley facility, while the wafer fab in Israel will be retained for development work.

Abouzari confirmed that CyOptics plans to sell the full range of TriQuint products that

were acquired in the deal, while implementing its own device designs in some cases. Examples of this strategy include CyOptics' offering of an uncooled laser operating at high temperatures, and also its quasi-cooled laser.

While concentrating initially on ensuring the continued supply of optical components to its new customers, CyOptics believes that it can return to profitability this year.

CyOptics has also won a contract awarded by leading supercomputer builder Cray. The high-performance computing firm says that copper-based interconnects fundamentally limit the speed of a computer, and it is looking for a fiber-optic solution to provide data transfer rates of more than 100 Gb/s.

Working under the Defense Advanced Research Project Agency's high-productivity computing systems program, Cray is aiming to build a computer that is capable of making a million billion calculations per second, known as one "petaflop" in supercomputer parlance, by 2010.

"This demonstration will make use of next-generation uncooled InP laser technology, wavelength division multiplexing and high-precision automated assembly processes," said CyOptics CEO Ed Coringato.

Avanex cuts deep at French fab

Avanex, the Fremont, CA, photonic chip-maker, is to make major cuts to its wafer manufacturing operations in Nozay, France.

The move, which Avanex CEO Jo Major described as "the most significant piece of its restructuring plans", will see the French workforce reduced by approximately 60% as the company strives to cut operating costs.

Avanex has begun closing its US manufacturing operations and switching production to a low-cost operation in Bangkok, Thailand. In addition, it has outsourced much of its component manufacturing as it aims to make an operating profit by June 2006.

The company expects to wipe out \$28 million in annual expenses through the restructuring of its French operation, but at a one-time cost of \$26 million – mostly in severance payments to its workers.

In another bid to stave off any impending

cash-flow difficulties, Avanex has agreed a \$35 million senior convertible note with institutional investors. The notes are due in 2008, and are convertible into common stock at \$1.21 per share initially. Interest will be payable up until May 19, 2007, and when the warrants expire in 2008 they can be exchanged for \$1.5125 per share. The \$35 million raised will be used in part to support the company's extensive restructuring.

In its most recent quarter, Avanex saw its revenue decline slightly on the prior quarter because of annual price reductions. But at \$40.3 million, the sales figure still represented a 34% increase on last year.

Although still relatively dependent on Alcatel as its key customer, the company has also managed to diversify its client base, with Ciena and Cisco both accounting for more than 10% of sales revenue in the quarter.

While it waits for the effects of restructuring to kick in, Avanex is still operating at a gross loss. Its net loss of \$18.9 million for the three months ending March 31 was at least an improvement on the same period last year, when it made a net loss of \$41 million.

Major added that Avanex had scored some design wins in the all-important Asian market, and that the fiber-to-the-home sector was picking up momentum. Noting growing confidence and improved market visibility, he is expecting to see 4–6% sequential growth in revenue in the current quarter.

● Avanex has replaced Syrus Madavi, who is leaving for personal reasons, with current CEO Jo Major as the chairman of its board. It has also appointed former JDS Uniphase executive Greg Dougherty as a director. Previously chief operating officer at both JDSU and SDL, Dougherty is also the acting CEO of laser start-up Picarro, which recently raised \$15 million in series C financing. Like Dougherty, Major was previously at JDS Uniphase.

Toshiba reveals a triple-layer high-capacity disc

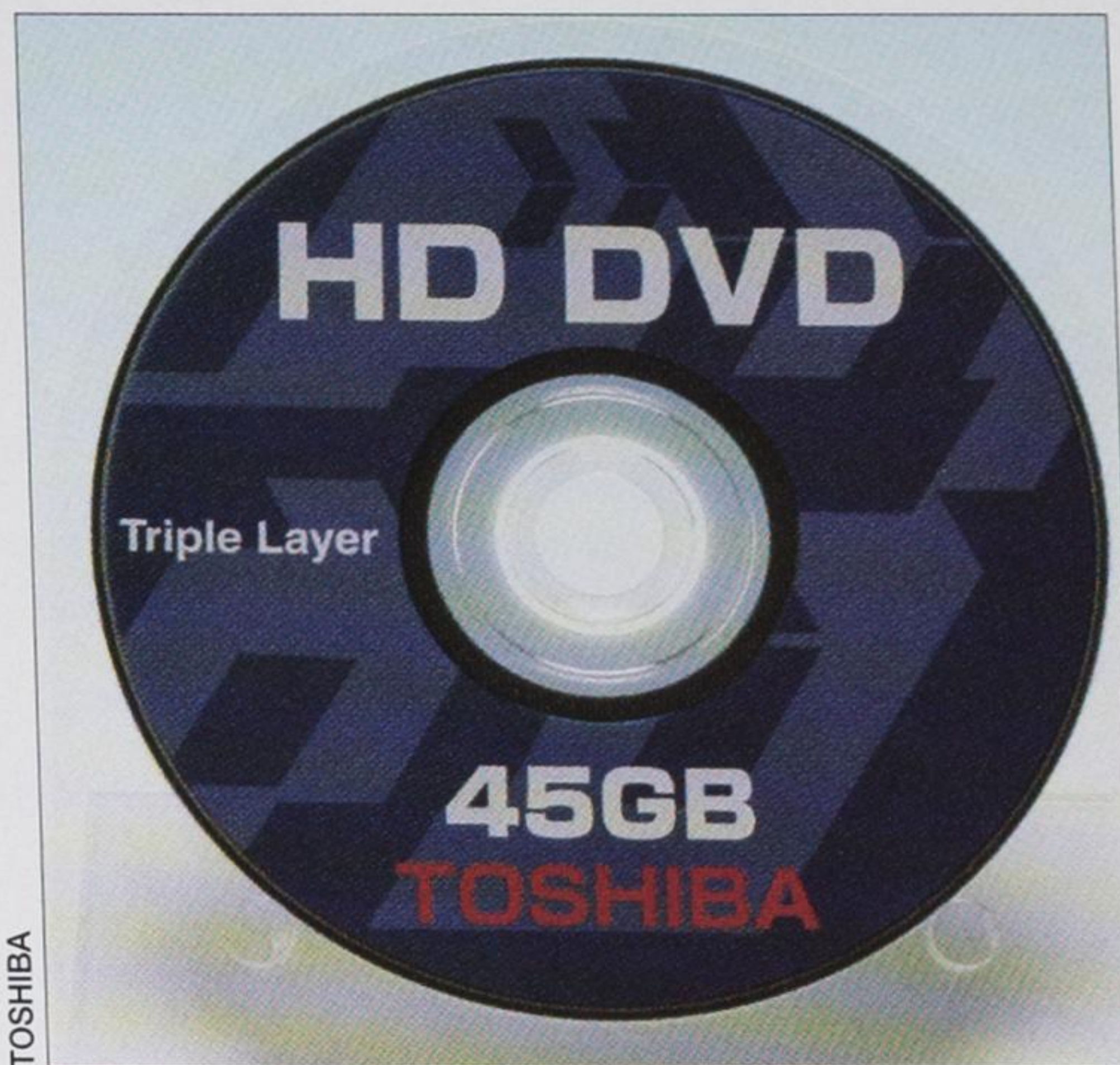
Toshiba has created a triple-layer version of its high-definition DVD disc that holds up to 45 GB of data. Read by an optical head featuring a GaN-based blue laser diode, it could record 12 hours of high-definition movies.

The company has also revealed a novel hybrid disc technology that will allow consumers to view standard DVD content using existing players, as well as high-definition content with next-generation technology.

This hybrid solution features two 0.6 mm thick discs bonded back to back. One disc has a 30 GB dual layer for HD DVD content while the second has an 8.5 GB dual layer for standard DVD content.

"The new disc allows consumers to view DVD content on standard DVD players and, after purchasing an HD DVD player, to enjoy high-definition content from the same disc," said the company.

Meanwhile, Toshiba's Blu-ray Disc Association rival Matsushita Electric Industrial is



Toshiba's 45 GB discs can store up to 12 hours of high-definition films.

to start operating a pilot production line for Blu-ray Disc (BD) replication in Torrance, CA, this month. Pilot production of dual-layer BD-ROM discs is expected in December.

Intense lands extra £2.5 million funding

UK-based laser manufacturer Intense has raised a further £2.5 million (\$4.8 million) in venture finance as it looks to scale up laser-module production. Noble Venture Finance, the supplier of the extra cash, has an option to purchase shares in the manufacturer at a preferential discount of 20–25% as a result.

"We have big plans to build our client base and increase market share over the coming year, particularly in the printing industry," said Intense CEO David Lockwood.

Intense has already transferred some of its R&D activity to the local Photonix foundry in Glasgow in a bid to free up some space at its own fab in High Blantyre. Using its patented quantum-well intermixing process, it makes a standard multibeam laser platform and adapts it to custom requirements in applications ranging from high-resolution printing of magazines to lower-end commercial uses, such as patch printing for cardboard boxes.

Currently making thousands of laser modules per year, Intense believes that demand from printing could grow to more than 10 times as many, partly driven by new applications such as printing of digital photos.

US firm helps establish a novel DVD format

US-based manufacturer of miniature optical technology Dataplay says that it plans to develop optical drives for Forward Versatile Disc (FVD), a red-laser based technology that's being promoted in Taiwan.

FVD is suitable for high-definition films of up to 135 minutes when used with Microsoft's Windows Media Video-9 compression technology. Some 5.4–6 GB of data can be stored on a single-layer disc and nearly twice that amount on the dual-layer version.

The technology has been developed by Taiwan's Industrial Technology Research Institute (ITRI) and its Advanced Optical Storage Research Alliances.

Dataplay has established a memorandum of understanding with ITRI to develop FVD-based technologies that include the engine, media and content protection system.

The FVD format was released in Taiwan in March. Players should appear in the shops this summer with a price tag of around \$175.

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Stretch your limits

Silicon carbide set to reduce s

Sales of hybrid electric vehicles are climbing but, unless the prices of such cars fall, stagnation could follow. The solution, says **Will Draper**, is to use silicon carbide chips to reduce the size of the power electronics and increase operating temperature.

Hybrid electric vehicles (HEVs) represent a major challenge for automobile designers, especially in terms of their size, weight, the choice of electronic systems and controls, as well as the thermal management of these additional systems. For the HEV industry to continue to grow, these challenges must be overcome with efficient, cost-effective solutions. One option is the deployment of silicon carbide (SiC)-based components. This technology is already poised to provide a means to improve HEV system efficiency, while reducing the need for elaborate thermal-management systems that add size, weight and cost to vehicles.

Since the introduction of the Toyota Prius in Japan in 1997, worldwide HEV sales have grown rapidly year on year. In 2003 they represented 0.15% of the total automobile market, and in 2005 this figure is predicted to rise to 0.5%. Car buyers are now being offered an increased range of models. In addition to Toyota, Ford and Honda have joined the hybrid revolution and DaimlerChrysler, General Motors, Hyundai, Nissan and others are expected to follow with the introduction of their own hybrids in coming years.

The advantages of HEV

With fuel efficiency ratings as high as 60 mpg, HEVs consume up to 50% less fuel per mile than many other cars, thereby reducing fossil-fuel emissions. As a result, government subsidies are available in many countries for HEV drivers living in high-congestion areas. Sales suggest that an increasing number of consumers are attracted to the efficiency, the environmentally friendly operation, and the subsidies associated with HEVs. But despite the clear attractions, HEV growth is projected to stagnate at around 3% of the total automobile market unless HEV prices fall to compete with traditional cars containing internal combustion engines (ICEs).

Current HEV platforms, which use silicon-based power electronics, are faced with two major challenges: size and weight. In addition to an ICE, HEVs must also accommodate

power electronics, energy storage, and an electric motor in the predefined volume of the automobile platform. Engineering solutions to combat these challenges, such as using alternative frame or body materials and reducing either passenger or cargo space, result in less capable, more expensive HEVs than their traditional ICE counterparts.

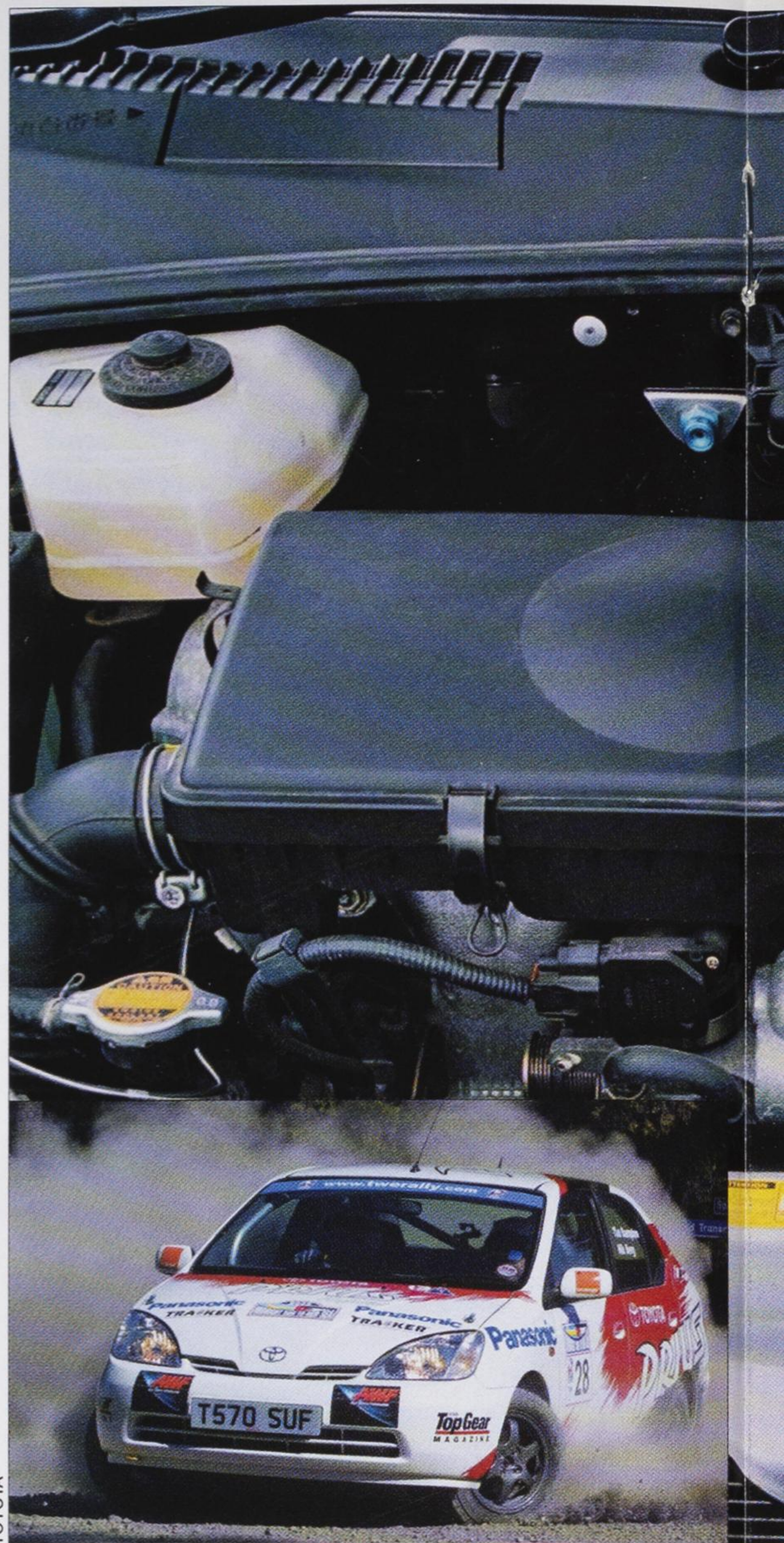
The HEV's motor drive – a power-electronics component that converts stored energy into an alternating-current (AC) source needed to operate the electric motor – is one of the main contributors to the system's size and weight. Typically, HEV motor drives use silicon insulated-gate bipolar transistors (IGBTs) for the primary switching element, with silicon *pin* diodes as the fly-back diode, configured in a module designed to control three-phase motors. The module is positioned inside the engine compartment as close to the electric motor as possible to minimize parasitic inductance and reduce cabling weight.

The combination of silicon IGBTs and *pin* diodes is ideal for high-power applications, because the devices can be scaled to handle hundreds of amps per die. But, like all silicon devices, they are limited to junction temperatures of 150–175 °C. Controlling the junction temperature of the silicon electronics in the engine compartment's harsh environment requires large heat sinks and liquid cooling, but both of these solutions are costly and difficult to integrate into the volume available within the engine compartment.

The temperature limitations inherent to silicon technology mean that state-of-the-art silicon electronic components cannot meet the demands of HEV platforms and represent an area for significant improvement if the HEV market is to continue to grow.

This is where the opportunity for SiC lies. The ability of SiC-based power electronics to address these issues more efficiently than their silicon counterparts is a fundamental strength of the technology.

