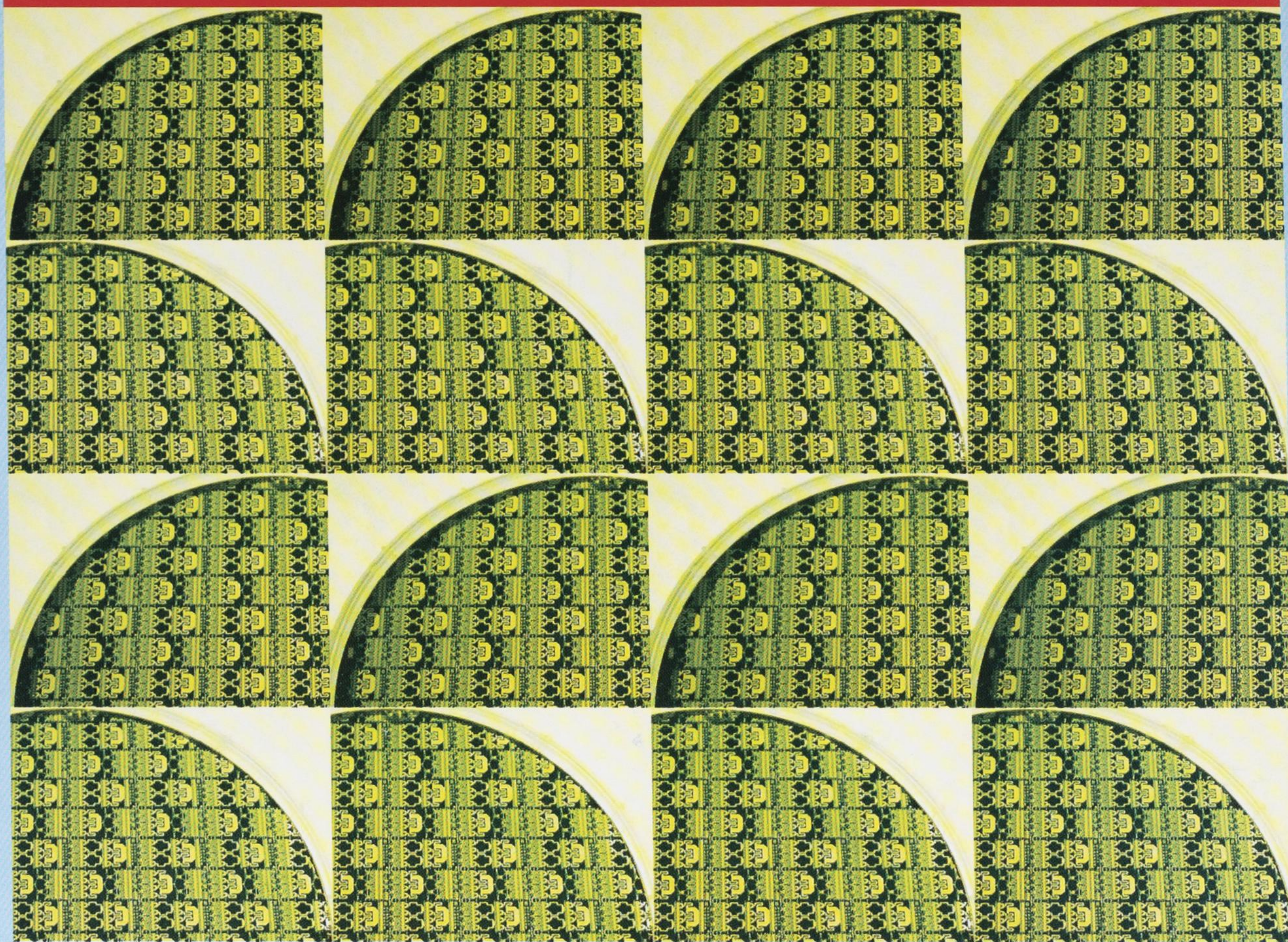


COMPOUND SEMICONDUCTOR

Three-Fives and Silicon Heterostructures

November 2005 Volume 11 Number 10



GAAS MANUFACTURING
Filtronic ramps PHEMTs for
handset transmit modules

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grow LED capacity**

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NOVEMBER 2005 VOLUME 11 NUMBER 10

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The solid-state lighting community is urged to tackle industry infrastructure issues. **p8**

CPFC



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CREE



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On the cover: Filtronic's rapid ramp in the manufacture of PHEMTs for antenna switches is driving its 6 inch GaAs production to profitability. The cover image shows PHEMT-based MMICs for cellular base stations manufactured on the company's production line (image courtesy of Filtronic).

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Institute of Physics PUBLISHING

Editorial

99% perspiration



Picture the scene: California, the year 2030. No, we're not all flying around powered by jet-packs or airborne cars, but some things have changed. Your new Toyota, as well as being powered by fuel-cell technology, features LEDs in every lighting function. Yes, that includes your headlamps. You crawl home down the 101, which is now illuminated by Luxeon XXV chips. Opening the door to your solar-powered apartment, your frazzled mood is sensed, and the room is instantly bathed in a calming, warm-white light from LED fixtures as your new Sony ButlerStation opens a bottle of Napa white and runs you a bath. It's the promised land, right?

But just how do we get to that point in the future from the current status quo, where the illuminated world is still dominated by Thomas Edison's incandescent "invention"? It's a question that Makarand Chipalkatti from Osram Sylvania pondered in his plenary talk at the recent LEDs 2005 conference in San Diego.

The message from "Chips" was that for solid-state lighting (SSL) to go mainstream, getting the right industry infrastructure in place takes precedence over any lumens/Watt milestones. Sure, the reliable production of brighter LED chips is crucially important, but given the right level of investment in research and development, this can be all but guaranteed.

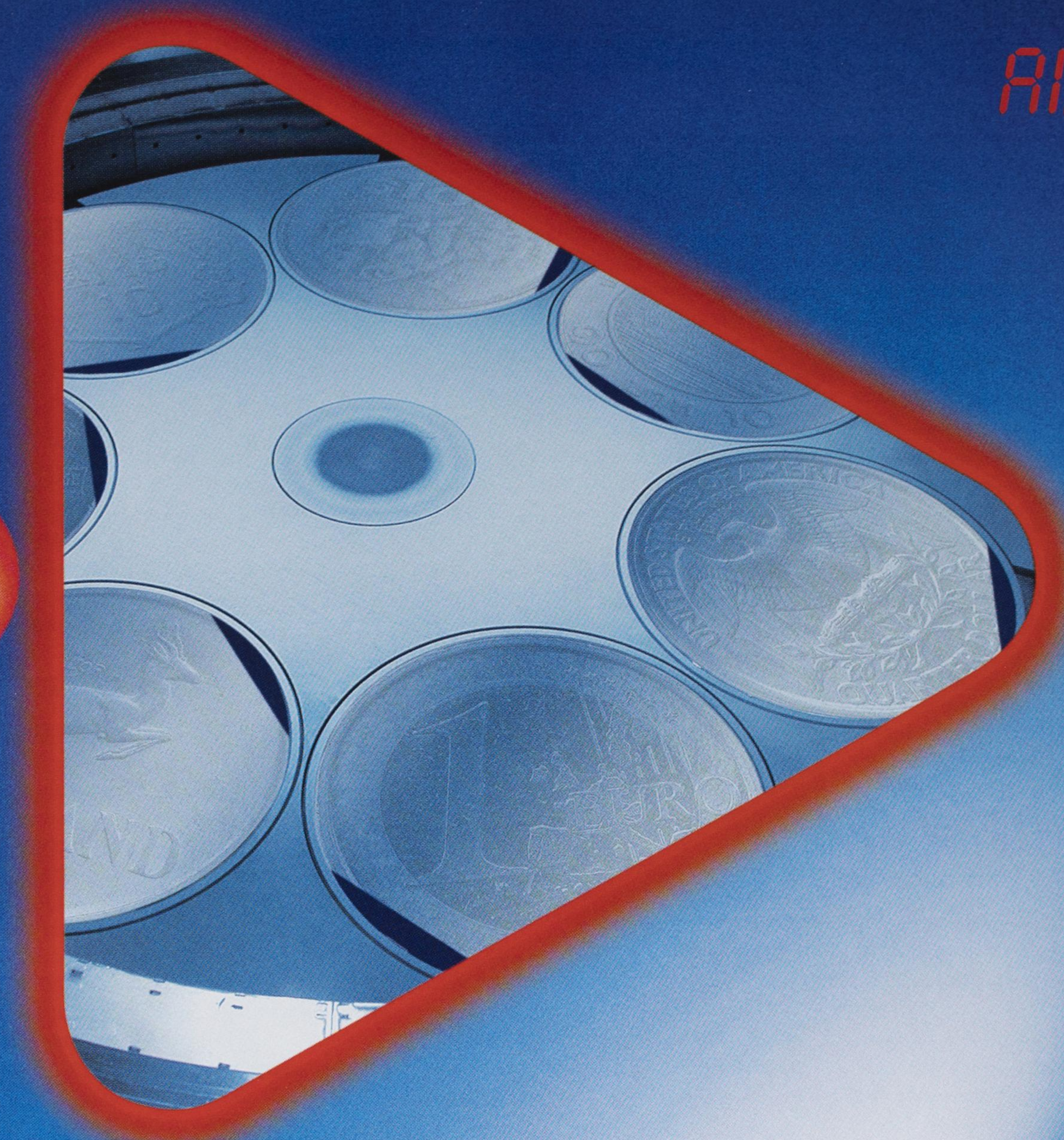
And chip brightness records will count for nothing without the apparatus to disrupt the lighting industry. Just as Edison and co. had to take on the incumbent gas lighting business without an infrastructure for electric lighting, so the SSL community must do likewise. This effort will represent the "perspiration" required to complement the technological inspiration that will ultimately result in a fully fledged, well defined SSL industry in years to come.

For all of its technological prowess, that industry is somewhat messy at the moment – at least in terms of its value chain, where boundaries between the various layers are blurred. Increased transparency, trust between the makers of HB-LED chips and their customers, along with new characterization standards, will all be required to usher in SSL.

Michael Hatcher

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Showa Denko plans LED capacity ramp

Showa Denko (SDK), the huge Japanese company that sells a wide range of chemical products, has revealed details of two new GaN-based LED chips that it plans to produce in large volumes.

SDK says that its proprietary green and near-ultraviolet (UV) LED chips are aimed at applications in general lighting and in the backlighting of large LCD screens.

The company has previously commercialized blue LEDs based on similar structures, and it has the capacity to produce 30 million GaN-based chips per month at its plant in Chiba, Japan. However, SDK is much better known as a manufacturer and supplier of petro-

chemicals, aluminum products and ceramics.

The company's blue devices are manufactured using a flip-chip approach: the chip contacts are fabricated on the epitaxial layer of the structure before the chip is "flipped" upside down for assembly.

The newly developed near-UV chips emit at 390 nm, and SDK plans to combine them with a red/green/blue phosphor mix to provide white-light sources. They are said to deliver a power of 14 mW at around 400 nm.

SDK also says that its new green GaN-based LEDs are far brighter than today's commercial products, emitting 6.5 mW at 505 nm (blue-green) and around 6 mW at 525 nm.

The company will also market "pure-green" LEDs that emit at 555 nm. SDK says that new crystal-growth conditions have been the key to developing the green LED sources.

These green products are intended for the large LCD-screen backlighting market, with SDK estimating that around 14 million LCD televisions are produced annually.

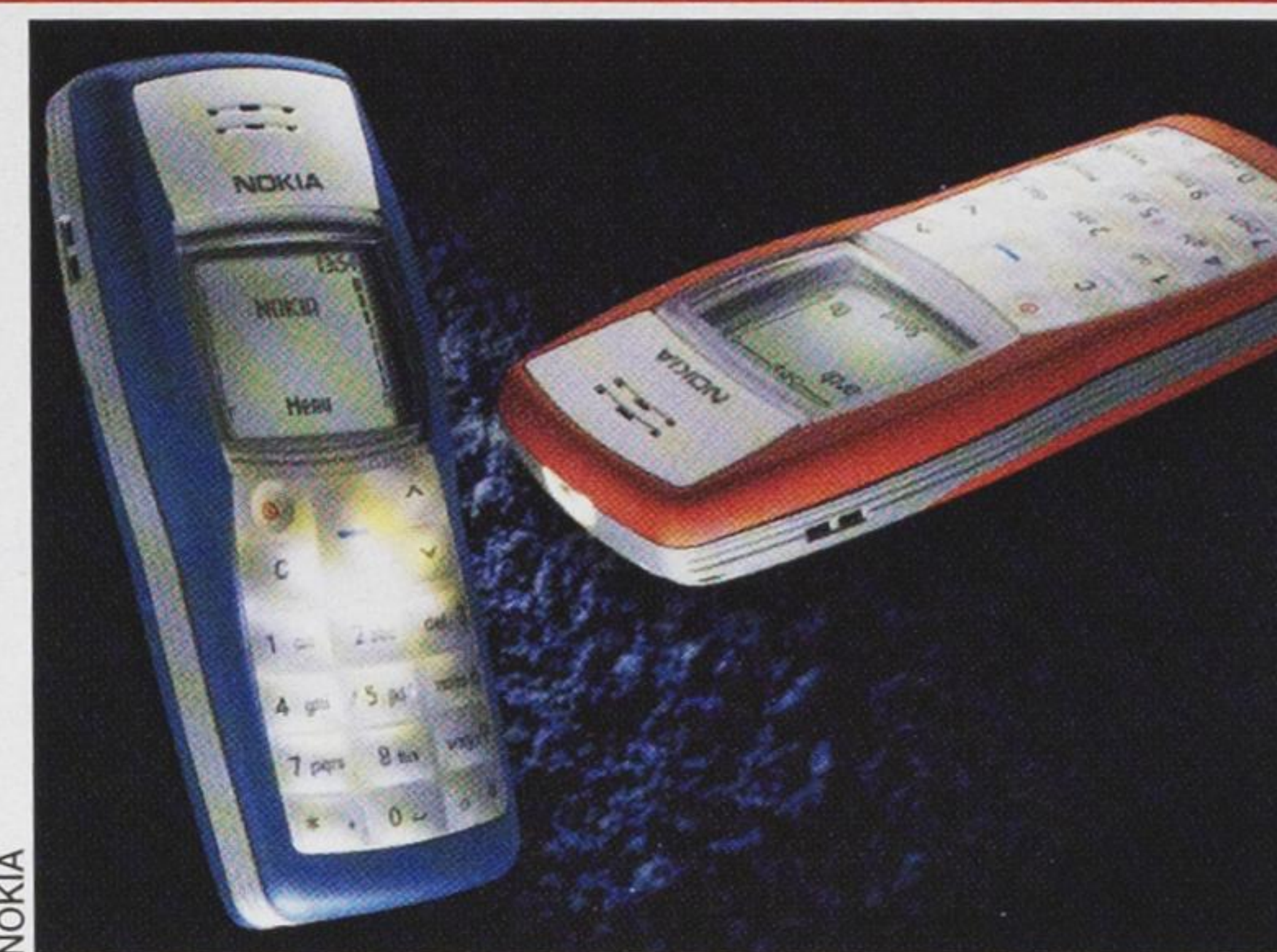
With a complete set of LED products spanning the color spectrum, SDK now plans to ramp production capacity while continuing to research new chips. The initial development of the epiwafer technology that is fundamental to LED performance took place under Japan's Light for the 21st Century project.