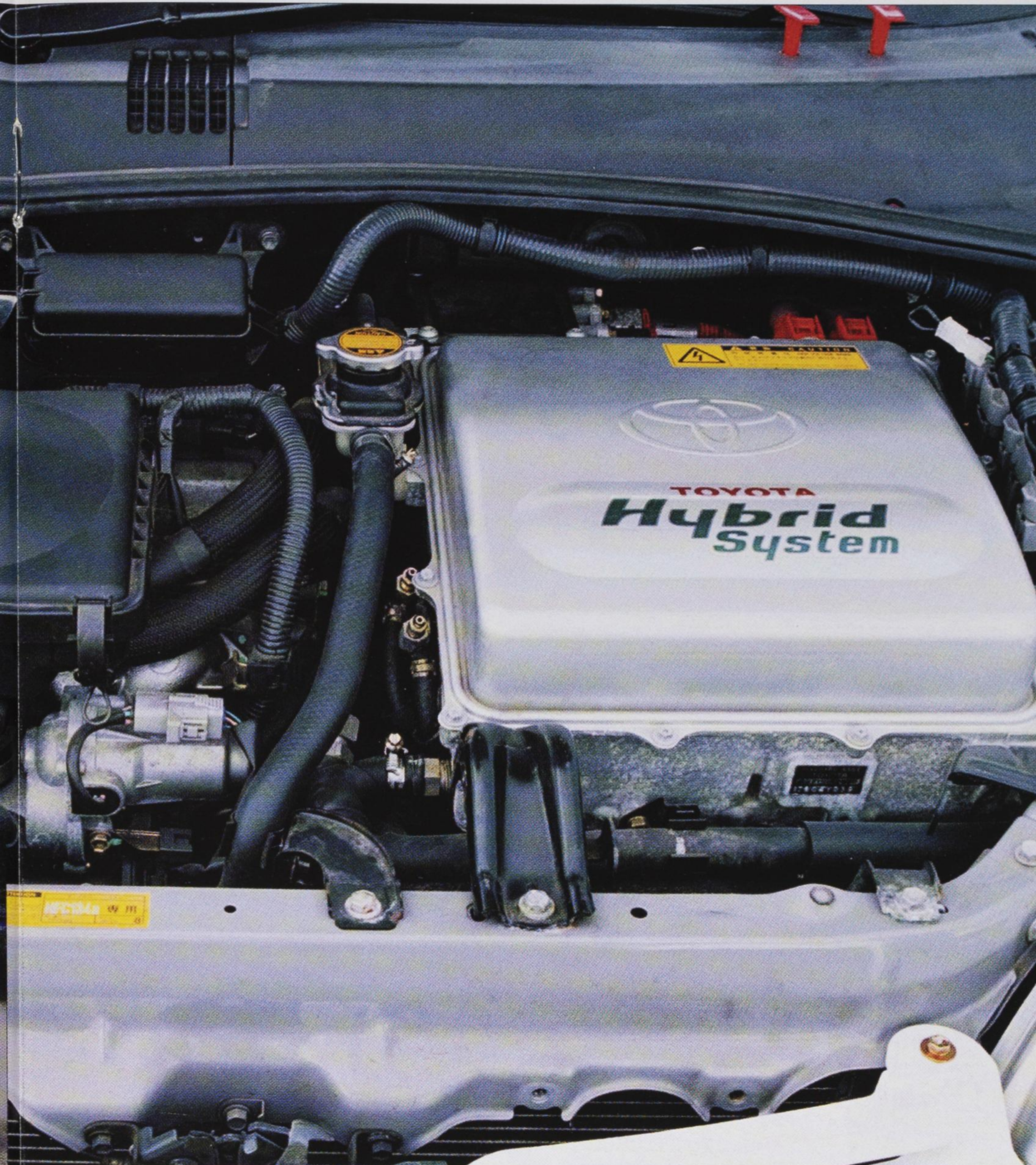
SiC is a wide-bandgap semiconductor that has been considered suitable for next-generation power electronics for many years.



The Toyota Prius (inset), with a fuel efficiency of 60 miles per gallon, won the 2002 Midnight Sun to Red Sea Rally, a three-week race from Alaska to Saudi Arabia. SiC devices should help to reduce the weight of HEVs and

Fundamental material advantages, such as higher breakdown voltage and reduced thermal generation of intrinsic free carriers, separate SiC from traditional semiconductor materials such as silicon and GaAs (see table, p20). As a result, SiC electronics can operate at substantially higher temperatures, power densities and frequencies than conventional silicon. The combination of these three strengths translates into smaller, lighter, and simpler electrical systems for HEVs.

size of hybrid electric engines

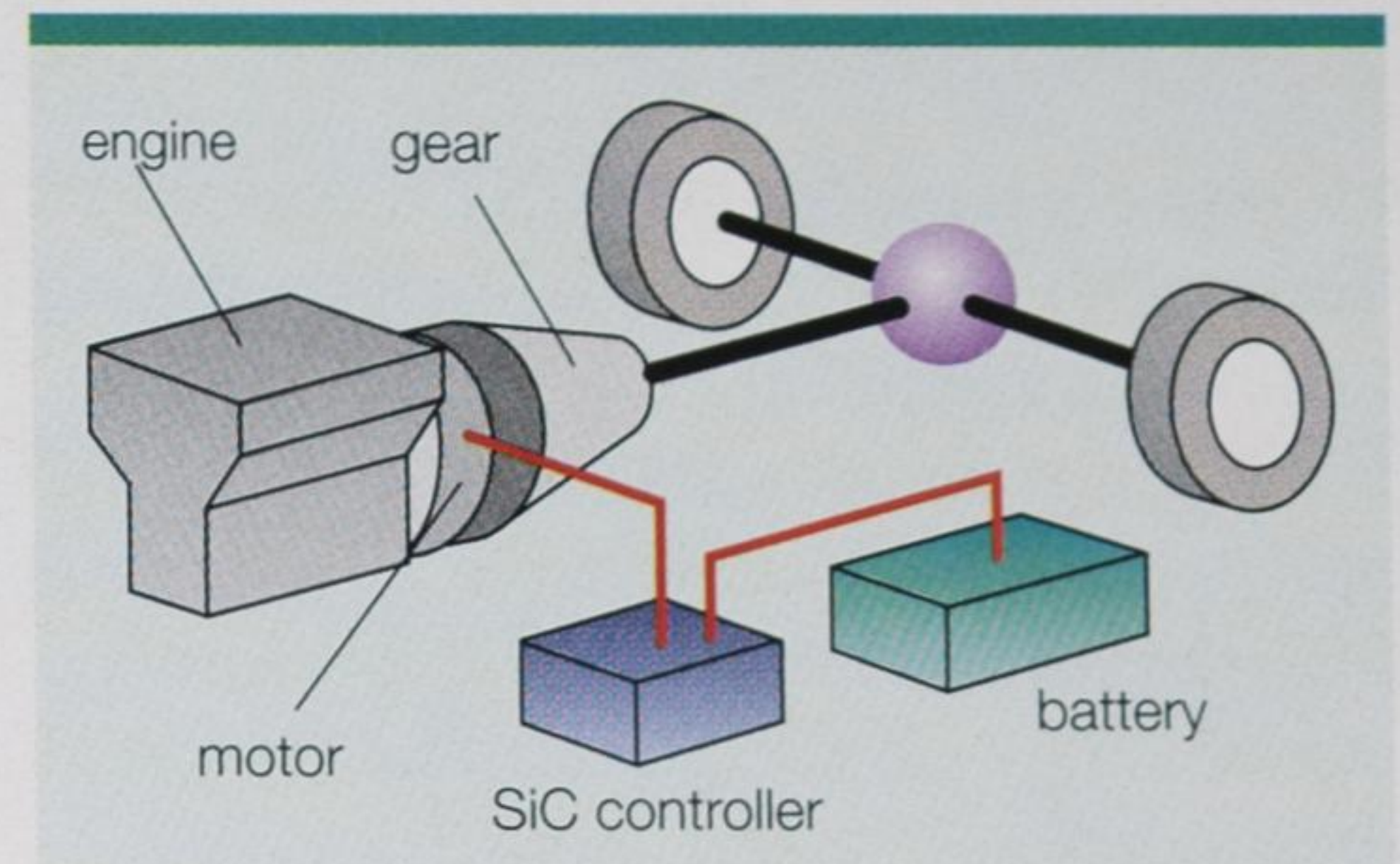


les per gallon, uses a hybrid electric engine. The world's first hybrid electric rally car, it competed in the ce from the north of Sweden to the shores of the Red Sea in Jordan. Replacing the silicon electronics with s and increase their overall competitiveness.

Of course, SiC semiconductor devices face some challenges that must be overcome before they can reach the power levels demanded by HEVs and become economically feasible. SiC substrate costs have been high for many years and availability has been low, although this situation is starting to change as additional substrate suppliers create competition for customers.

Substrate quality and diameter have also limited the advancement of SiC devices.

Crystal defects called micropipes have long been the nemesis of the material. They cause catastrophic device failure and inhibit chip scaling to higher current levels. However, over the last several years, micropipe densities have been reduced to one-hundredth of previous levels, and this trend is set to continue as the technology matures. Further improvements to SiC material quality and availability are also expected as the industry migrates to 4 inch substrates and beyond.



Toyota and Ford both use this parallel configuration that allows the vehicle to be powered by either the internal combustion engine or the battery. SiC components, which would be located in the controller, are able to convert the battery's DC output into an AC source suitable for the motor.

Another area of difficulty is that the device topologies exploited in silicon technology – such as CMOS and IGBT devices – are not directly transferable to their SiC counterparts for practical and physical reasons. Conventional silicon CMOS relies heavily on dopant diffusion. This process is unsuitable for the SiC material system, because dopant diffusion is negligible at practical processing temperatures of below 1500 °C. Current research is investigating dopant diffusion in SiC at temperatures above 1800 °C, but semiconductor processing equipment operating in this regime is practically non-existent, and heating substrates to these temperatures is likely to cause them to bow, warp and crack.

There is also an absence of commercially available SiC *p*-type substrates that are required for IGBT structures. Although researchers in Germany have produced *p*-doped SiC substrates by using a growth chamber with additional gas-flow, this work is still in its infancy (see *Compound Semiconductor* March p23).

The difficulties associated with dopant diffusion, and the lack of availability of *p*-type substrates, are just two revealing examples of why alternative control circuitry and power-switching device topologies must be developed for the unique SiC material system. One such alternative is the SiC Smart Power Chip, an all-SiC three-phase motor drive developed by Mississippi State University spin-out SemiSouth. This component will be able to operate in high-temperature environments, such as an engine compartment, without a

large, complex cooling system. As a result, it should greatly reduce the size, weight and complexity of HEV system design.

This future product is the result of the combined efforts of SemiSouth and the US National Institute of Standards and Technology (NIST). Under NIST's Advanced Technology Program, SemiSouth is working to develop and integrate advanced SiC control circuitry and power transistors in a compact power module for use in HEVs. By using SiC, the HEV motor-drive-inverter volume can be cut by more than 50% and the liquid cooling system can be eliminated.

Power-switch scepticism

Although SiC smart-power technology is a well discussed topic, it has received limited scientific investigation. Proposed solutions have been met with skepticism, mainly related to the operation of the power switch. SiC bipolar junction transistors (BJTs) suffer from low current gain and forward-voltage degradation. Similarly, SiC MOSFETs are plagued with high-temperature reliability concerns and threshold voltage shifts.

SiC material properties

	4H-SiC	GaN	Si	GaAs
Thermal conductivity (W/cm K)	4.9	1.3	1.3	0.55
Bandgap (eV)	3.26	3.39	1.1	1.4
Critical field (MV/cm)	3	3.3	0.3	0.4

SiC's properties mean that devices based on this material operate at higher current densities and temperatures.

SemiSouth has also developed a SiC power FET technology that overcomes the MOSFET and BJT problems. The technology is ideal for efficient power conversion at high temperatures because the absence of the metal-oxide-semiconductor region improves device reliability, and its unipolar nature eliminates any effects from forward and reverse recovery. SemiSouth believes that this technology will be capable of operating at much higher temperatures (300–500 °C) and frequencies (≥ 1 MHz) than conventional silicon, as well

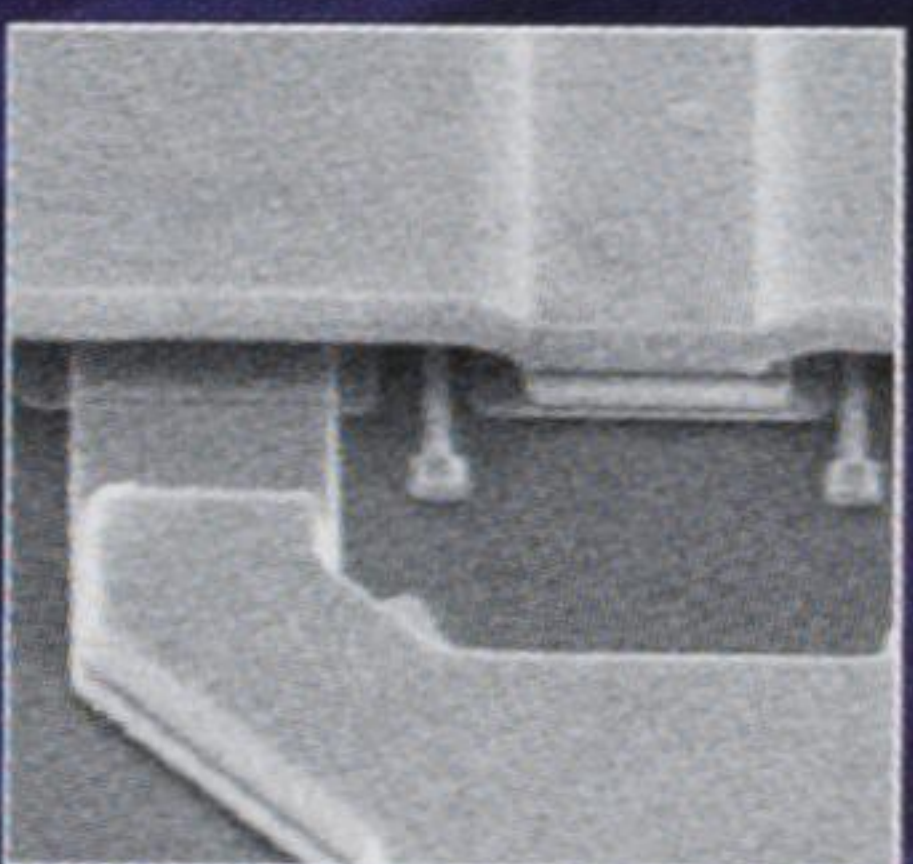
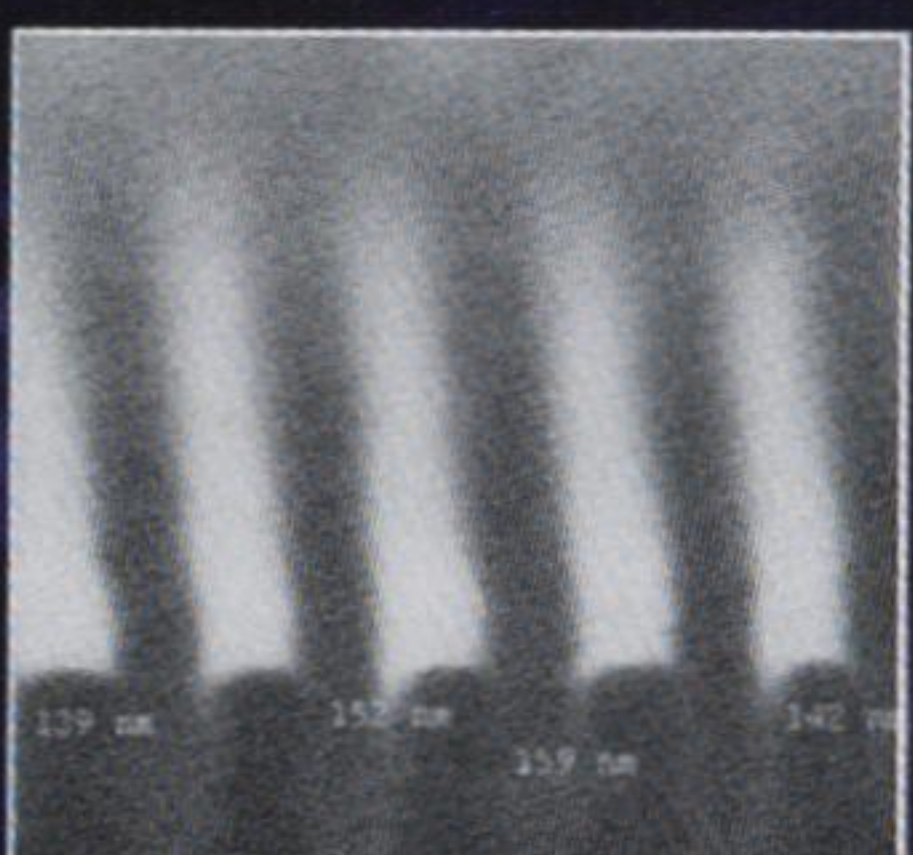
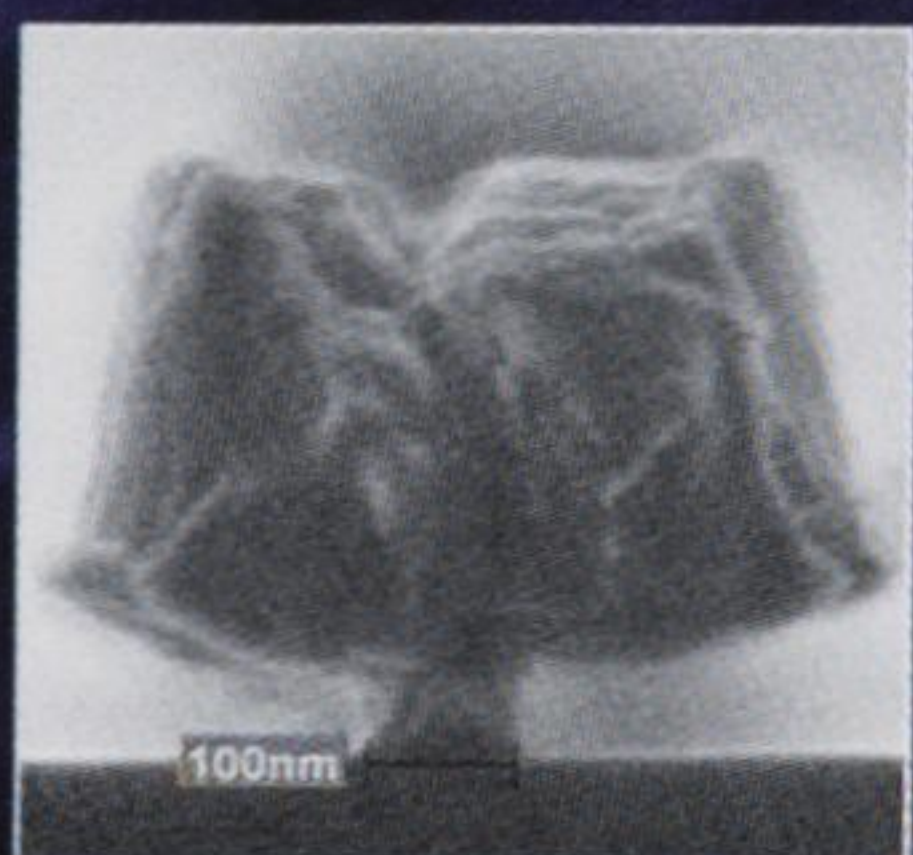
as reducing the overall size and weight of HEVs. Some progress has already been made in this area, with SemiSouth's engineers developing a variety of high-power devices that have operated at 500 °C.