Handset juggernaut heads toward 800 m

Following another positive quarter for its cell phone business, Finland-based handset market leader Nokia is yet again raising its forecast for total global shipments of handsets in 2005, upping its prediction from 760 million to 780 million units.

This latest forecast is in line with the most recent prediction by analyst company Gartner, and will be welcomed by makers of both LEDs and GaAs-based RFICs.

Meanwhile, Strategy Analytics says that it now expects the total number of unit sales to ratchet up even higher: "A record 209 million mobile phones were shipped worldwide during the third quarter," said Neil Mawston from the analyst company. "Following 566 million units during the first nine months of the year, we expect the full-year total to surpass the



One billion and counting...Nokia says that it racked up yet another milestone with the sale of a model 1100 cell phone in Nigeria.

800 million level," he added.

In early 2005, Nokia predicted a much more modest increase over the 2004 unit shipment figure of 643 million. At that point, Nokia said that it expected 705 million cell phones to sell in 2005 – a rise of just under 10%.

If the analyst's forecast proves correct, the actual growth figure will be more than 20%, a similar level to the strong increases seen over the last few years.

In the most recent quarter, Nokia sold 66.6 million mobile devices, equivalent to a 29.5% year-on-year increase in volumes.

Much of that growth was driven by uptake in China, where Nokia shipped 12.6 million phones – up 87% on last year's figure for the same quarter. The company believes that it has also taken market share in this region, where home-grown Chinese brands have traditionally dominated.

During the latest quarter Nokia also registered the sale of its billionth cell phone – said to be a Nokia 1100 that was sold in Nigeria.

On the infrastructure side, Nokia has also signed five new deals to deploy wideband-CDMA networks. There are now 88 W-CDMA networks in operation worldwide, serving 34.5 million subscribers with 3G services.

RFMD tipped to win 'arms race' as it increases dollar content

RF Micro Devices (RFMD) is being tipped to take market share away from its competitors in the RF power amplifier business as the cell phone buying season moves into top gear.

The Greensboro, NC, GaAs chip manufacturer posted \$177 million in sales for the quarter that ended September 30, representing a 19% year-on-year increase. Profit was \$5.9 million, and the company is now projecting further sequential revenue growth of up to 20% for the holiday period.

"During the September quarter, we experienced record order activity," said company CEO Bob Bruggeworth. And with the intro-

duction of transmit modules, RFMD believes that it will steal market share from its rivals in what is traditionally the strongest period of the year for handsets.

If its projection proves accurate, RFMD stands to post a record revenue of around \$210 million for the final quarter of the calendar year. Dean Priddy, RFMD's CFO, added: "Our strategy of increasing dollar content within the handset is working."

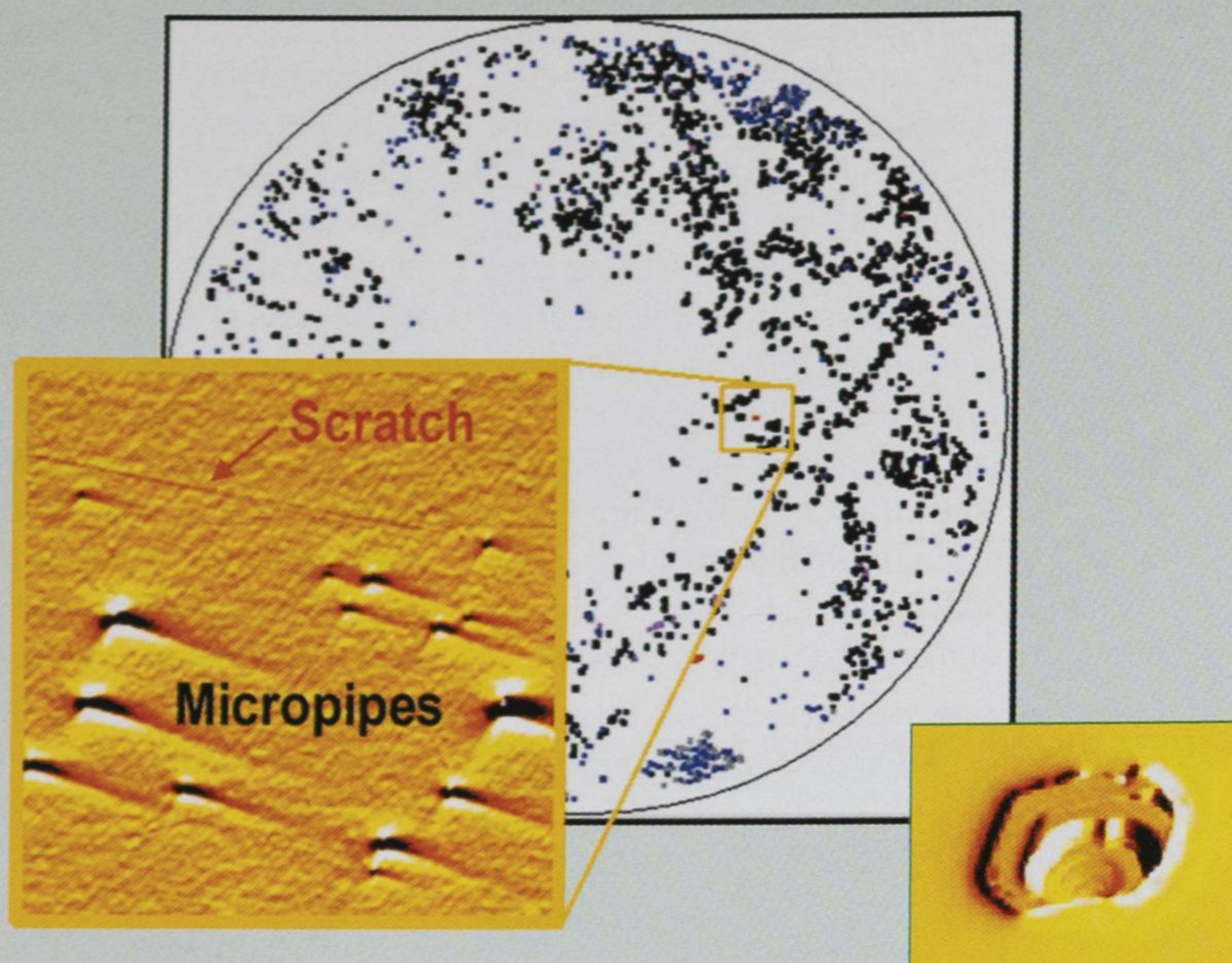
Investment analyst John Lau from Jeffries and Company believes that RFMD is emerging as the leader in the highly competitive RF semiconductor sector as it gains "signifi-

cant" market share and aggressively ramps production of transmit modules featuring GaAs PHEMT antenna switches manufactured by the UK company Filtronic.

"We believe this arms race should culminate with RFMD as the leader," said Lau.

At the moment Filtronic is supplying RFMD with switches made at its UK fab, but Lau believes that PHEMTs could be fabricated in-house by RFMD in the near future. That should improve the company's profitability as it also looks to expand its fabrication capacity. (See "Filtronic's PHEMT production rockets to meet RFMD orders" on p27.)

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French foundry in MMIC research collaboration

OMMIC, the France-based compound semiconductor foundry owned by Philips, has signed a deal with Queen's University Belfast (QUB) that should advance the development of monolithic microwave ICs (MMICs).

The university's high-frequency electronics research group will act as OMMIC's European "center of excellence", specifically with regard to the research and design of GaAs-based MMICs.

Vincent Fusco, QUB's director of high-frequency research, said the collaboration was a significant development that should lead to innovation in some important areas of microwave technology for a number of telecommunications applications.

The QUB high-frequency group, which is concerned with solving some of the toughest problems facing wireless front-end technology, has already designed MMIC products using OMMIC's processes. The group will

now have full access to the foundry's most advanced technology.

"This collaboration will improve time to market, provide additional support for customers, and enhance our joint-venture efforts," said OMMIC's marketing and sales director, Derek Smith.

The French foundry announced the agreement in Paris at European Microwave Week, where it also revealed details of a new device featuring two amplifiers fabricated on the same die that yields very low noise and high linearity. Also launched was a new range of phase shifters, attenuators and integrated core chips for X-band and C-band applications.

The devices are intended for use initially in phased-array radar systems. Marc Rocchi, the CEO of OMMIC, said: "We see a great demand for these products – not only for space and military [applications], but also for commercial products in the future."

450 MHz may boost low-cost handsets

Nokia, the Finnish company that sells more than 30% of the world's cell-phone handsets, is backing plans to develop the 450 MHz frequency band for cellular use.

The technology is regarded as one option open to service providers and handset manufacturers as they bid to increase the mobile-phone subscriber base throughout the world towards the 3 billion mark.

The company said: "Nokia believes that a GSM450 frequency is a viable solution in providing affordable handsets and mobile voice-centered services to new growth areas."

Soren Petersen, the company's senior vice-president of mobile phones, added: "Nokia believes that reducing the total cost of ownership for both affordable handsets and mobile voice services are the key when it comes to reaching the next billion customers in new growth markets."

Whether GaAs will feature as a key technology for power amplifiers (PAs) in such low-cost products remains to be seen. Silicon CMOS and SiGe solutions are often regarded as a lower-cost option, and could be more suited to the lower frequency compared with the conventional cellular bands that operate at 850 MHz and above.

Asif Anwar of Strategy Analytics believes that the key requirements of the phones will likely continue to be long talk and standby times, which could maintain the preference for GaAs-based PAs.

In fact, he says, these attributes could be viewed as being even more important in emerging markets, where electricity supplies may be less reliable.

Long talk and standby times are a function of the PA's efficiency and linearity, and GaAs has an advantage in both of these areas.

Hittite profits rise after impressive quarter

Hittite Microwave, the fabless RFIC designer and chip supplier, has reaped a net profit of \$5 million on revenue of \$21.2 million in its latest financial quarter.

The Chelmsford, MA, company, which completed its initial public offering (IPO) of stock in July, has benefited from both fast-increasing sales revenue and lower manufacturing costs.

The latest revenue figure was up nearly 33% on the equivalent period in 2004, while in terms of net profit the year-on-year increase was an even more impressive 52%.

Hittite has seen strong sales in the US over

the last year, with the domestic market representing 57% of total revenue in the latest quarter – up from 49% one year ago.

The healthy operational picture is now complemented by a balance sheet that features almost \$53 million in cash and cash equivalents following the summer IPO. In a busy period for the company, Hittite also released 26 new products and acquired Q-Dot, a company that researches and develops analog and mixed-signal technology.

Hittite is expecting revenue to continue on its upward trend, with sales forecast to hit around \$22 million in the current quarter.

Military sales help to get TriQuint back on track

GaAs chip manufacturer TriQuint Semiconductor posted revenue of \$75.2 million in its third fiscal quarter, which ended on September 30, representing a drop of 8% from the same period last year.

Despite that drop, the Hillsboro, OR, firm still registered a net profit of \$2.6 million as capacity utilization in its high-volume fabs improved and the disposal of its optoelectronics business benefited the bottom line.

Reductions in the company's workforce led to a 7% sequential decrease in operating expenses, while demand in key sectors is said to be looking healthier.

The company's CEO, Ralph Quinsey, attributed the improved performance to both increased shipments to CDMA handset makers and also a more buoyant military market than has been seen of late.

Quinsey said that both of these sectors had

returned to "normal" levels of demand, adding: "The outlook for the [current] quarter and beyond is exciting as we booked record orders of over \$13 million for our power amplifier products, largely in GSM/GPRS applications."

Revenue in the seasonally strong fourth quarter is expected to rise by at least 10% sequentially as consumers buy new cell-phones. Profitability is also expected to receive a boost as fab capacity use improves further.

Cree breaks revenue barrier of \$100 m

Cree posted \$103.9 million in revenue for the quarter that ended on September 25. The figure represents a company record, and also marks the first time that the Durham, NC, firm has broken the \$100 million barrier.

The 8% increase over the equivalent period in 2004 translated to a \$21.7 million profit for the supplier of LEDs, RF chips and compound semiconductor materials.

In what company CEO Chuck Swoboda described as an increasingly competitive environment, Cree believes that it has gained market share particularly in the white LED sector, and primarily for applications in cell-phone display backlights. More than half of Cree's chips are now destined for use in cell phones.

Earlier this year the company agreed a white LED cross-licensing deal with Japanese rival Nichia, which enables Cree to clamp down on the unauthorized use of its technology more effectively. Cree has also signed a \$200 million distribution deal with its key customer, Sumitomo Corporation.

Overall, sales of LEDs accounted for \$84.6 million of the quarterly revenue, equivalent to a 7% increase on last year, although in terms of sequential growth this figure is up only slightly. But in terms of volumes, growth is much more impressive, with a year-on-year increase in LED shipments of 42%.

This is in part due to the use of larger wafers in manufacturing – Swoboda estimates that more than half of the company's chip production now takes place on 3 inch wafers. Meanwhile, Cree is already initiating plans to switch to 4 inch production for both micro-electronic and optoelectronic devices.

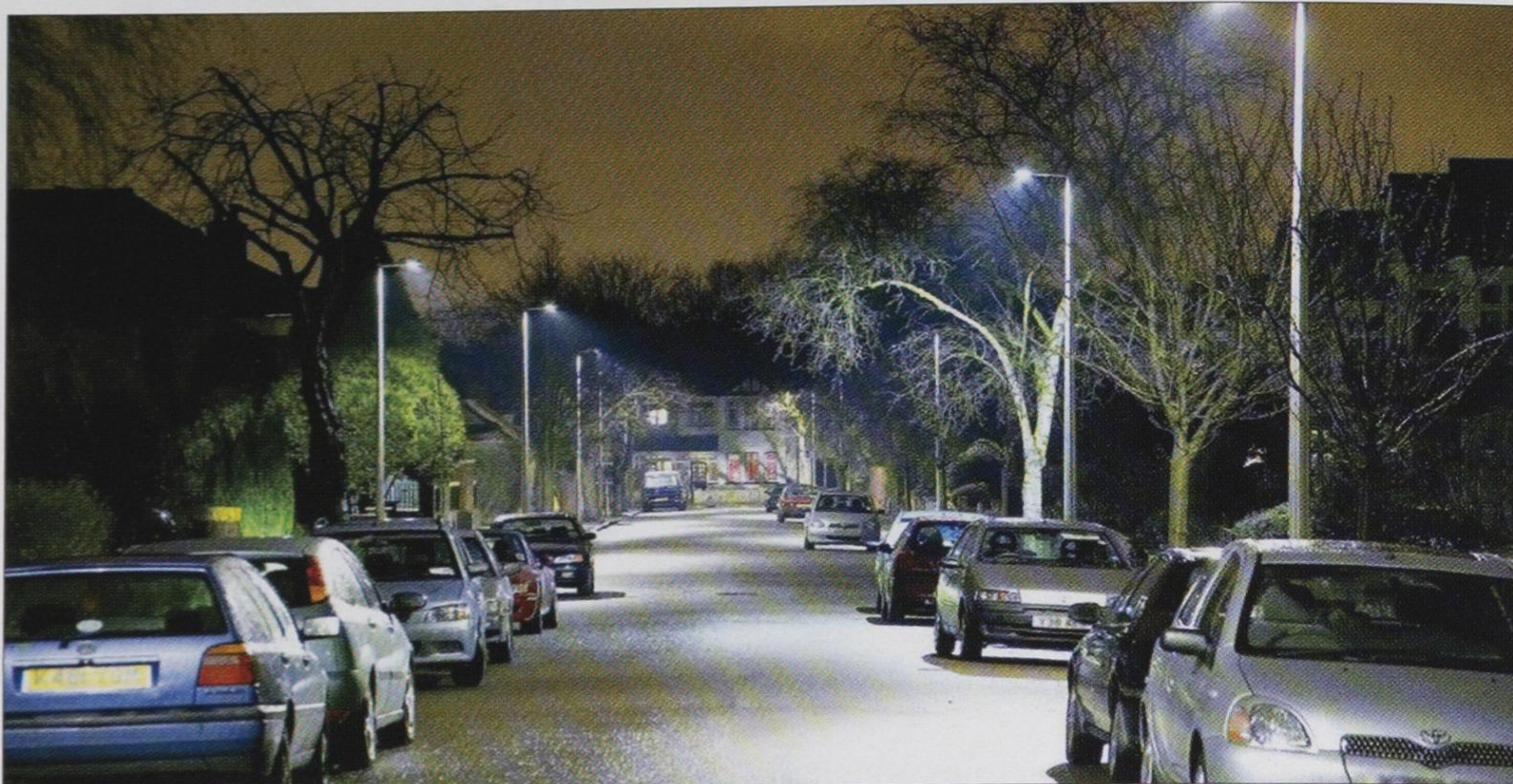
With the traditionally strong December quarter now in full swing, Cree estimates that revenue will increase again, to between \$106 million and \$109 million.