Through continued research and advancements in technology, such as those undertaken by SemiSouth, future control electronics will be realized through the monolithic integration of SiC FET devices to form logic gates and operational amplifiers. These basic building blocks will combine to create ICs for controlling HEV motor drives. In addition, discrete, high-power SiC FETs will be integrated with the monolithic control elements to form a complete multichip power module.

All of these technological advances are expected to be integrated into HEVs during the next three to five years, and together they should lead to lighter, smaller, and more fuel-efficient cars that will in turn promote further growth in this industry.

Will Draper is director of technical product marketing at Semisouth Labs. E-mail: will.draper@semisouth.com.

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HIGH-POWER DIODE LASERS

Efficiency drive delivers greater laser reliability

High-power diode-laser manufacturers are now implementing new processes developed under various research programs in volume device production, as **Michael Hatcher** discovers.

Manufacturers of laser diodes are increasingly targeting the industrial-laser market as relatively new laser designs such as fiber and thin-disk architectures gain greater acceptance. These new designs (see box) rely on optical pumping by diode emitters, and are regarded as prime growth areas in the industrial-laser market.

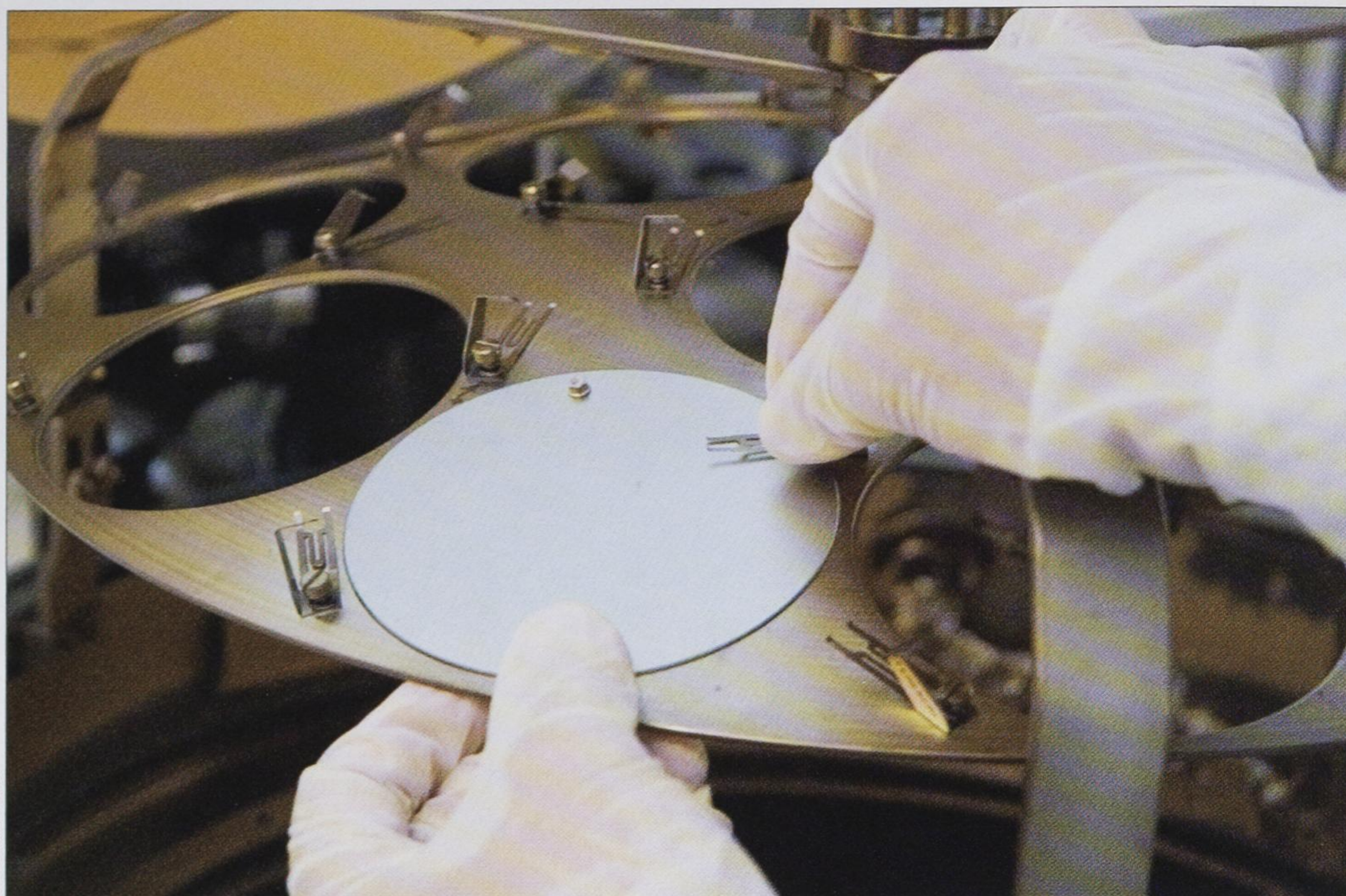
According to Strategies Unlimited analyst Bob Steele, the market for diode lasers used in industrial applications dipped 13% in 2004, with rising unit shipments more than offset by declining prices. Despite this, the industrial market for diodes is widely regarded as a good long-term prospect, with German company Jenoptik Diode Lab now building a 500 m² facility for 3 inch GaAs wafer production in Berlin. And the acquisition of diode-pumped-laser-system maker Lightwave Electronics by JDS Uniphase in March this year demonstrates the latter's commitment to becoming a bigger player on the industrial-laser scene.

Major industrial-laser OEMs such as Germany's Trumpf and RoFin-Sinar are increasingly looking to improve their products, which are used in applications as diverse as shaping medical devices and welding car-body parts. Predictably, these laser-system builders want more power from diodes and a reduction in the price per watt delivered. The cost issue is particularly sensitive, as it's estimated that the diodes in a laser system account for one-third of the overall system cost.

More watts per dollar

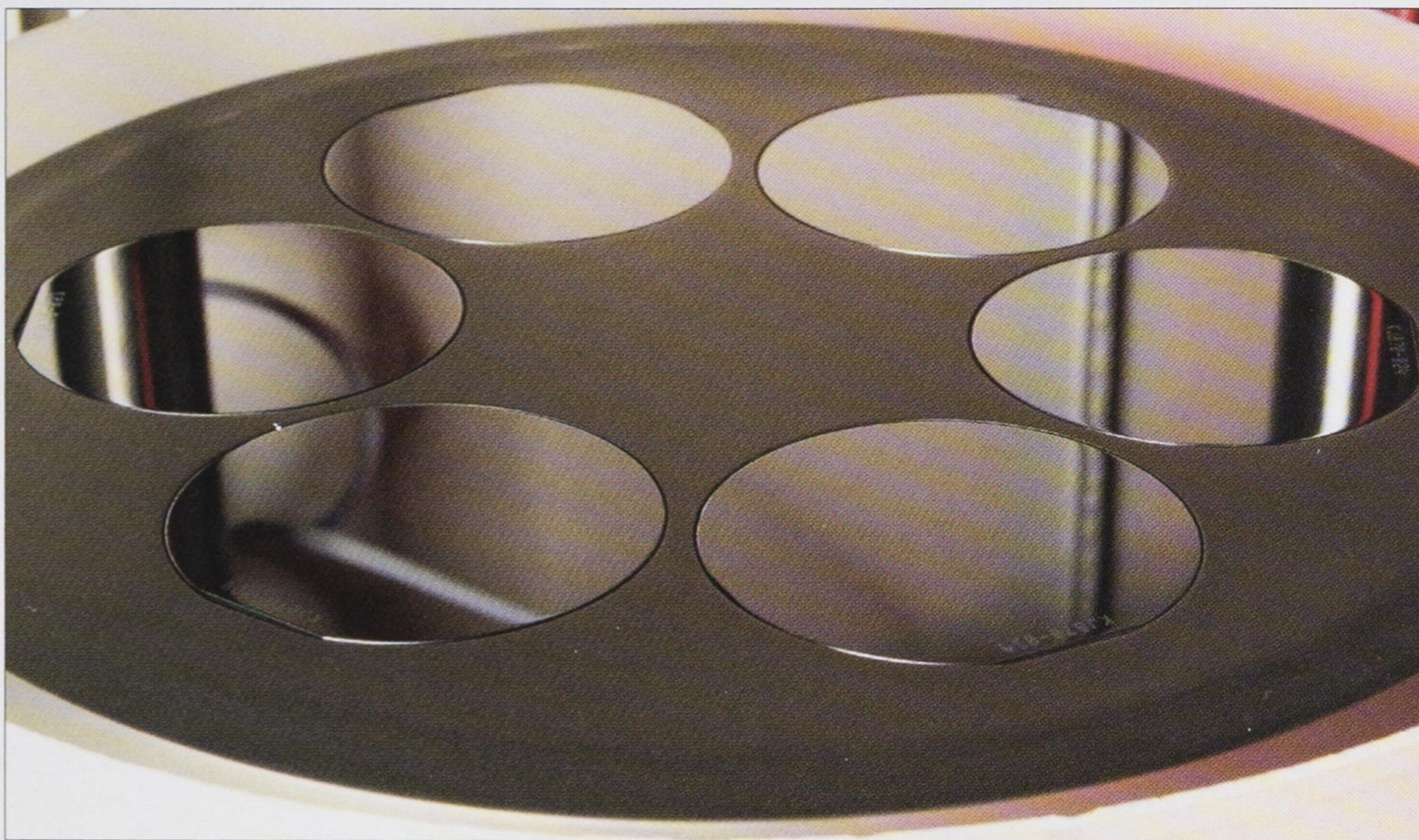
One way to improve the dollar-per-watt metric is to raise the efficiency of individual emitters. As well as increasing the overall power output of any laser system based on diode-pumped crystals or direct-diode emission, it also improves reliability.

In fact, this added benefit is arguably of greater importance than increased power output. This is because improvements in diode efficiency mean that less heat is produced per



JDS UNIPHASE

JDS Uniphase, the leading supplier of 980 nm pump laser diodes, now manufactures all of its lasers and photodiode detectors at its only remaining III-V fab in San Jose.



ALFALIGHT

Alfalight's 2 inch GaAs wafers set in a graphite susceptor are ready for MOCVD growth.

High-power lasers: rods, disks and fibers

So-called diode-pumped solid-state lasers (DPSSLs) are a mainstay of the industrial-laser-system market today. Based on a rod-shaped yttrium aluminum garnet (YAG) crystal, usually doped with neodymium, the emission from an array of diode bars is focused on the crystal to produce a powerful pulsed or continuous-wave beam, suitable for applications such as cutting and welding all sorts of materials. The conversion efficiency of diode emission into crystal-laser emission varies, but is generally less than 20%.



amounts of energy, so Volkswagen needed to build a separate power plant simply to meet the energy requirement.

But after lots of initial worries over reliability, DPSSLs are now widely established in industrial materials processing. In recent years two new architectures have emerged to challenge conventional DPSSLs. The more advanced, in terms of market penetration, is the thin-disk laser. Based on the same principle as a normal DPSSL, the disk is essentially a shortened rod, no more than a

few millimeters thick (see photo). Because it is smaller in volume than a rod, the crystal geometry needs more concentrated doping to produce a high output power, and so the YAG crystal tends to be doped with ytterbium. The result is a slight shift in the wavelength of the output beam, but the benefits include much smaller industrial-laser systems and, importantly, an improvement in the beam quality that is delivered.

Beam quality is a critical issue, and the more circular beam delivered by a disk laser means that it can be used to cut or weld materials with less power than would be required with a conventional DPSSL. It also means that the working distance between the part being manufactured and the laser system can be increased, and this in turn means that parts can

be machined at a higher speed. "There can never be enough beam quality!" is how Toby Strite of JDS Uniphase puts it. Another benefit of the thin-disk geometry is that at around 30%, the conversion efficiency from diode to crystal is higher than for a conventional DPSSL.

The fiber-laser concept takes the geometry of the laser medium a step further by using a doped optical fiber in place of the rod- or disk-shaped crystal. The key benefits are, again, better beam quality and conversion efficiency, with the latter reaching about 50%.

Crucially for diode-laser manufacturers, the fiber and disk architectures are only compatible with diode-pumping, whereas conventional DPSSLs can also be powered using flashlamps. So any market penetration by the newer designs is good for diode manufacturers.

device. And excess heat is a killer for laser diodes. Toby Strite, the manager of high-power diode-laser marketing at JDS Uniphase, says that as a rule of thumb the lifetime of a diode is cut by two-thirds for every 20° temperature increase in the diode junction.

So while there has been an understandable focus on achievements made in pushing diode power conversion efficiency (PCE) to new highs in excess of 65% from many companies, especially those working under DARPA's super-high-efficiency diode sources (SHEDS) program, it perhaps makes more sense to look at the progress made in a different way: "We were wasting 50% [of the power input] in heat, and now we're only wasting 35%," is how Strite likes to think about it. "The relative [reduction] in waste-heat generation outstrips the PCE enhancement."

Under the SHEDS program, JDS Uniphase has taken two approaches to improve diode performance, both of which Strite says can be "productized". The first is in the management of the optical field, where the aim is to reduce the impact of dopant absorption. This can be done by changing the vertical structure of the diode – either depressing the mode downward

into the wafer, or shifting it up toward the wafer surface – using optical engineering. In JDS Uniphase's developmental diodes, the center of the laser mode is also directed away from the most highly absorbing regions of the doped semiconductor.

Some of those refinements to diode design are now flowing back into JDS Uniphase's product pipeline, with prototyping currently in progress. Once commercialized, the devices will be manufactured at the firm's one remaining compound semiconductor wafer fab in San Jose, CA, before being shipped out along with telecom lasers for packaging in the company's China facility.

JDS Uniphase's "L-3" diode laser, which emits 5 W into 100 µm core, 0.22 numerical aperture fiber, has been shipping from China for a year. A 6.5 W version of the device is set to be released next month, with 8 and 10 W emitters to follow.

Made in China

A "made in China" stamp on JDS Uniphase's products presents an obvious advantage. "We've actually commoditized the industrial [diode] laser market by virtue of that low-cost

structure," said Strite. The diode-laser demand from telecom applications is sufficient to support the Chinese packaging base, and the industrial side of JDS Uniphase's business can exploit the same manufacturing infrastructure.

While JDS Uniphase is best known for its telecom products, Strite believes that the relative maturation of this industry means that it is now the industrial-laser business that offers more scope for growth. "Essentially, there's no longer a demand for a bigger, better 980 nm pump laser," he explained. "It's a little bit like Intel's problem, in that [once it had made] a 1 GHz chip, there wasn't really a need for a 2 GHz one, so they went into things like wireless connectivity instead."

According to Strite, the design of JDS Uniphase's single emitters provides the ideal combination of power coupled with reliability. Reliability requirements in the telecom market are demanding, and with innovations such as passivated mirrors, JDS Uniphase's devices come rated with a mean time to failure of anywhere between 100,000 and 2 million hours, depending on the application.

JDS Uniphase has its own fiber laser business and this type of laser design complements

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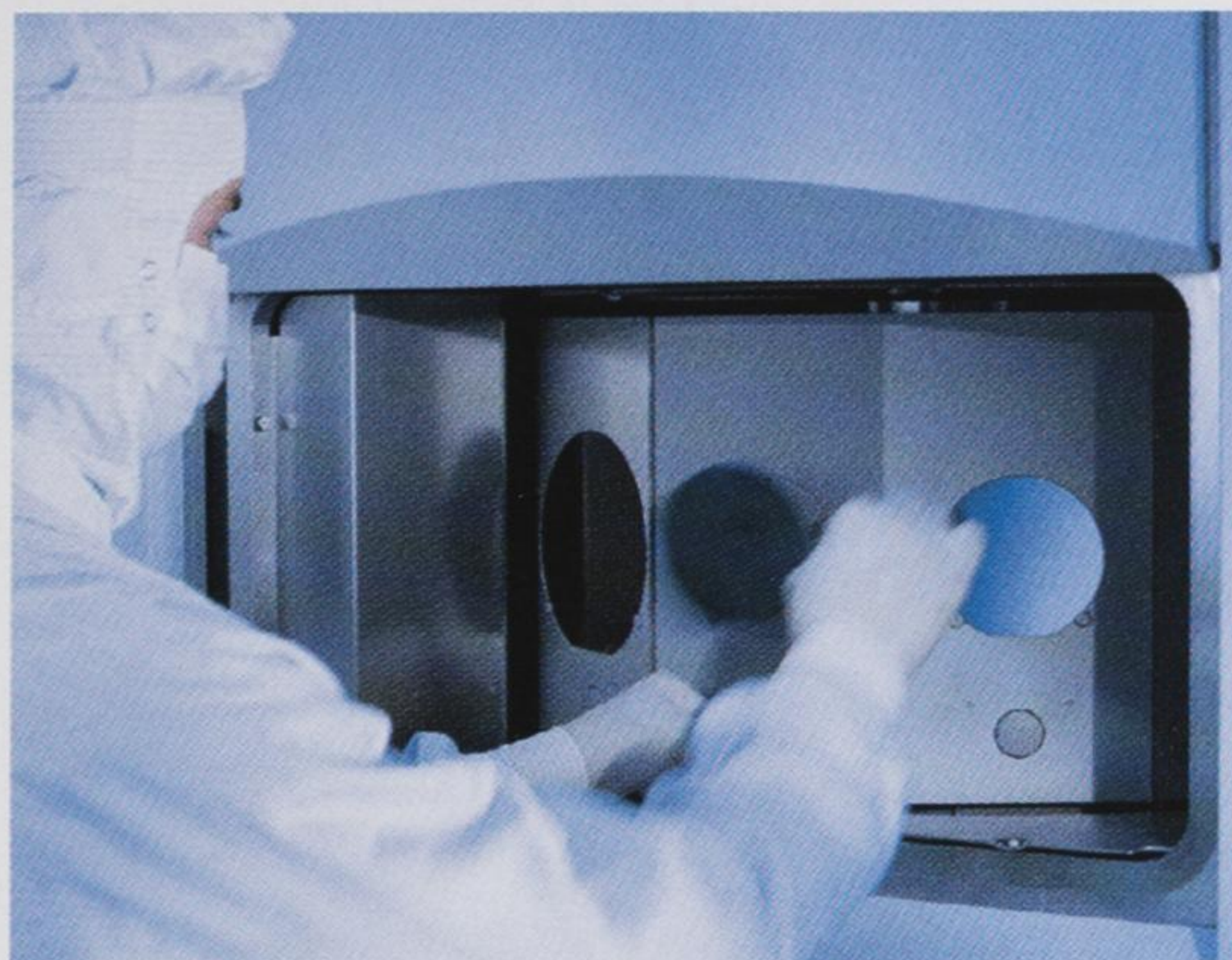


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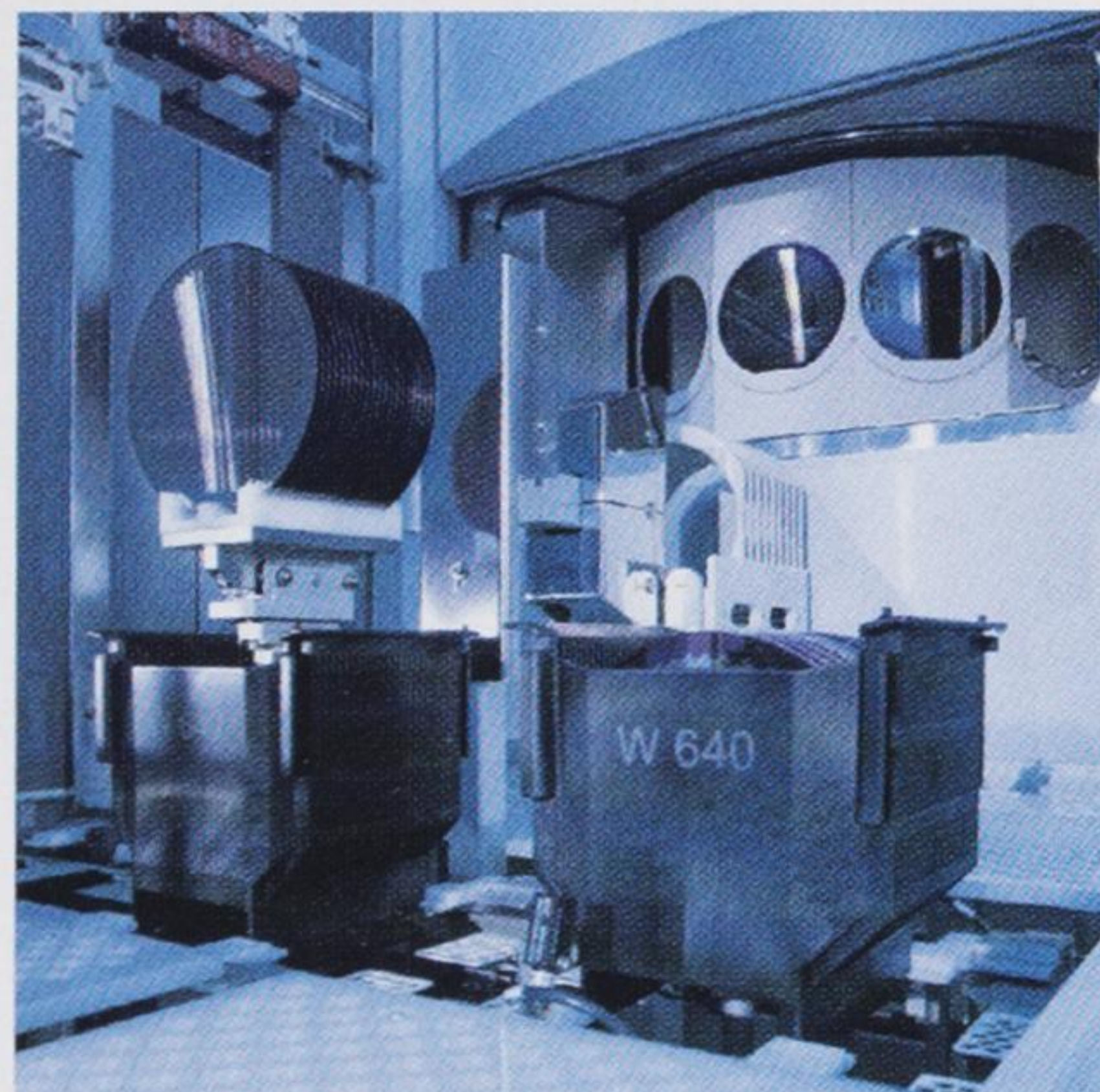
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HIGH-POWER DIODE LASERS

the company's high-power single emitters. "Imagine a 100 W fiber laser," said Strite. "This will require about 200 W of diode power. To do that with bars, you need four bars rated at 50 W each. If one of those bars fails you're a dead duck, so you've got to add some redundancy to the system with extra bars."

But simply adding one extra bar will not be sufficient, explained Strite: "A typical bar is rated at 20,000 hours mean time to failure. If you have five in your system, you haven't guaranteed that the system will run for five years continuously. So you need six or seven bars, and that's a huge incremental expense."

The advantage with ultrareliable single emitters, says Strite, is that you'd deploy perhaps 50 5 W L-3s to power a 100 W fiber laser, and that 20% added system-redundancy cost is affordable. "That's why we're really making some hay in the low-to-mid-power solid-state-laser market," said Strite. "Some day a fiber laser producing 4 kW will be out there and then you will be able to enjoy bar economies of scale."

Clearly, concentrating on the fiber-laser market plays to JDS Uniphase's strengths and experience in the fiber-optic communications sector, where it is the leading manufacturer of 980 nm pump lasers. However, Strite says that the other markets also present the firm with an opportunity. "We could bring to market a bar that's four times as powerful [as a competitor's product] and are currently in discussion with customers willing to pay only twice as much for the technology."

Alfalight readies new processes

Like JDS Uniphase, Alfalight is now looking at how to implement advances in diode structure in its commercial products. Through incremental improvements, Alfalight's best research effort has produced a 976 nm device with 73% PCE. According to the company's vice-president of research and development Manoj Kanskar, the SHEDS-inspired reductions in diode turn-on voltage, free-carrier absorption and Joule-effect heating will be implemented in the production environment first, since they are not expected to have any negative effect on device reliability.

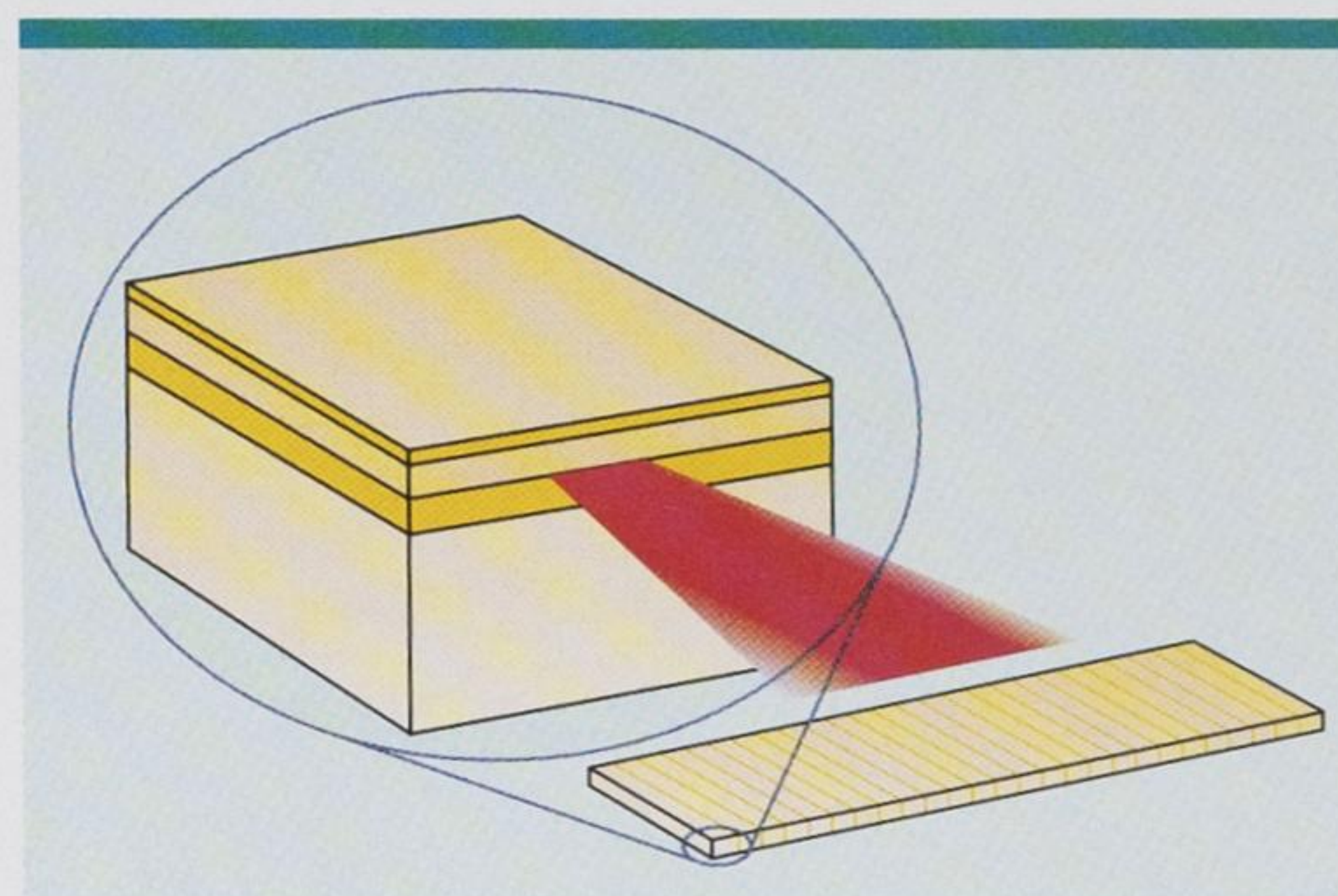
Secondary improvements will follow once sufficient lifetime-testing data have been collected. So far, Alfalight says it has demonstrated 797, 808 and 915 nm laser bars with a peak PCE of 66% by introducing the initial changes to its production process.

However, the SHEDS program calls for the demonstration of diodes with 80% PCE. JDS



JDS UNIPHASE

All of JDS Uniphase's lasers, including those destined for industrial-laser applications, are now packaged at its assembly plant in Shenzhen, China, which provides obvious cost benefits.



Alfalight's grating-stabilized laser bar shows a typical incoherent array of broad-area lasers. A single emitter from the bar shows the emitting region with a beam emerging and a holographically defined grating that is used for wavelength stabilization.



JDS UNIPHASE

JDS Uniphase's 6.5 W version of the L-3 package is due to be released in July, while 8 and 10 W emitters are scheduled to follow.

Uniphase and Alfalight are taking different approaches to meeting the target. Strite believes that JDS Uniphase can get close to the 80% figure with practical, commercializable technology. Meanwhile, Kanskar is of the opinion that while Alfalight could push a little higher than its current best of 73% with similar efforts, some revolutionary technology will be needed to hit 80%. Critically,

Kanskar says, reducing the laser threshold current will require a radical approach.

That revolutionary technology could come in the form of quantum-dot structures or by growing quantum wells in a different crystal orientation, both of which Alfalight is working on. "Quantum dots is a high-risk, high-pay-off method," admitted Kanskar. "But by growing the quantum wells in the 110 direction, where the electric field is in line with the dipole moment, we expect a two-fold enhancement in gain, and a reduced [lasing] threshold."

Quantum goal

The problem with current quantum-dot gain media, says Kanskar, is that these structures require 7–10 layers of nanostructures to produce sufficient gain, and the overall diode efficiency suffers from a high lasing threshold. "Our goal is to make a single-layer [quantum-dot] gain medium with a much higher density and uniformity, and that's what we're working on to reduce the threshold current."

So far, Kanskar and colleagues have made quantum-dot lasers in aluminum-free high-bandgap material, without incorporating the wetting layer that most developers have used.

In the laboratory, Kanskar and colleagues have also grown quantum wells in the 110 orientation, and he says that the photoluminescence of these devices is much higher than that of conventional diodes. "The challenge is that the growth temperature required is significantly different," he said.

A separate development that Alfalight has been working on under a US Air Force Research Laboratory project could lead to precision pumping applications of diode lasers, and also have benefits in terms of wafer yields. The goal is to wavelength-stabilize a multi-mode diode laser, and the company has begun implementing a new process to do this. By using holographically defined gratings and wavelength-dependent feedback, the wavelength drift is effectively limited to less than 0.065 nm/°C instead of the usual 0.32 nm/°C. This means that lasing can be tuned to within ± 0.2 nm, and so a larger proportion of the die on the wafer can be used.

Currently, a wavelength tolerance of around ± 3 nm is required to get a high device yield, but with customers increasingly demanding tighter tolerances, that yield can take a big hit. "I think we're going to see some huge benefits," said Kanskar, who adds that because the holography step is a wafer-level process, the per-device added cost of incorporating the extra manufacturing step is tiny. ●



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Manufacturers are wary over push for larger substrates

One of the ways to cut chip costs is to transfer manufacturing to larger substrates. Is the LED-manufacturing industry in Taiwan ready for such a change? **Richard Stevenson** investigates.

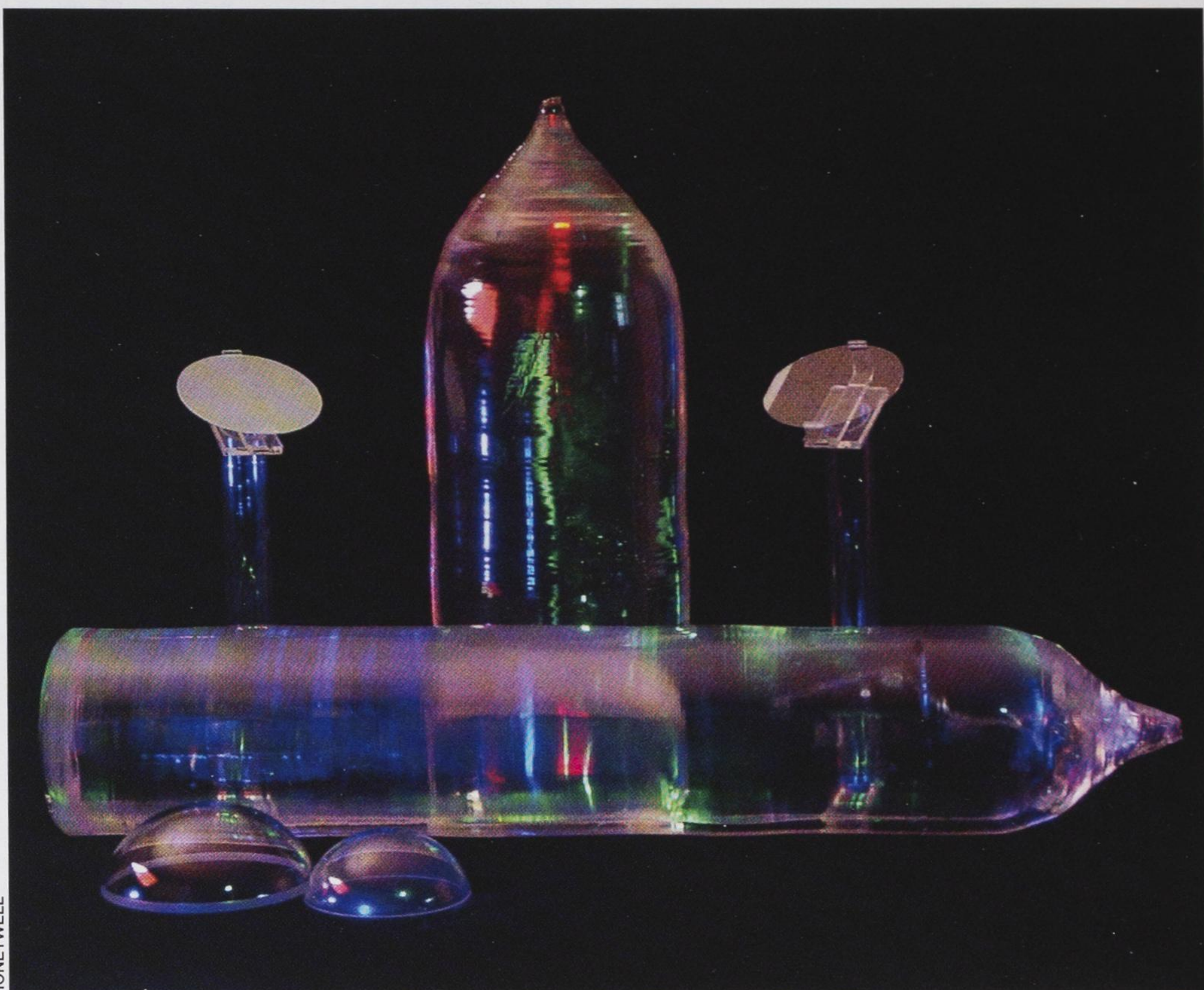
LED performance improvements and price cuts have driven the significant growth of the LED industry over the last decade. However, according to Jed Dorsheimer – an analyst at investment bank Adam Harkness who covers the LED business extensively – the cost per lumen remains 10 times too high to penetrate the general lighting market. Dorsheimer thinks that significant reductions in the cost per lumen are possible, but only if manufacturers move to larger substrates, device performance improves and more partnerships are established between major international LED manufacturers, such as Nichia and Cree, and low-cost producers in Asia.