● US Immigration and Customs Enforcement (ICE) agents arrested 36 foreign nationals said to be working in the US illegally during a shift change at Cree's premises on October 18.

According to a statement by ICE, eight of those arrested were Cree employees while the others were employees of two Cree subcontractors. The workers are said to have used invalid, altered or falsified documents to get jobs at Cree or its subcontractors.

ICE added that Cree had cooperated fully in the arrests and that the company itself was not the subject of any investigation.

Infrastructure change is vital for SSL revolution



PHILIPS LIGHTING

The general use of solid-state lighting in applications such as street lamps will not take off as an industry until infrastructure issues are tackled, according to Makarand Chipalkatti.

By Michael Hatcher in San Diego

The drive to establish solid-state general lighting featuring LED technology should focus more on creating a meaningful, standard infrastructure. That was the key message from Osram Sylvania's Makarand Chipalkatti in his plenary talk at the recent Intertech LEDs conference held in San Diego.

"Chips" Chipalkatti, who is also chairman of the solid-state lighting (SSL) section of the US National Electrical Manufacturers Association, said that supply lines in the nascent SSL industry were far more blurred than in the classical lighting industry.

Whereas the roles of companies supplying materials, lamps, systems and luminaires, as well as their market channels, are clearly established in the industry based on Edison's light bulbs, the SSL world features many companies that operate throughout the value chain.

"Some underlying standards need to be developed as a stable platform around which change can be sustained," said Chipalkatti. He indicated that establishing the necessary infrastructure for SSL implementation was more important than meeting a "magic" chip brightness benchmark such as 150 lm/W.

The rapid cycle of innovation and technological change in the LED world also needed to be harnessed more effectively so that manufacturers could sustain a focus on new product development, he said.

Chipalkatti added that a useful example for the SSL industry to imitate was the PC industry's development of the universal system bus (USB) port, where a single open-source design has provided a standard technological base for product designers to work from. Cooperation across the industry in as yet uncommercialized areas was also needed, he said.

Huga and LG Innotek ramp chip production

Veeco Instruments' new GaNzilla II production MOCVD system has been placed into production at LG Innotek in Korea and Huga Optoelectronics in Taiwan.

The second-generation machine, which succeeds the high-throughput GaNzilla platform, is said to increase significantly the production of premium GaN-based devices.

"We have responded to our customers and

designed MOCVD technology that improves their process and wafer yield, and delivers brighter LEDs," said Richard Wissenbach, the general manager of Veeco Compound Semiconductor.

Wissenbach expects more GaNzilla II systems to enter production use during this quarter. The system is available as an upgrade or as a new machine.

Nichia reveals Kirameki devices for headlamps

By Tim Whitaker in San Diego

With its competitors capturing both attention and market share in the high-power LED market segment, it sometimes appears that Nichia is lagging in this area. However, the company has dispelled any misapprehensions with the unveiling of a new line of power devices going under the name Kirameki.

At the Intertech LEDs conference held in October in San Diego, Drake Stalions, sales manager with Nichia America, described the products, which have been developed with the automotive headlamp market in mind.

Two variants of Kirameki were discussed: a 5.5 W device with a flux of 200 lm, and an 11 W device with a flux of 400 lm. The packages measure $14 \times 9 \times 5.6$ mm and contain multiple chips. Both devices operate at 700 mA and produce warm-white light at 4300 K, which is the desired white color for automotive forward lighting.

Another critical feature for this application,

and one demonstrated by the Kirameki, is that both the package and the die should have a very small optical area to achieve the required beam pattern with multiple devices.

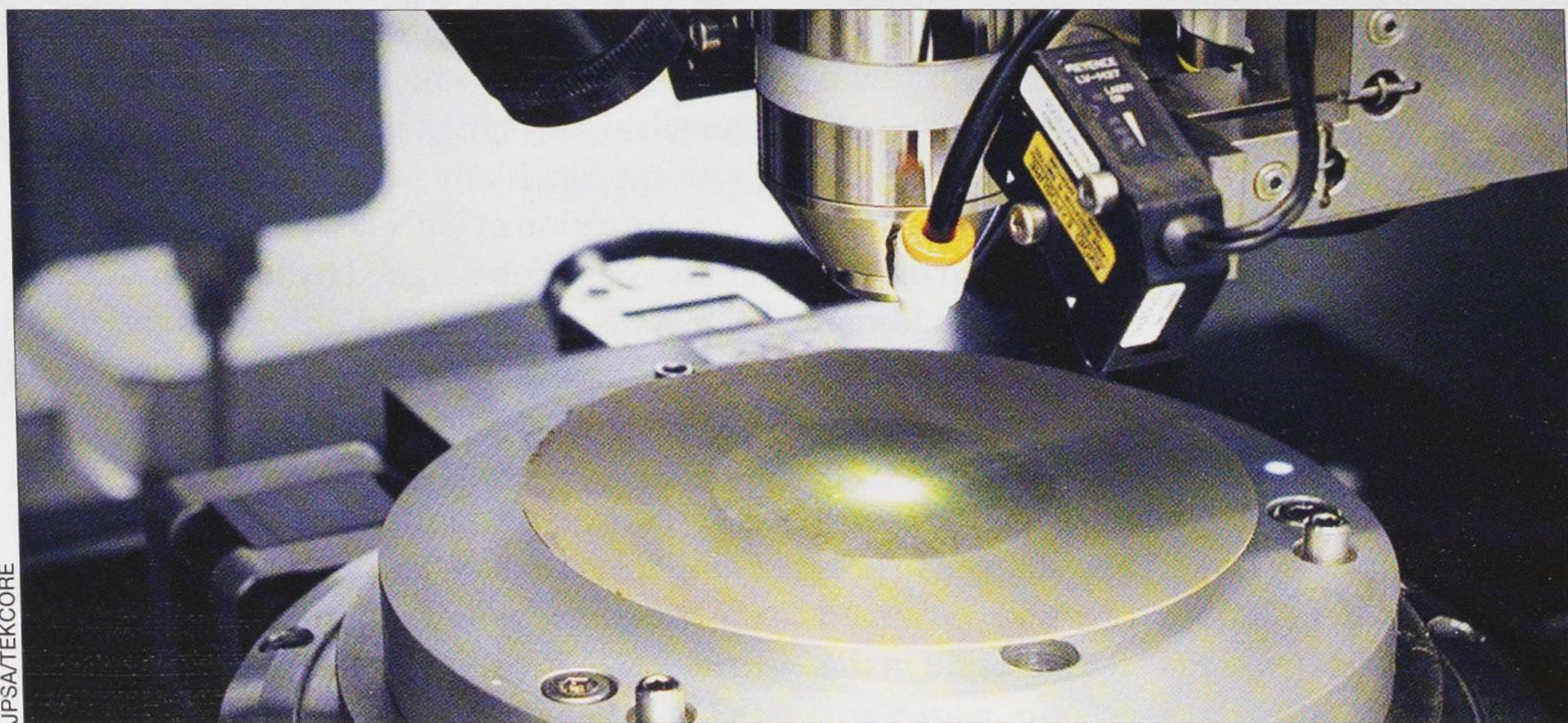
The power devices have an efficacy of 36 lm/W and will operate within the temperature range -40 to $+105$ °C, as specified for automotive applications.