While Cree has already switched much of its LED output to a 3 inch SiC line, Honeywell, a supplier of sapphire substrates for GaN-based epitaxy, released 100 mm diameter substrates in the fall of 2004 to complement its 2 and 3 inch material. According to David Reid, Honeywell's product line manager for the sapphire group, larger substrates reduce production costs through more efficient use of gas, and decrease the overall substrate-handling time. And sapphire expenditure is important, explains Reid, because it is second only to ammonia when it comes to LED chip manufacturing costs.

Bigger is better

Reid thinks that 100 mm sapphire substrates will have the greatest appeal to manufacturers of high-brightness devices that use large die areas of typically $300 \times 300 \mu\text{m}$ and $1 \times 1 \text{ mm}$. Although the cost per square inch of the 100 mm sapphire substrates is currently higher than that of equivalent 3 inch material, he predicts that the price of his 100 mm products will soon fall. The firm's 100 mm substrates are already attracting some interest, with several LED manufacturers conducting trials to verify that their production line is suitable for larger wafers, Reid says.

He believes that LED manufacturers are now far more concerned with the quality of the substrate, because poor-quality wafers increase



Honeywell hopes that its recently released 100 mm sapphire substrates will appeal to LED manufacturers that are looking to cut their overall production costs.

production costs through low device yields. Reid says that even small improvements are significant: a 5–10% yield increase translates into a 10–15% gain in revenue on an epiwafer and an equivalent drop in the cost per chip.

Honeywell evaluates its wafers by discussing with its customers the influence of its substrates on device performance. This is a time-consuming process because, according to Reid, the insularity of many manufacturers means that they are unwilling to divulge information as a group. Honeywell is therefore forced to consult each LED manufacturer individually. Reid believes that substrate specifications are increasingly reflecting customer needs, with a greater focus on the effect of warp and bow on LED performance.

A significant proportion of Honeywell's sapphire substrates are sold to LED makers in Taiwan, a region of the world that Dorsheimer highlights as being critical to reducing the LED cost per lumen. The company started shipping large numbers of wafers to Taiwan in 1998, and since then a collection of start-up firms have become high-volume manufacturers.

Although dramatic growth was seen up until 2004, additional expansion was put on hold following a recent slow down in activity. Despite the decline in growth of Taiwan's LED industry, and the saturation of lower-brightness LED production, Reid believes that Taiwanese manufacturers will still take an interest in Honeywell's 100 mm substrates. "They need to improve their product mix," he

said, adding that some manufacturers in Taiwan are already moving toward production of the higher-brightness devices that he believes should benefit the most from larger substrates. However, Reid acknowledges that many manufacturers in Taiwan still use old reactors and 2 inch substrates.

Arima Optoelectronics is one such firm that uses 2 inch sapphire substrates for the majority of its LED production. The company produces ultrahigh-brightness InGaN and AlGaInP LED chips, as well as laser diodes, but does not package the devices. Its LED chips have contributed to a little more than half of the company's revenue, which rose from \$67 million in 2003, to \$85 million in 2004, and is projected to hit \$100 million this year.

Arima president Pei-Jih Wang disagrees with Reid: "Right now I don't see any advantage for using the bigger sizes of sapphire." He believes that substrate manufacturers encouraging migration to larger substrates to mirror progress made in the silicon and GaAs industries fail to take into account the relative immaturity of the LED business. According to Wang, the vagaries of MOCVD dictate that



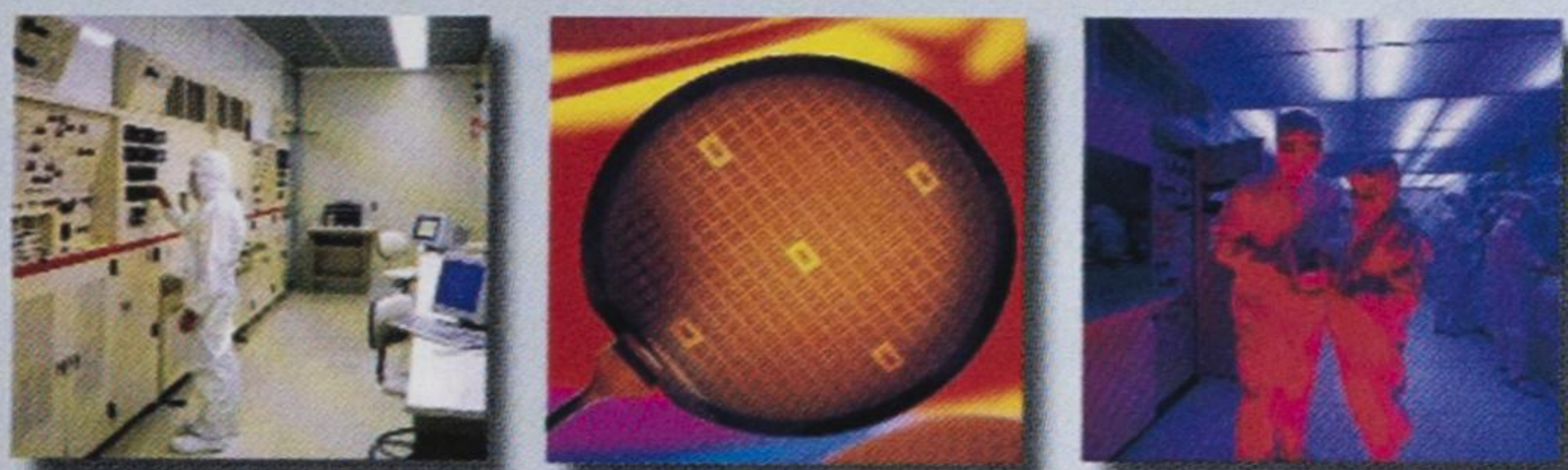
A large fall in the cost of LED production is required if future sales are to be dominated by general lighting applications instead of today's major revenue provider, cell phones.

the input of skilled engineers is essential to maintain consistent products. He also believes that improvements to wafer yields will be more important than increasing substrate sizes. In addition, he thinks that Taiwan's LED manufacturing industry is not set up for the 100 mm material, and that the expense of implementing these changes would not be compensated by any ensuing cost savings.

Wang is more interested in building relationships with major international high-brightness-LED makers, and believes that the low-cost manufacturing offered in Taiwan will be essential for the growth of global LED sales to continue. He says that although Osram has licensed its phosphor technology to several Taiwanese companies, he doesn't expect other major players, such as Nichia, Toyoda Gosei and Cree, to work with more than one or two companies at most, because of worries over illegal sharing of their technology.

If the cost per lumen of high-brightness LEDs falls significantly, everyone associated with the industry will benefit as the technology penetrates general lighting applications. As yet it is not clear how this will happen. ●

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Water-guided laser speeds up rate of SiC-wafer dicing

The sheer hardness of silicon carbide means that dicing wafers that are based on the material gives device manufacturers a big headache. Now, a novel laser technique – that uses a water jet to cool the material between pulses of the laser – developed by Swiss company Synova may offer a solution, as Infineon Technologies engineers have discovered.

Silicon carbide (SiC) is a wide-bandgap semiconductor offering many advantages over common silicon for power devices, as it can be doped to a much higher level to achieve a specific blocking voltage. As a result, SiC is an attractive solution for many carrier devices, such as Schottky diodes, extending their voltage operation to more than 3000 V. SiC devices are also able to withstand high temperatures.

These new power devices based on SiC dice are produced from 2 and 3 inch wafers. Today's most common tools for SiC-wafer dicing are diamond blades or tips, and these are what many device manufacturers use in their SiC fabs currently. However, because SiC is such a hard material – very nearly as hard as diamond – problems arise when using mechanical wafer-dicing techniques.

Blade wear

One important issue is blade wear, which for SiC is approximately 100 to 500 times as high as that for silicon. Where nearly 3 km of silicon can be cut with one diamond blade, only 10 m of SiC can be processed.

Additionally, the sawing blade may occasionally be damaged. This is because at the beginning of each new dicing line the blade penetrates the wafer edge at a sharp angle, which can cause the blade to break. The smaller the wafer diameter, the more likely it is that the blade is damaged or breaks.

Figure 1 shows a SiC wafer diced with standard diamond sawing equipment. Along the kerf, slight chipping can be seen due to mechanical effects caused by the blade. Additionally, the wall of the wafer has suffered from blade loading.

Although conventional lasers emitting in the ultraviolet (UV), green and infrared have been used to cut SiC, they are not ideal because the machining process tends to cause heat damage and particle contamination.

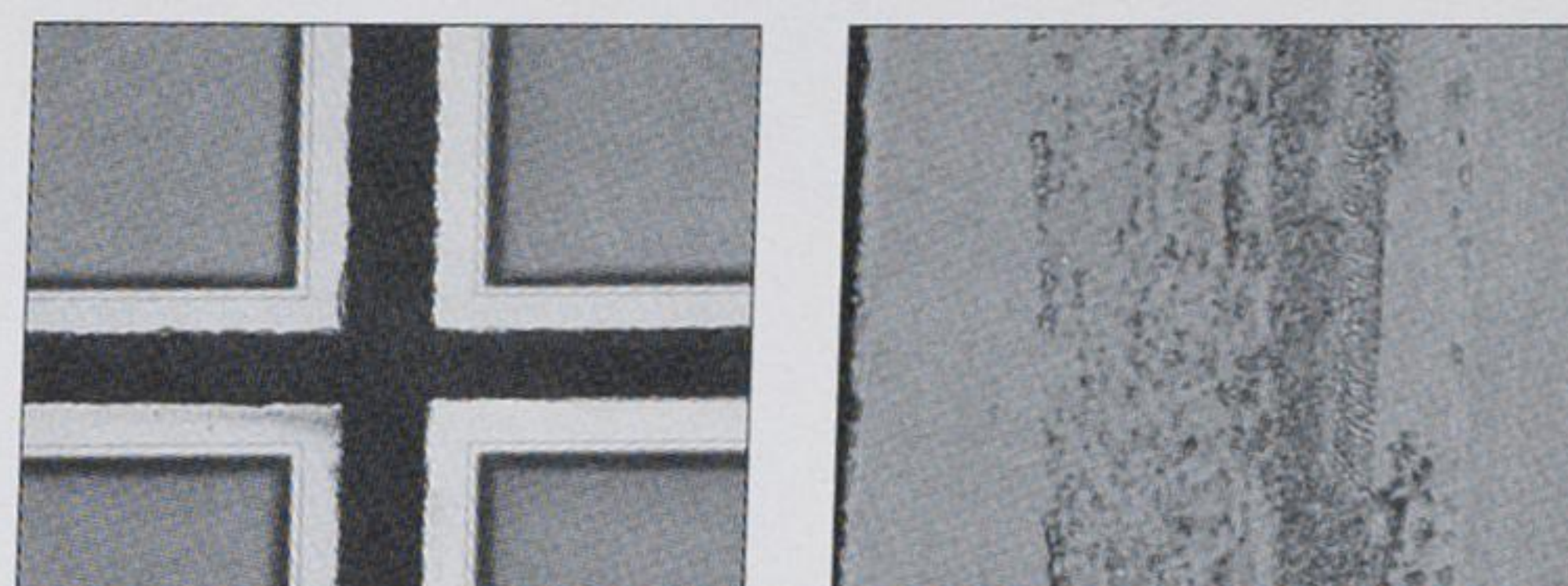


Fig. 1: This Infineon SiC wafer, diced with an abrasive saw, shows slight chipping along the kerf on the front side (left image) and blade loading on the wall of the wafer (right). The kerf width is 45 μm .

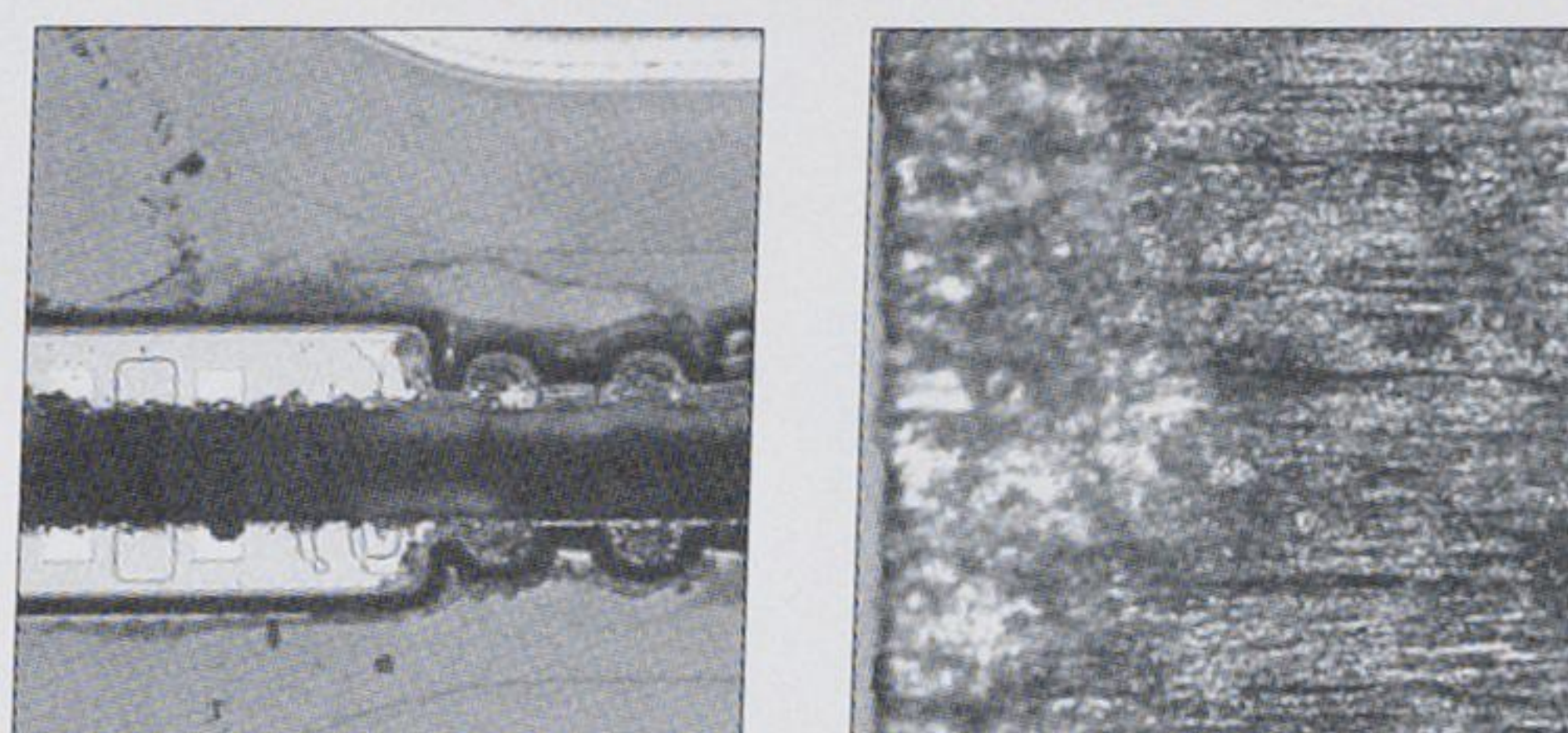


Fig. 2: Processed with an ultraviolet laser that had not been optimized for cutting, this SiC wafer shows burning effects along the kerf (left) and wall (right).

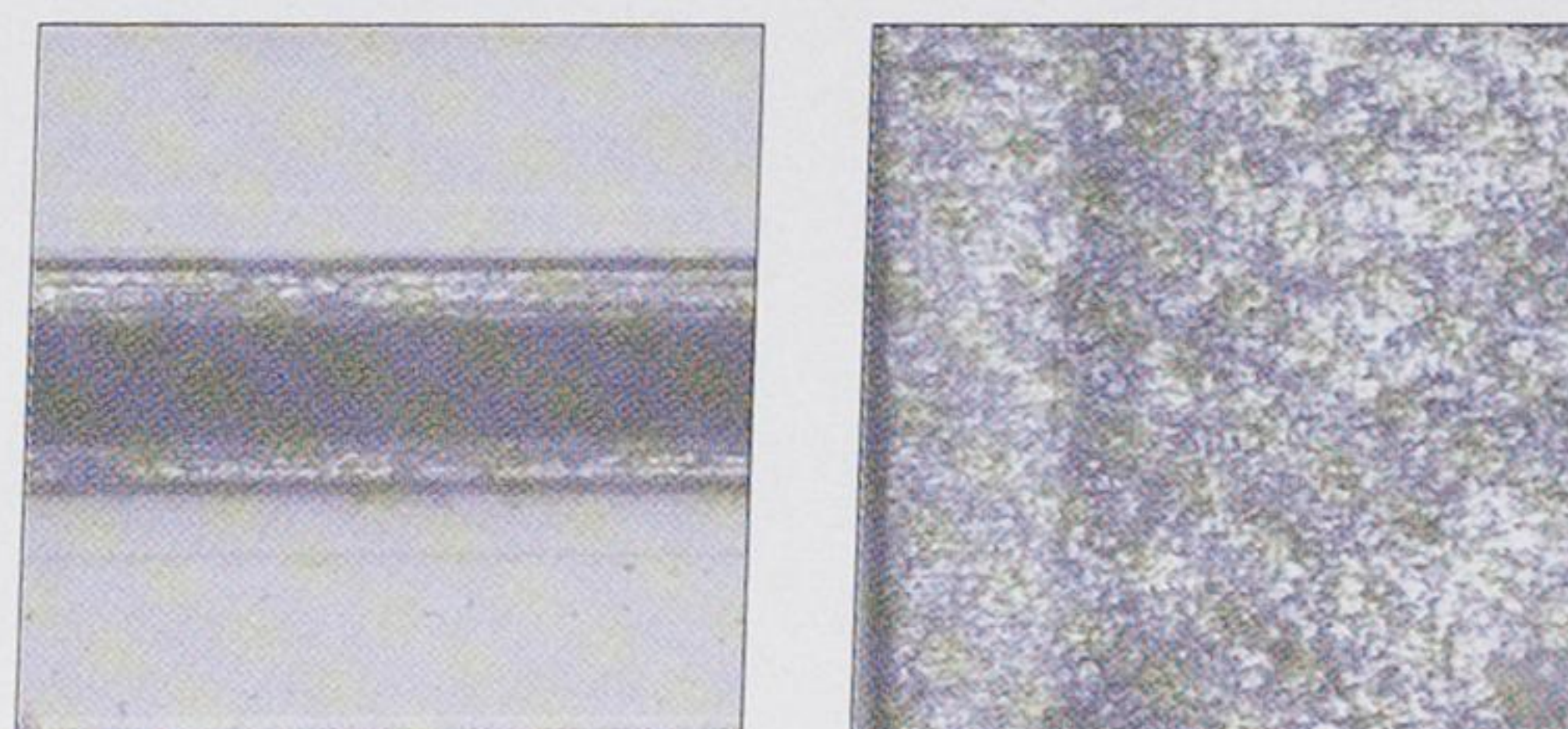


Fig. 3: The water-jet-guided laser does not burn or chip the SiC wafer. There is less contamination compared with dry laser cutting, and non-adhering particles can be removed using a standard cleaning process.

Lasers typically remove material by a melting, vaporization or ablation mechanism, all of which tend to generate a heat-affected zone in the target material. Additionally, molten material is not always completely removed during cutting by the assist gas, which is directed co-axially with the laser beam, and

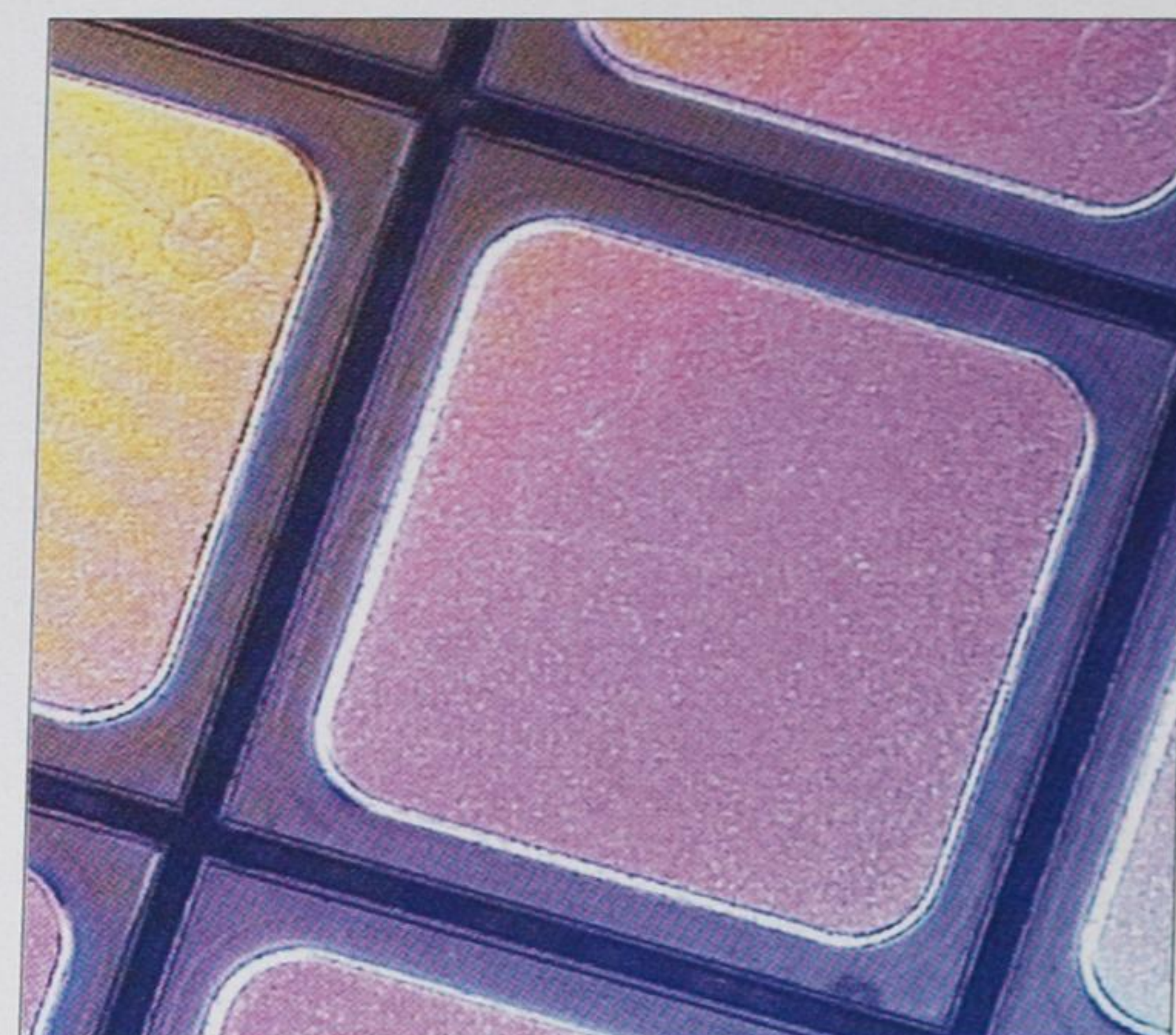
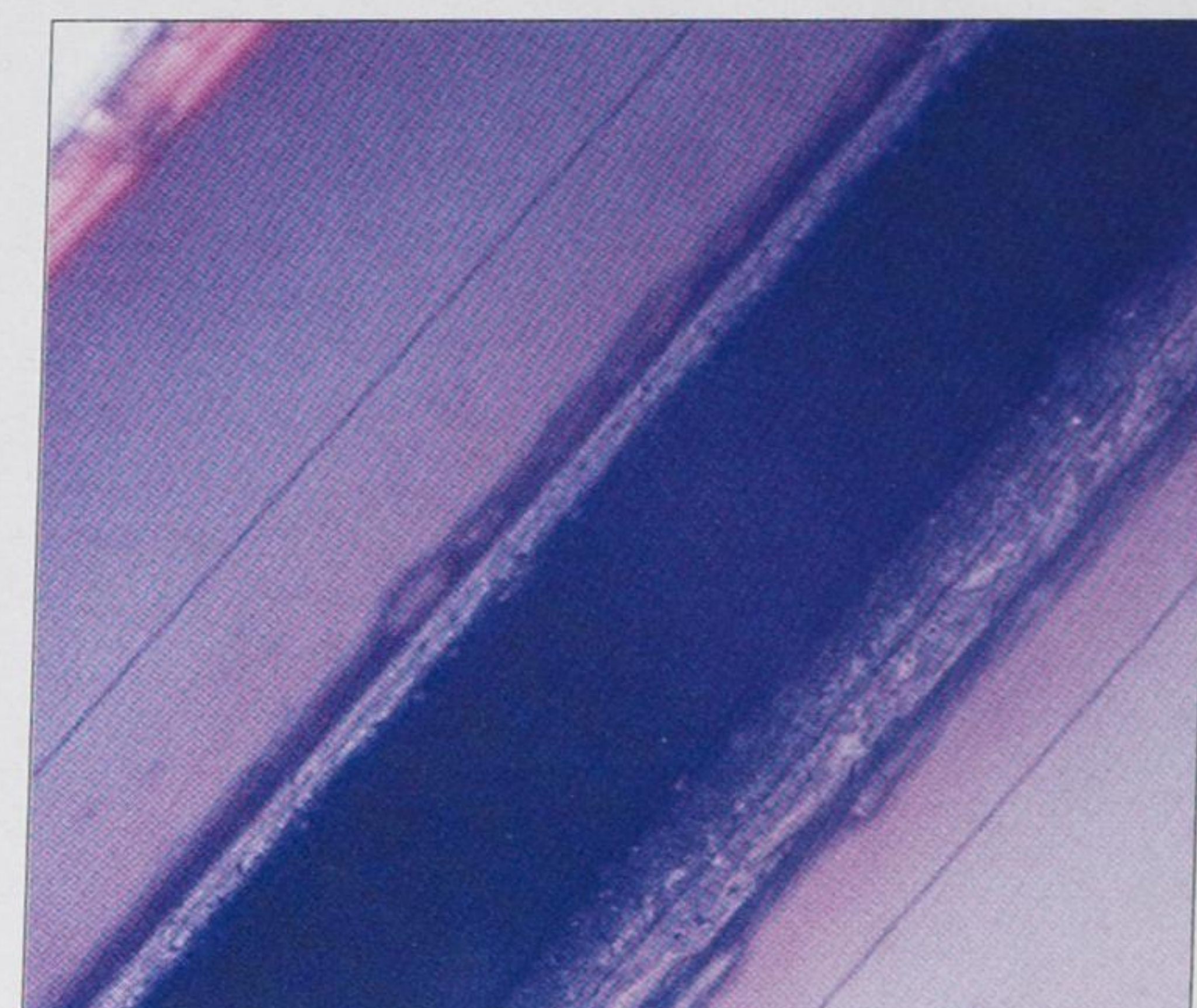


Fig. 4: (Above and below) Synova's water-jet-guided laser can cut through a 380 μm thick SiC wafer.



Figures 1 to 4 show structured SiC substrate wafers. They were made specifically for testing the dicing equipment, so the resulting devices have not been electrically tested. No layer was present in the streets.

this can result in droplets being deposited on the surface of the wafer.

The results of tests performed by Infineon in collaboration with a UV-laser manufacturer were inconclusive (see figure 2). The conditions for these tests were standard for the dry UV-laser cutting of SiC. Along the kerf, the



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material has been burned and many particles and burrs are visible on the front side of the wafer, as no protective layer (such as a photoresist) has been used. The wall of the wafer also shows side burning, while more than 10 passes of the laser were necessary to cut through the wafer completely.

Although the output of the UV laser had not been optimized for cutting, further tests were not carried out because of the poor-quality dicing achieved. Indeed, the possible improvements that may have resulted from laser optimization are not expected to have been sufficient to produce high-quality cutting, with no particle generation or heating effects.

Having concluded that neither abrasive sawing nor dry laser cutting are ideal solutions for SiC-wafer dicing, Infineon decided to test the feasibility of a different laser-based process, featuring a high-power beam guided by a narrow jet of water.

Water-guided laser

The basic principle of the water-jet-guided laser involves focusing a laser beam into a nozzle while passing it through a pressurized water chamber. The water jet emitted from the nozzle guides the laser beam by means of total internal reflection that takes place at the water-air interface, in a manner similar to conventional glass fibers. Thus, the water jet can be thought of as a fluid optical waveguide of adjustable length.

One of the major differences of this technology compared with conventional laser dicing is that there is no thermal damage. This is because the water jet cools the material between laser pulses. Another advantage is that the water jet removes molten material during the cutting process, which reduces contamination. A water film is maintained on the surface of the wafer while the laser cuts, acting as a protective layer and preventing particle deposition.

As with other laser methods, the water-jet-guided technique does not generate mechanical damage, such as chipping or cracking, because it is a non-contact process. The force applied by the water jet is negligible (less than 0.1 N), as its diameter ranges from 75 to 25 μm with a pressure of between 50 and 500 bar.

Several laser-beam characteristics can be adapted to improve the cutting quality and speed on each specific type of wafer. For example, to cut the 380 μm -thick SiC wafer shown in figure 4, a pulsed, infrared laser (wavelength 1064 nm, average power 56 W) was combined with a 40 μm -diameter jet.

In production, using the water-jet-guided laser for silicon cutting has reduced hourly running costs by about 45%.

Although SiC dicing dominates today's chip production, the water-jet technique does offer several advantages.

First, the water-jet technique is faster than mechanical methods, especially when processing thinner wafers. For example, for the 380 μm -thick wafer shown in figure 4, the cutting speed was improved by 40% compared with abrasive sawing. Second, laser methods cut down on the cost of ownership, since there is no need to replace the diamond blade or saw.

Water consumption is also kept to a minimum, amounting to around 1 liter per hour at 300 bar water pressure. Finally, individual devices are not weakened by the dicing step, as the process generates no thermal or mechanical damage to the wafer edge and wafer surface, although it should be noted that SiC devices diced with this method have not been tested electrically. Ultimately, however, the laser tool should ensure higher yields and faster wafer processing.

Benefits for SiC chipmakers

The water-jet-guided laser is expected to generate substantial cost savings for SiC chip manufacturers. In production, using the water-jet-guided laser for silicon cutting has reduced hourly running costs by about 45%. This is mainly because the blades do not have to be replaced and there is also a reduced operator cost. And, since SiC is a much harder material than silicon, causing more frequent blade replacements, cost savings associated with this material could be even greater.

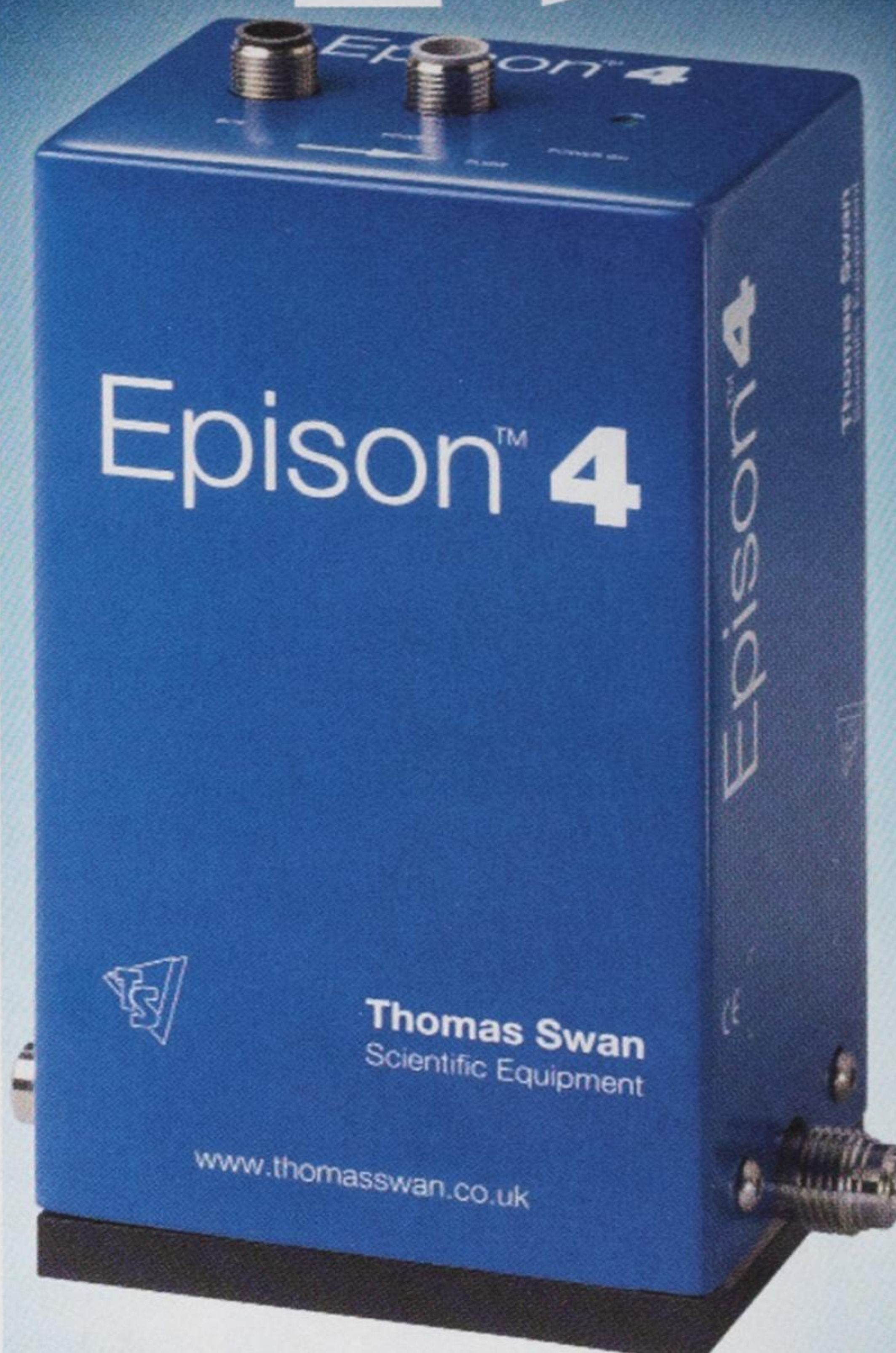
Allowing a damage-free, clean and fast cutting process without expensive maintenance costs associated with tool wear, the water-jet-guided laser holds great promise for next-generation SiC-wafer dicing. ●

Further reading

Compound Semiconductor January/February 2004 p27.

Carsten von Kobinski and Gerald Lackner are with Infineon Technologies; Delphine Perrottet, Max Wiki and Bernold Richerzhagen are with Synova.