The maximum junction temperature for the products is 150 °C. Both packages have an extremely low thermal resistance: 6 °C/W for the 5.5 W device, and 3 °C/W for the 11 W device. Because of this, the devices are not suitable for reflow soldering and must be mounted mechanically.

Samples have been sent to several customers, and Nichia is awaiting feedback before finalizing the device specifications. Stalions said that the Kirameki is likely to be available for use in automotive applications by 2007.

Tim Whitaker is the editor of LEDs Magazine.

LED wafer scriber meets 4 inch capability



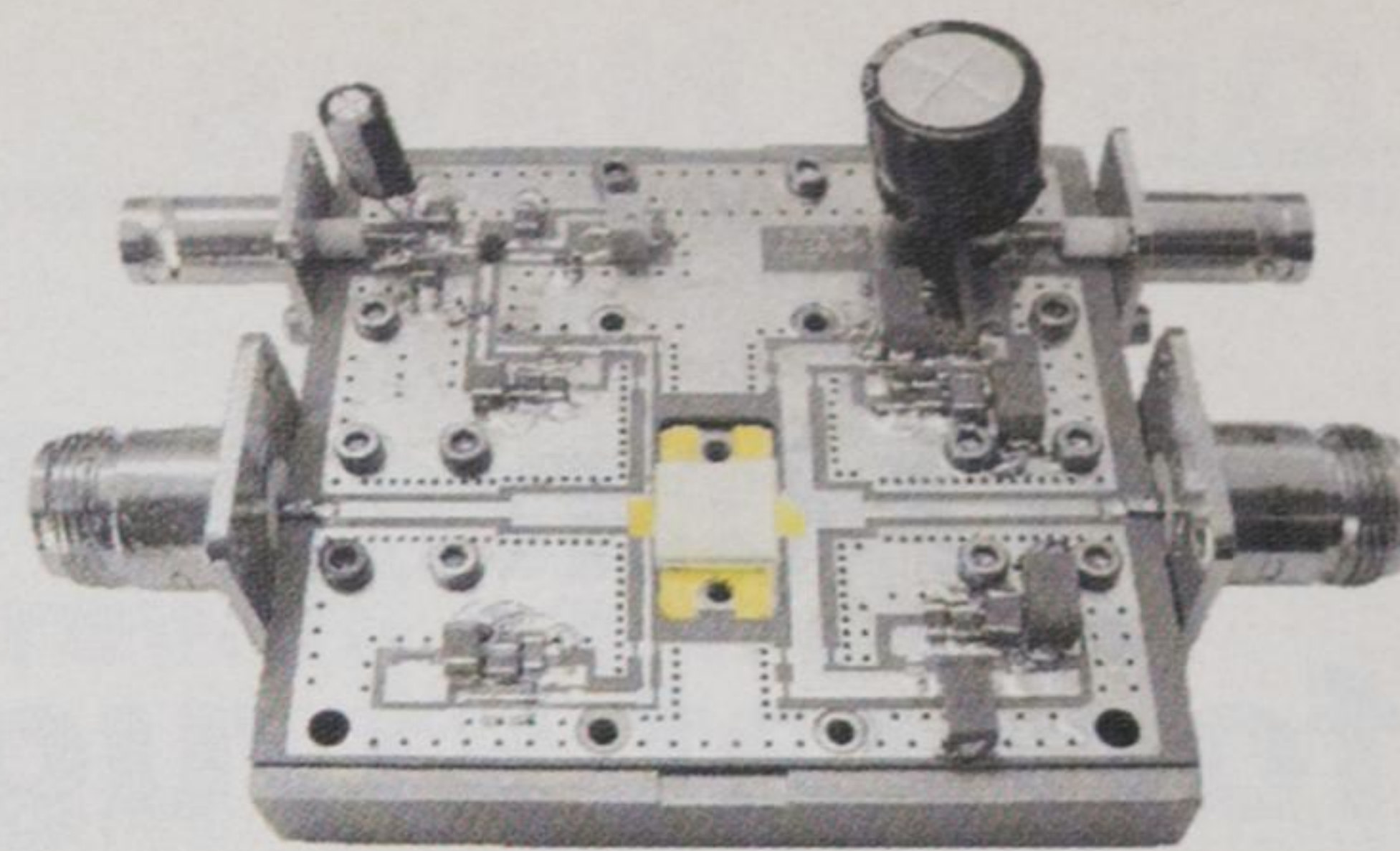
Tekcore is said to be using JP Sercel Associates (JP SCA) laser wafer scriber to process its 4 inch LED wafers.

Laser scribe supplier JP Sercel Associates (JP SCA) says that it has developed and proved the capability to scribe 4 inch LED wafers.

The larger format is expected to be the platform for the next-generation production of many LED manufacturers. According to JP SCA, the Taiwanese company Tekcore recently introduced the 4 inch format. Tekcore makes mainly high-brightness blue, cyan, green and ultraviolet LED chips.

The scribe utilizes JP SCA's diode-pumped solid-state laser system, which is claimed to combine high-speed wafer scribing with high yields and very low operating costs.

Scribing of 4 inch wafers can be difficult owing to handling and bowing issues, claims the Hollis, NH, company. JP SCA says that its process involves scribing a wafer that is held precisely in a vacuum fixture to correct wafer bowing consistently to within a few microns.



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DVD camps continue war of words as format struggle enters critical period

Matsushita Electric says that early next year it will mass-produce Blu-ray Disc drives based on GaN lasers for both notebook and desktop PCs. The drives will be sold through its Panasonic electronics brand.

Sample shipments of the recordable drives, which are the first of their kind to be released, are said to have already begun. Volume production of drives for use in desktop PCs will begin in January 2006, while production of the slimmer notebook version of the technology is expected to follow in March.