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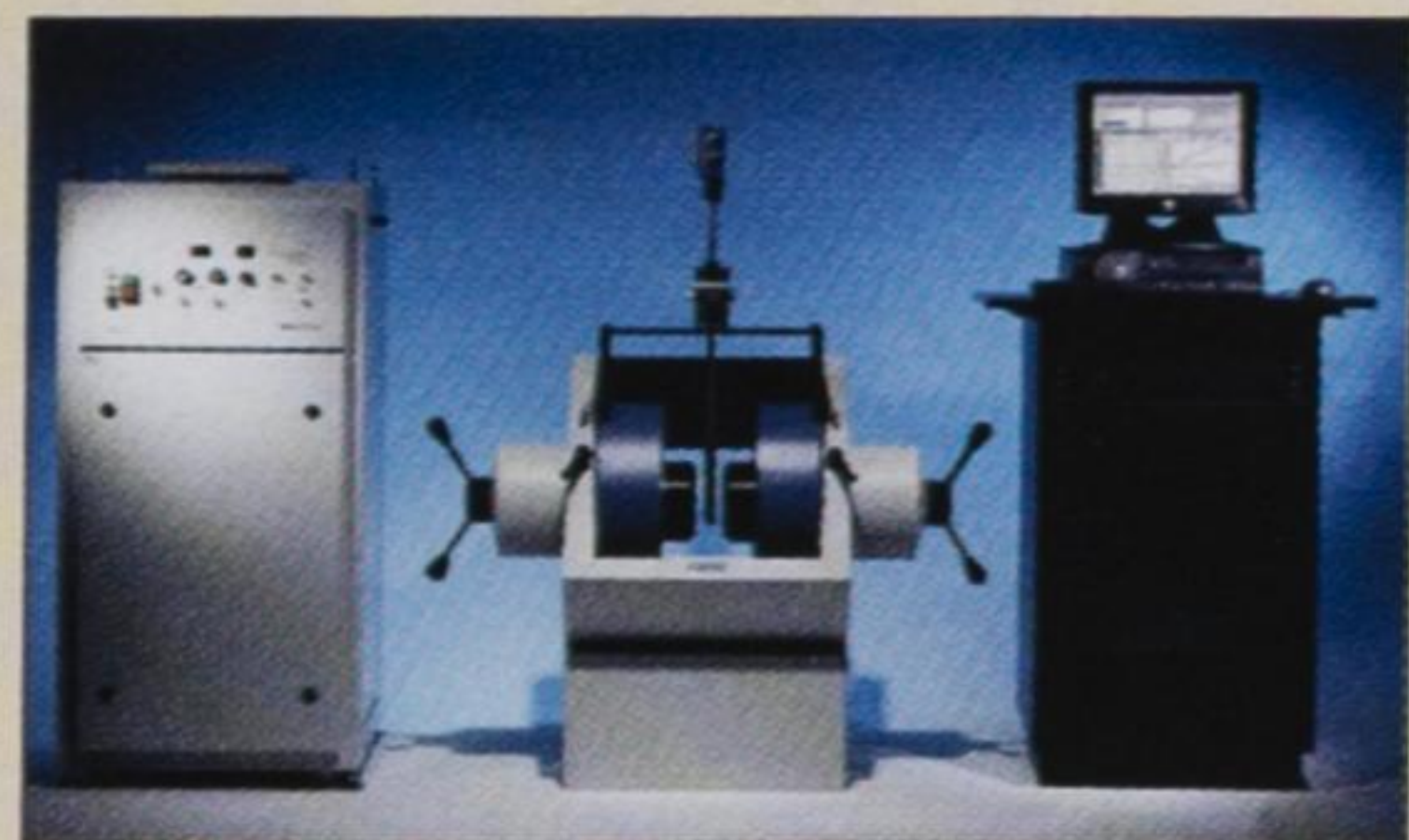
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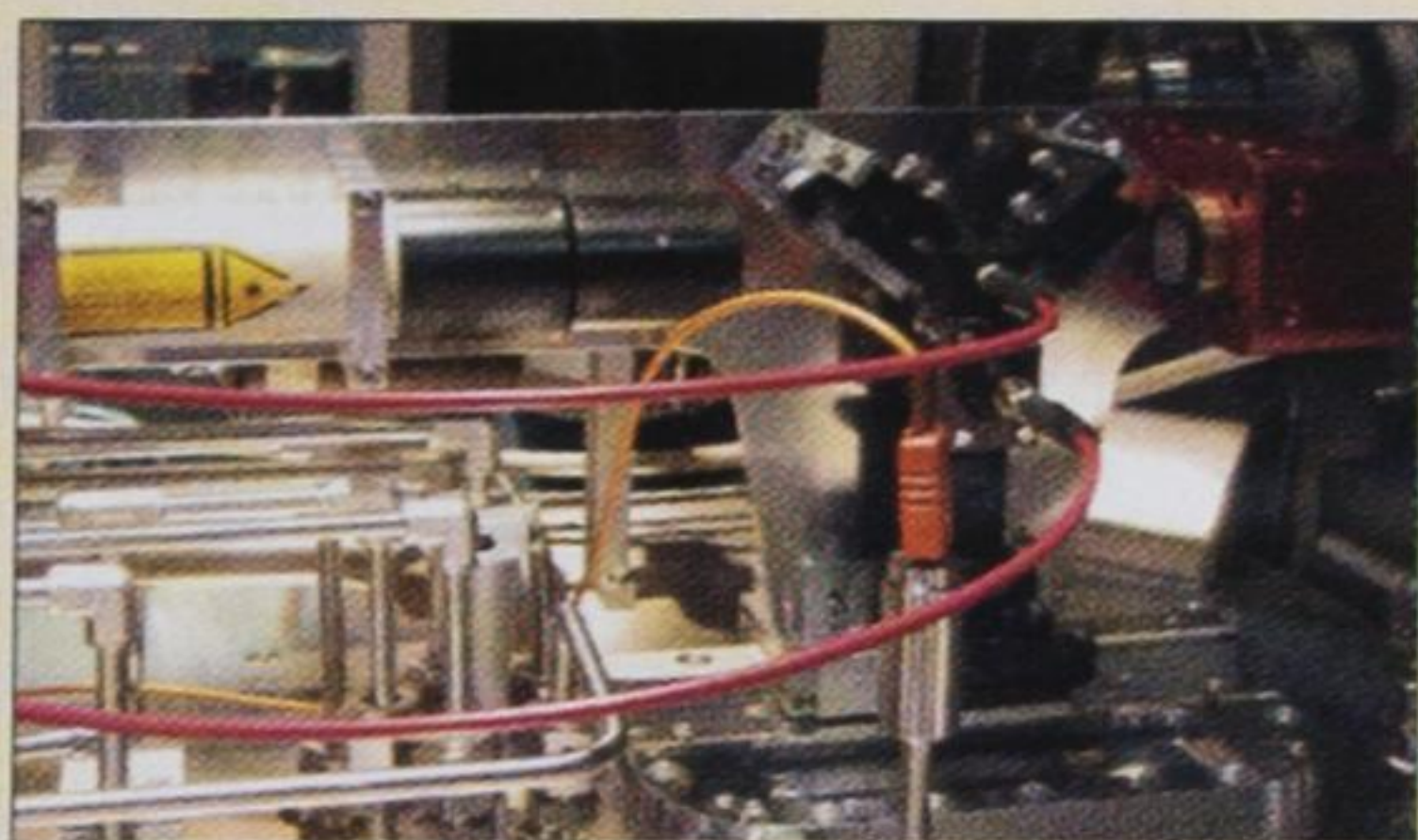


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EpiCurve

LayTec GmbH

Through co-operation with the University of Magdeburg, Germany, LayTec has developed a new *in situ* curvature sensor for production-line MOCVD: **EpiCurve**. **EpiCurve** allows real-time measurements of wafer curvature, emissivity-corrected wafer temperature and double-wavelength reflectance used for growth-rate analysis! **EpiCurve** can be used in single- and multiwafer reactors and even with planetary rotation, as well as on transparent and low-reflectance substrates. Its unique combination of wafer-temperature and bowing measurements allows you to track temperature deviations caused by wafer bowing and enables growth optimization by minimizing bowing-related non-uniformities.

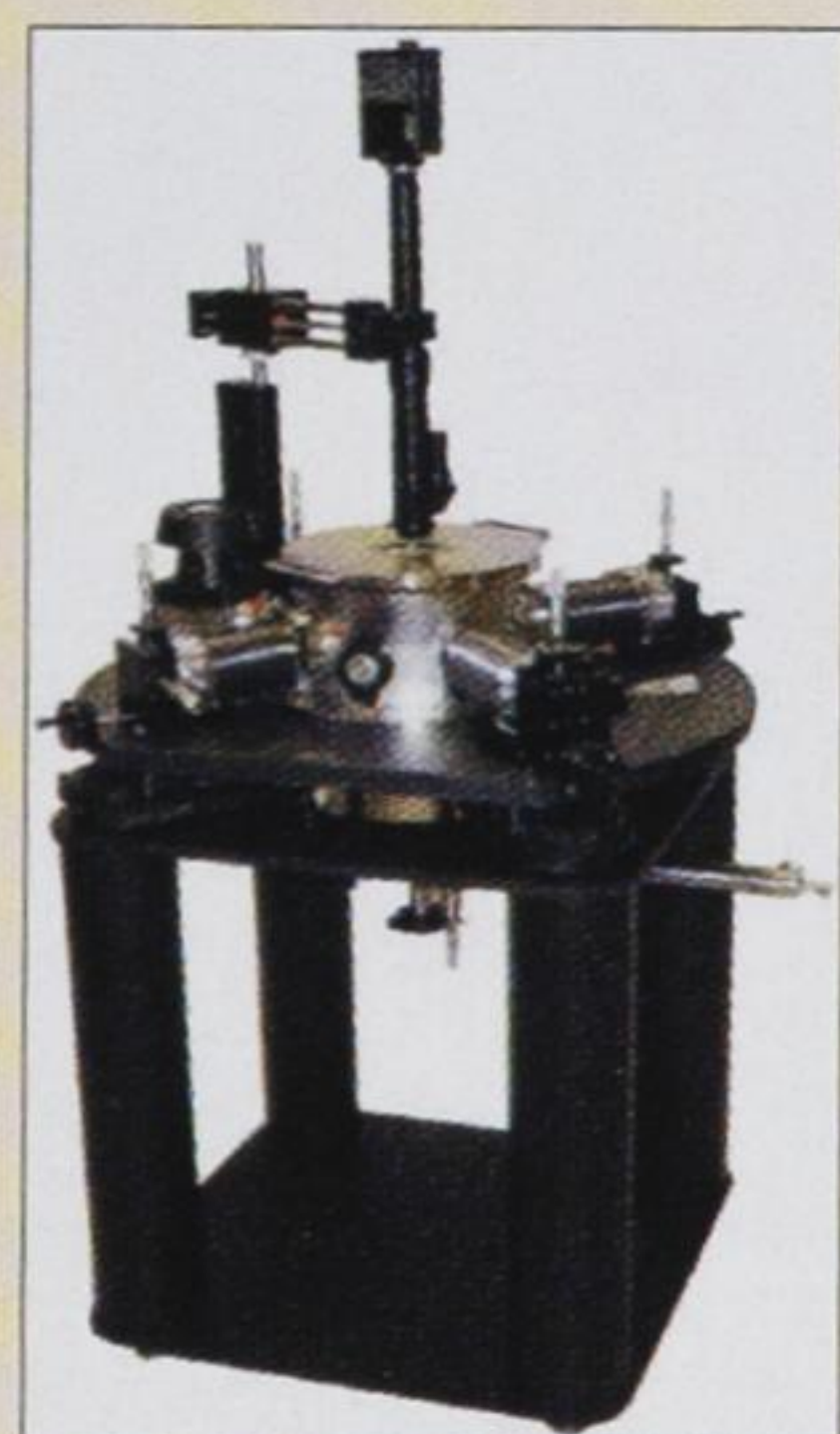


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Chinese institute makes first near-UV laser diode

Researchers from the Institute of Semiconductors at the Chinese Academy of Sciences (ISCAS) in Beijing, China, have used a Thomas Swan MOCVD reactor to produce a 410 nm laser diode. The device is claimed to be the first near UV laser diode to be produced in mainland China.

The laser, fabricated on a GaN-on-sapphire template wafer, contained a five-period InGaN/GaN multiquantum well active region, and an AlGaIn/GaN superlattice

was used for the cladding layers. The 410 nm device operates in a gain-guided mode, and it has a strip width and length of $5 \mu\text{m}$ and $800 \mu\text{m}$, respectively.

Epitaxial growth was conducted on a 3×2 inch (1×4 inch) Thomas Swan Close Coupled Showerhead MOCVD reactor that was installed in ISCAS two years ago. The machine has been primarily used for growth of short-wavelength laser diodes and UV photodetectors.

Dowa to develop GaN-on-sapphire substrates

Non-ferrous metals producer Dowa Mining intends to mass-produce GaN-on-sapphire wafers, says a report in Japanese newspaper *Nihon Keizai Shimbun*.

Dowa Mining, which is headquartered in Tokyo, Japan, will work with Nagoya Institute of Technology to develop the wafers. According to the report, some of the technology will also be provided by NGK Insulators.

Dowa is expected to invest more than ¥5 billion (\$46 million) in the new venture and aims to begin mass-production at the start of fiscal 2007. The company hopes that wafer sales will hit ¥10 billion in fiscal 2008.

Dowa says that its GaN-on-sapphire business will not infringe the patents of companies such as Nichia that are already working in this sector.

In brief

- Sandia National Laboratories in Albuquerque, NM, has purchased a GEN20A MBE system from **Veeco Instruments**. The deposition tool, which will be installed in the US Department of Energy's Center for Integrated Nanotechnologies, will be used for the growth of terahertz quantum cascade lasers.
- Toshiba has installed one of **Accent Optical Technologies'** Vektor X-ray diffraction tools in its DVD laser manufacturing facility in Kitakyushu. "The Vektor double-crystal has the

best performance for a mass production environment, even in comparison with the latest four-crystal systems," said Toshiba in a statement.

- **Unaxis Wafer Processing** is to supply the Korea Advanced Nano Fab Center (KANC) with six of its Versaline plasma process tools for dry etching applications. Unaxis says that the large order from KANC, which is housed at the Korean Small Business Center in Suwon, Gyeonggi, brings the total number of systems ordered since last year to 30.

Equipment vendors tough it out

Despite renewed optimism in fiber-optic communications and the prospect of important new LED and laser applications, deposition-equipment suppliers still face a difficult market, with the share prices of Veeco, Aixtron and Riber all falling significantly in the past three months.



There's no doubting the optimism surrounding the LED industry currently, which has continued to show the strongest growth of all compound semiconductor applications.

Add to that the continuing growth in the cell-phone sector, which recently received a further boost from Nokia's upwards projection for global sales of handsets in 2005, and something of a bounce in the market for fiber-optic components, and it should culminate in a healthy market for equipment vendors.

But that optimism isn't yet translating into increased orders for MOCVD and MBE machines, it seems. In Aixtron's recently published annual report, the German company's chairman, Paul Hyland, expresses fears that 2005 will be another tough year, citing predictions by leading economists expecting slowing growth in the world's major economies.

Other macro-economic effects, particularly a continuing weakness in the US dollar, will also have a negative effect on Aixtron's business overall, while the company now says that it expects to record a net loss in 2005 as it accounts for the acquisition of atomic-layer-deposition (ALD) specialist Genus and integrates this business with Aixtron's existing silicon division.

Now reporting its sales figures quarterly, with its shares listed on the NASDAQ as well as the Frankfurt exchange, Aixtron says that low levels of customer spending on capital equipment affected its revenue in the seasonally weak first quarter. At €22.2 million (\$28.1 million), sales were down on the €26.6 million figure posted in the equivalent period last year.

Aixtron predicts annual loss

Based on expected revenue of €160 million–170 million for 2005 overall, the Aachen-based firm believes that it will make a €10 million–15 million loss for the year. However, that loss will include charges related to the Genus acquisition, with ongoing MOCVD operations expected to break even.

And despite providing a fairly gloomy picture overall, Aixtron believes that it has taken market share away from Veeco, whose TurboDisc division provides the competition in the MOCVD market.

While the future markets of GaN lasers for next-generation DVD, and high-brightness LED chips for large-scale LCD backlights will no doubt become big revenue drivers for Aixtron and Veeco eventually, the precise timing of any surge in equipment sales remains unclear.

Feeling the effect of the market

Veeco looks to have resolved many of the problems relating to the TurboDisc division's finances, and registered sales of \$22.5 million in the HB-LED and wireless markets in its first quarter, which ended March 31. Orders for epitaxy equipment in that period amounted to \$13.6 million, versus Aixtron's overall first-quarter orders of €22.7 million. Around 80% of Aixtron revenue typically comes from sales to LED chip manufacturers (the figure was 81% for fiscal year 2004).

While Veeco can rely on its other business sectors to bolster its overall profitability – the company is expecting increased sales in the data-storage industry to balance out weaker epitaxial equipment sales – and Aixtron toughs out the slow-down in orders from Asia-based LED manufacturers, Riber looks to be feeling the effects of the weak market demand more acutely.

The France-based MBE equipment vendor is relying heavily on sales to the research-machine sector. The seasonality of this business meant that no Riber machines were delivered in the quarter that ended March 31.

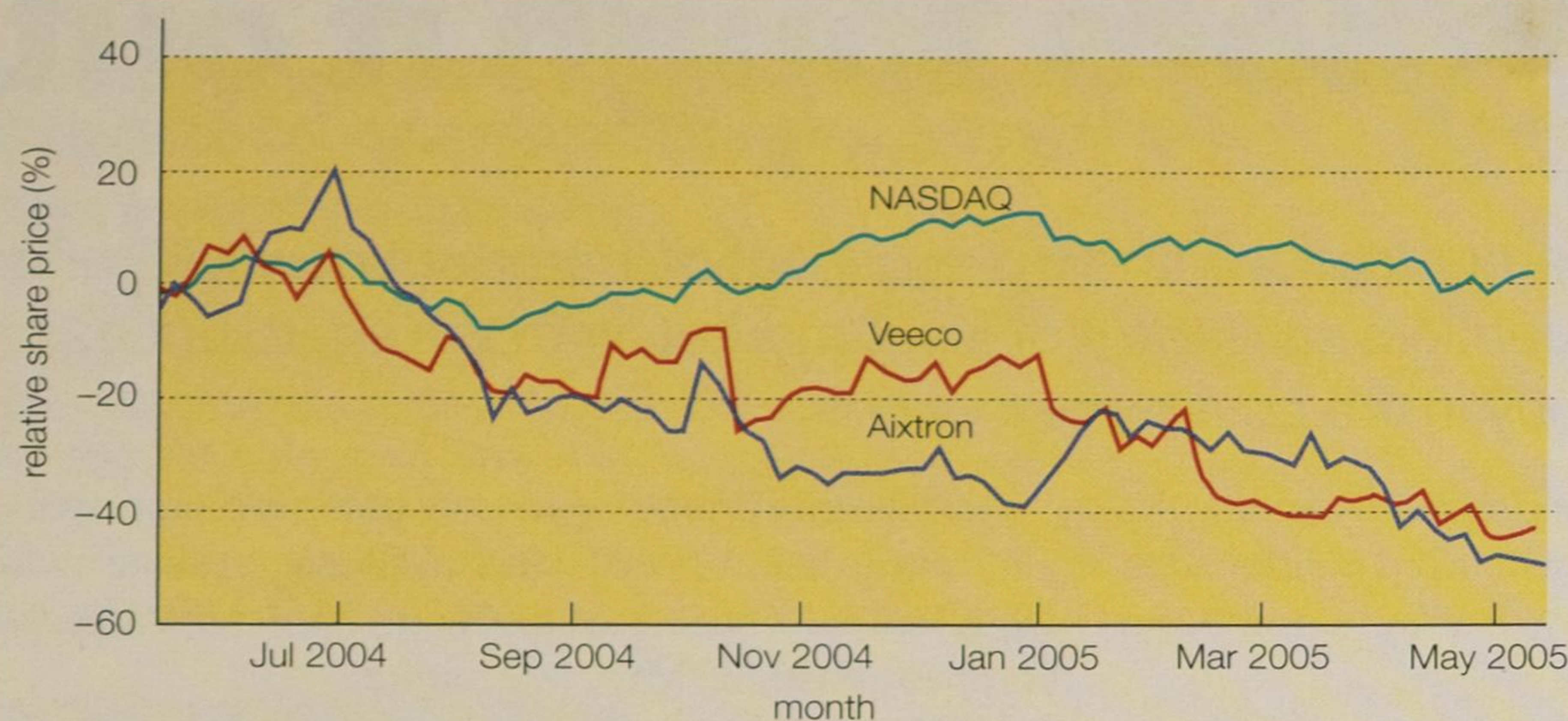
Two orders for Riber's Compact 21 machines were received, however, and the company's order book – now totaling €9.6 million – is 10% fuller than it was one year ago. But with no major upturn in the production-machine market envisaged, Riber has decided to cut its losses with a 24% reduction in workforce and a refocused development program. The company is also selling off one of its production sites.

Deposition equipment suppliers: March quarterly results

Company	Exchange	Quarterly revenue (\$m)* (% change, year on year)	Order book (\$m)	Share price May 24 (52-week range)
Aixtron	Frankfurt/NASDAQ	28.1 (–17)	22.7	€2.52 (2.36–6.22)
Riber	Paris	1.26 (–23)	12.1	€0.71 (0.59–1.59)
Veeco**	NASDAQ	22.5 (n/a)	13.6	\$15.10 (12.83–26.48)

* Currency conversion as of 17 May ** Veeco's figures relate to its quoted HB-LED/wireless sales

SOURCE: YAHOO FINANCE



This shows the relative performance of Aixtron and Veeco shares versus the NASDAQ composite over the past year. All of the companies that supply material-deposition equipment have seen a sharp fall in their share value since January.

Such drastic cuts have appeared inevitable since Riber made a loss of €11.6 million on sales of €13.5 million in fiscal year 2004. Badly affected by the weakened US dollar as well as the stagnant market for its machines, there is only expected to be a steady improvement in overall sales this year.

Other suppliers of process equipment are also seeing weak demand, although, on a more positive note,

Unaxis recently registered the sale of six Versaline process tools to the Korea Advanced Nano Fab Center.

ST Systems' chairman, Nigel Randall, describes 2004 as "another difficult year" in the UK firm's latest trading report, with sales to the photonics and wireless industries amounting to less than 10% of its £14 million (\$25.8 million) revenue in the year. In 2003, these two markets accounted for 30% of ST Systems' sales. However, Randall concludes that trading in 2005 would at least be an improvement on 2004, citing evidence of an increasing number of enquiries for its products.

Other equipment suppliers

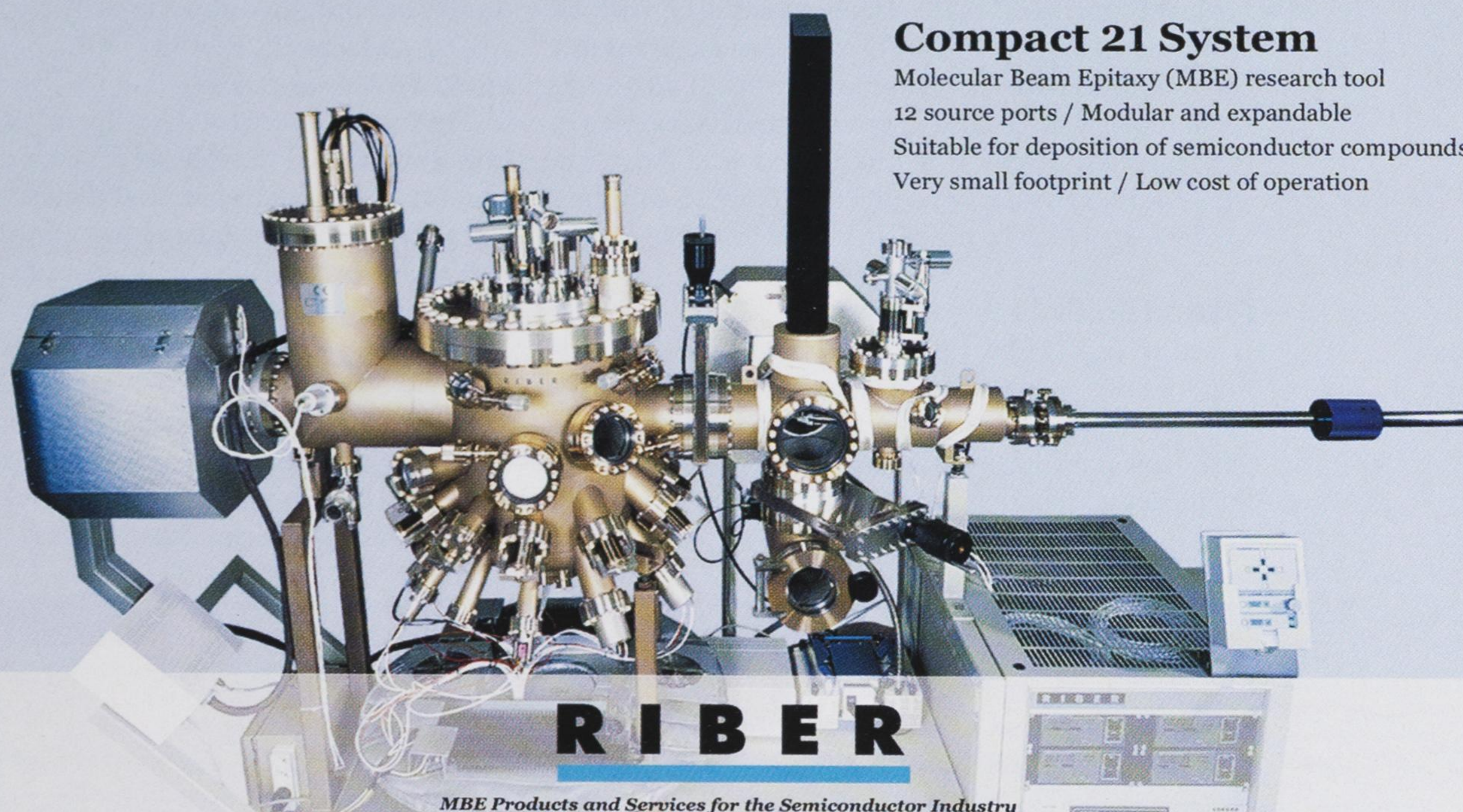
And UK-based Trikon Technologies, which should soon merge with ALD equipment supplier Aviza Technology, reported a 15% year-on-year increase in revenue for the quarter ended March 31. Its sales of \$7.8 million included a license revenue of \$2 million attributed to a joint-development agreement with Aviza that is separate to the merger deal.

Trikon CEO John Macneil sounds a positive note on 2005, saying that shipments in the quarter are at the highest level seen since late 2001. "I believe that this level of shipments, which includes two evaluation systems to major customers in Asia, is a strong indicator of revenue growth in 2005," said Macneil. ●

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ELECTRONIC MATERIALS
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Injectorless quantum-cascade lasers make the grade at room temperature

By Richard Stevenson in Glasgow, UK

Substantial progress in quantum-cascade-laser (QCL) research was reflected in the content of the presentations delivered at the Indium Phosphide and Related Materials conference held in Glasgow, UK, in mid-May. Developments included fabrication of high-performance injectorless QCLs, faster laser growth by using MOCVD instead of MBE, and the use of alternative material systems to target the atmospheric window that exists at 3–5 μm .

Andrea Friedrich from the Walter Schottky Institute in Garching, Germany, outlined the efforts of an all-German collaboration that claims to have delivered a three-fold improvement in the threshold current of injectorless QCLs. This means that the devices are comparable to conventional QCLs. According to Friedrich, injector regions have often been considered as an essential part of the device, as they act as electron reservoirs and provide electron transfer between the active sections. However, the downside of the injector regions is that they contain slightly absorbing material, which decreases device efficiency. Up until now, though, Friedrich says that researchers have been unable to unlock the benefits of injectorless QCLs, as operating temperatures have been restricted to below 200 K.

Friedrich and co-workers fabricated their QCLs, which contain 60 periods of strain-compensating pairs of $\text{Al}_{0.56}\text{In}_{0.44}\text{As}$ and $\text{Ga}_{0.4}\text{In}_{0.6}\text{As}$ layers, by MBE growth on an InP substrate. Photolithography and wet chemical etching defined the ridge-waveguide laser dimensions to give stripe widths of 22–30 μm . As expected, the device's emission was strongly temperature dependent, varying from 10 μm at 77 K to 8.4 μm at 300 K. Its best performance was obtained with 30 μm stripe-width QCLs mounted on copper heatsinks; for pulse-mode operation consisting of 250 ns pulses and a repetition frequency of 250 Hz the maximum operating temperature was 350 K, and the associated threshold current density was 4.3 kA/cm^2 .

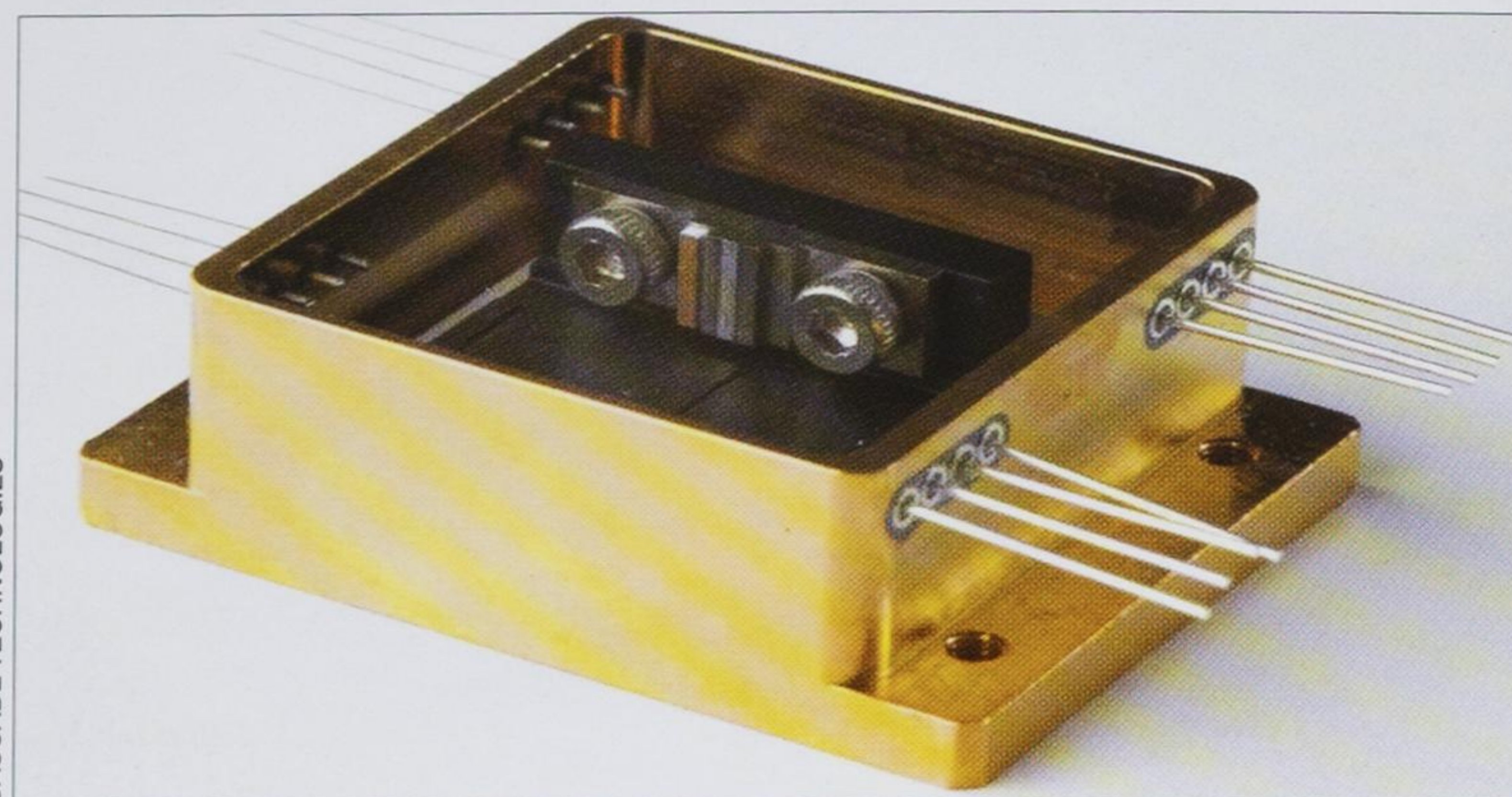
Slashing reactor growth times

The development of MOCVD-grown QCLs by researchers at the University of Sheffield and its National Centre for III-V Technologies was detailed by Dimitry Revin. According to Revin and colleagues, MOCVD should offer several advantages over MBE for QCL fabrication, including higher growth rates, easier reactor maintenance, and an established route for high-quality phosphide deposition.

The team, which also featured scientists from universities in Vienna, Austria, and Eindhoven, the Netherlands, produced lasers emitting at 10.3 and 7.6 μm on InP substrates for the detection of ethane and methane, respectively. With a growth rate of 0.8 monolayers per second (ML/s) for the active region, and one that is four times as fast for the waveguide, Revin claimed that the MOCVD growth time of only four hours was three times as fast as a typical MBE run.

Revin and colleagues verified process reproducibility by making seven devices with emission spectra within 5 meV of each other. The structural quality and pulsed performance of the MOCVD-grown QCLs was "indistinguishable" from those produced by state-of-the-art MBE.

Revin gave a separate presentation describing an effort to develop MBE-grown QCLs operating at 3–5 μm . To achieve emission at these



Targeting one of the largest markets for QCLs – gas sensing – is UK-based Cascade Technologies. The company uses QCLs produced by Alpes Lasers, a spin-off from the University of Neuchâtel, Switzerland.

relatively short wavelengths demands material systems with large conduction-band offsets that can be used to produce structures with very deep quantum wells. Revin said that the most promising candidates were QCLs based on $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}/\text{AlAs}_{0.56}\text{Sb}_{0.44}$ and InAs/AlSb , which have conduction band offsets of 1.6 and 2.1 eV, respectively.

The researchers fabricated QCLs based on the latter material system, which lased in pulsed mode at 4.4 μm and 240 K. These devices were similar to structures that the group had previously investigated, but the n -type doping in the bridging region was increased from 2.5×10^{17} to $8 \times 10^{17} \text{ cm}^{-3}$, an adjustment that is claimed to deliver sustained higher currents that lead to lasing. Revin and colleagues have also observed emission at shorter wavelengths of around 3 μm , which is believed to result from tunneling through barrier layers.

Cross-sectional tunneling microscopy showed that the Sb atoms are uniformly distributed in the barrier regions. According to Revin this means that the interface quality of these emitters is comparable to the more common $\text{InGaAs}/\text{InAlAs}$ QCLs.

Increased spectral coverage

At Tohoku University, Japan, Hideo Ohno and Keita Ohtani have been producing QCLs operating in the mid-infrared region of 8–14 μm . Their lasers feature 20–50 periods of InAs/AsSb injector layers and $\text{InAs}/\text{Al}_{0.2}\text{Ga}_{0.8}\text{Sb}$ active regions, which are 6–14 μm thick in total. With growth rates of 0.3 ML/s for InAs and 0.45 ML/s for AlSb and AlGaSb, leading to growth times of between 10 and 27 hours, the process highlights one of the downsides of the MBE approach.

For ridge-based lasers with a stripe width of 25 μm and a cavity length of 1–3 mm, the best results were delivered by the 50-period variant, which emitted at around 10 μm and had a maximum operating temperature of 305 K. At 80 K the laser threshold current was 0.42 kA/cm^2 , a value the researchers claim is one of the lowest reported for QCLs operating in the mid-infrared region. ●

Further reading

Compound Semiconductor September 2004 p28.



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