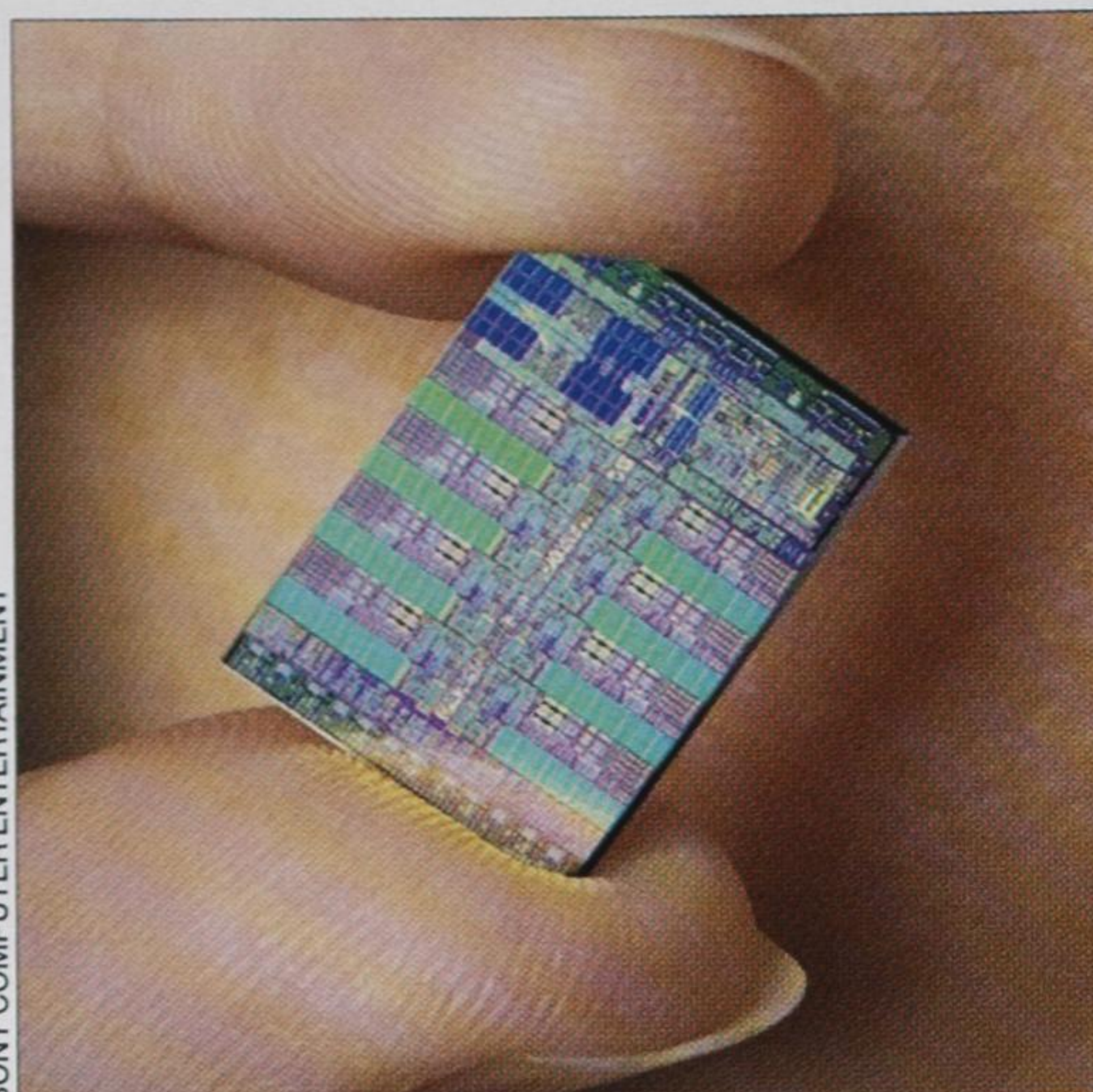
The Panasonic notebook drive features a glass-plate prism that is said to reduce the size of the optical pick-up housing the blue-violet laser by a factor of 12. And while previous incarnations of the Blu-ray format have featured a cartridge that is unlike today's CD and DVD technology, a new "bare disc" has been developed for use with the slimline drives.

Leading PC maker Dell, which is a key partner in the Blu-ray Disc Association (BDA), plans to promote the 50 GB drives through its desktop and notebook range of PCs.

Recent announcements that Microsoft and Intel support HD-DVD, as well as the news that the Warner Bros movie studio is to join the BDA board of directors, sparked a war of words between the two camps.

First, Matsushita and its collaborators in the BDA hit back against "inaccurate information" spread by Intel and Microsoft that the rival high-definition format is superior to Blu-ray.

In a statement, the BDA stressed that Blu-



The Cell processor chip (above) will be at the heart of Sony's PlayStation 3 games console, along with a next-generation DVD drive featuring GaN-based blue laser technology. However, developing a high-yielding process is proving to be a difficult step for all GaN laser manufacturers.

ray's read-only and recordable storage capacity were much greater than that of HD-DVD, that its content protection system was identical, and that Blu-ray players were backwards-compatible with CD and DVD formats.

Then Toshiba issued a statement to clarify Warner Bros' position, stating that the studio, which distributes the largest film library in the industry and also owns the New Line Cinema and Home Box Office (HBO) brands,

continued to support HD-DVD.

In what looks like being a critical period in determining the eventual winner of the next-generation format war, another movie studio, Paramount Pictures, is widely reported to have swung behind the BDA. Having previously only pledged support for HD-DVD, the Viacom-owned company is, like Warner Bros, saying officially that it supports both groups.

Toshiba said in a further statement that it was still collaborating with Paramount, and that the lower cost and greater productivity would ultimately favor the HD-DVD format over Blu-ray.

"Once HD-DVD comes to market at the end of 2005 in Japan, and early next year in the US as planned, it will not take long to know which format really delivers the benefits of high definition to the consumer," said Toshiba. "In terms of development, HD-DVD is far in advance of Blu-ray."

BDA champion Sony is now expected to mass-produce GaN-based lasers in spring 2006. *Compound Semiconductor* learnt that production of the devices will be ramped to meet demand for the company's PlayStation 3 games console, which was originally due to launch in May next year. However, this launch now appears likely to be delayed.

Fabrication of GaN lasers on sapphire substrates has been plagued by low manufacturing yields of around 2%, although fabrication on higher-quality native substrates should improve this figure in the longer term.

UK team to develop terahertz imager

The UK's Engineering and Physical Sciences Research Council (EPSRC) has initiated a four-year project to develop portable terahertz devices based on InP semiconductors.

The £1.2 million (\$2.1 million) PORTRAIT program is led by principal investigator Ian Henning from the University of Essex. It also features the Centre for Integrated Photonics (CIP), where the InP components that are crucial to the work will be fabricated.

At CIP, the team will be able to draw on many years of experience in fabricating optoelectronic InP technologies that have been

developed for optical communications.

That technology is set to be adapted to produce a new generation of battery-powered "torches" and "cameras" that operate in the terahertz region of the spectrum, which sits between the infrared and microwave bands.

The terahertz band is useful in applications such as medical imaging, chemical analysis, security and astronomy, largely because many common materials are transparent at terahertz frequencies.

The main drawback is the difficulty associated with producing terahertz radiation, currently done by aiming high-energy laser pulses at semiconducting materials.

This method has proved sufficient for medical applications, where bulky imaging equip-

ment is expected, and has allowed pioneering companies such as Teraview to commercialize imaging systems. The Cambridge, UK, firm is also involved in the project.

However, a much more compact source is needed to make the technology cheaper, more versatile, and to widen the range of applications that it is suited to.

"Making the devices small, low power and portable will allow people to use terahertz radiation in applications like airport security, to look for pollution, and even to be used in a pharmacy or a doctor's surgery to help with diagnosis," predicted the team.

The project also involves the University of Bath, the National Physical Laboratory, and University College London.

Princeton plans to launch cryptography detector

Chip manufacturer Princeton Lightwave (PLI) has licensed single-photon detector (SPD) technology developed by IBM for use in highly secure optical communications.

The Cranbury, NJ, company plans to combine the SPD with its own InGaAs/InP avalanche photodiode that was launched last month. By doing this, PLI believes that it can become the first commercial supplier of single-photon detectors for so-called quantum cryptography systems.

Bruce Nyman, PLI's vice-president of System Solutions, told *Compound Semiconductor* that the company already had some interested customers, and that it planned to ship products based on the combined technology early next year.

PLI will develop a fiber-pigtailed version of its own avalanche photodiode, and integrate it with IBM's circuit-board-based SPD.

According to Nyman, the IBM SPD features a transient-canceling circuit technology that provides exceptionally high-speed, low-noise detection of single photons at 1.5 μm – a key requisite for quantum cryptography.

While quantum cryptography has long been considered a viable method for providing "uncrackable" communications, the application is in its infancy as far as commercial deployments are concerned.

Invented in 1984, quantum cryptography takes advantage of the quantum physics of light. In theory, it enables two users to communicate securely over a normally insecure channel such as regular optical fiber.

Nyman believes that the method, which is expected to be used by government and financial institutions initially, will eventually find widespread use. "This [SPD] is a key piece of the enabling technology," he said.

Bookham's figures reveal cash boost

Bookham posted increased revenue figures and a substantial improvement to its cash position for the financial quarter ending October 1.

The InP chip maker netted \$62.6 million in sales, a year-on-year increase of 44% largely due to the new supply agreement with key customer Nortel.

Increased output from Bookham's Chinese test and packaging site, and UK staff cuts are helping the company get nearer to financial break-even. Bookham reported a net loss of just \$0.5 million, which included a one-time tax break of nearly \$12 million relating to a sideline in aircraft leasing.

Following that tax break and a recent sale of land in the UK, the company's balance sheet now shows \$43 million in cash and cash equivalents, up from \$32.3 million just three months ago. And the balance sheet will receive a further boost thanks to Bookham's latest public offering of stock, which raised approximately \$50.2 million.

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SatCon selects SiC for power converter

SatCon Technology Corporation, a US-based company that is developing power electronics systems based on wide-bandgap technology, is working on a 100 kW SiC inverter design for use in the electrical grid.

According to president and chief operating officer Millard Firebaugh, SatCon's SiC developments should help to produce smaller, lighter, more robust power converter electronics. "[This] is important for all applications and is certainly the case for utility-scale energy storage systems, where round-trip efficiency, system reliability, volume and weight benefit directly," said Firebaugh.

The inverter module is being developed under a program sponsored by the Department of Energy, while the defense industry is also showing an interest. The US Army has awarded SatCon funding under a phase 1 small business innovation research (SBIR) project covering high-temperature packaging technology for SiC semiconductors.

Oki's GaN HEMT delivers record transconductance

Oki Electric says that its latest GaN HEMTs on silicon substrates with dramatically improved amplifying characteristics have closed the performance gap with their rivals fabricated on SiC.

The transistor delivers maximum oscillation frequency ($f_{\max}$) of 115 GHz and a record transconductance of 350 mS/mm. And because it is fabricated on a silicon substrate instead of SiC, the manufacturing costs are said to be reduced by 50%.

"By enhancing the output of transistors based on this technology, we can contribute to the acceleration of WiMAX and next generation wireless communication systems," said Harushige Sugimoto, Oki Electric's chief technology officer. The company plans to start volume shipments of these products in 2007.

As well as the record transconductance, the latest devices work at significantly higher fre-

quencies, comparable to HEMTs produced on SiC. Previous GaN HEMTs on silicon typically had $f_{\max}$ values of only 70–80 GHz, claimed Oki.

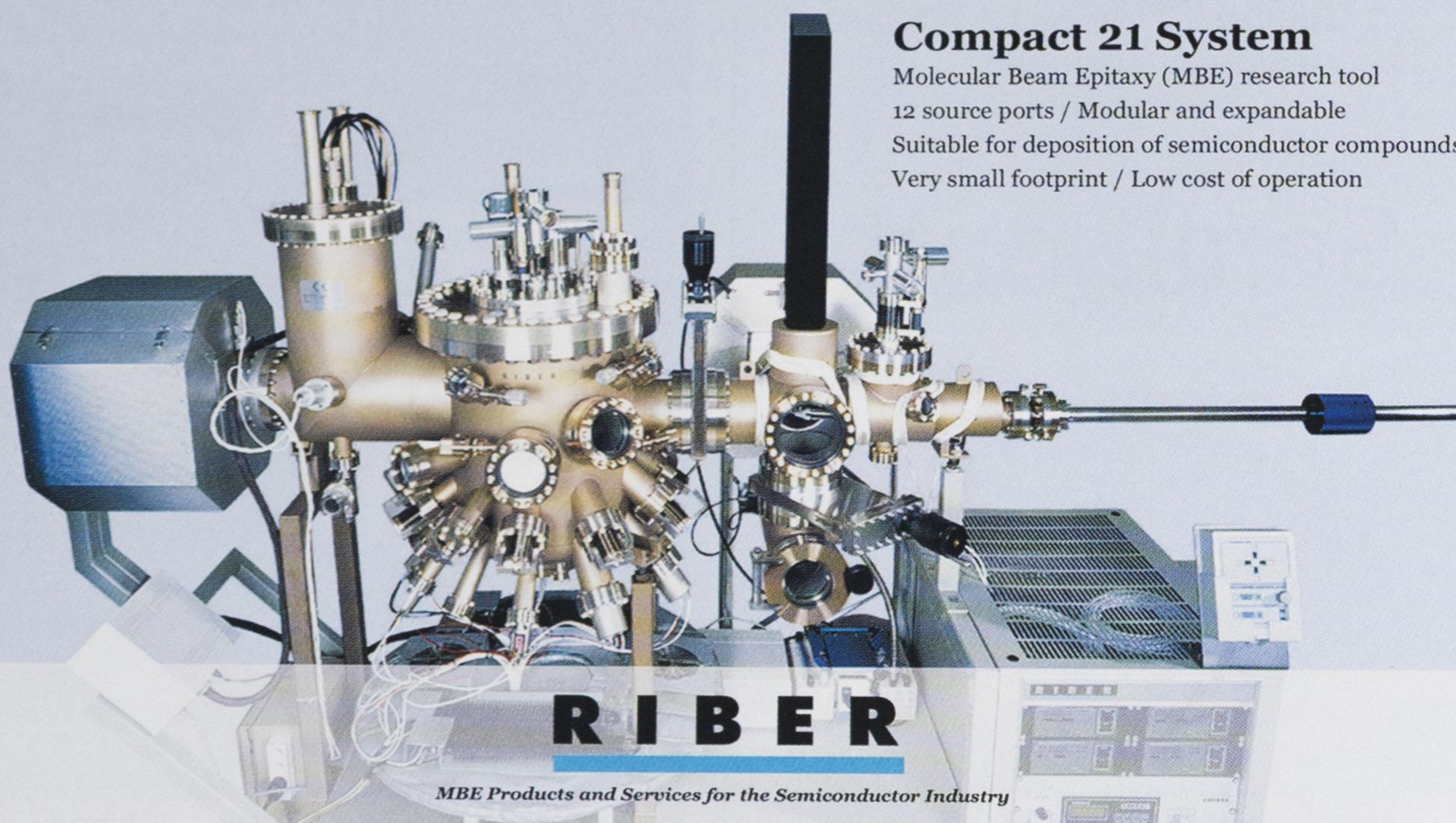
The Japanese company says that the increased performance results from improved crystal growth technology for GaN on silicon, which produces higher electron mobility, and ultimately a better designed device.

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Finally optical component makers dare to dream again

Whether it was 40G, tunable lasers or storage-area networking, optical-component vendors were in resurgent mood at the recent European Conference on Optical Communications. **Tami Freeman** and **Joe McEntee** conclude that the next year holds many opportunities for innovative suppliers.

Iron-grey skies, driving rain and chilly north winds served up a gloomy backdrop for the 3000 and more hardy souls who made the trip to Glasgow in late September for the 31st European Conference on Optical Communications (ECOC). But this is 2005, and not the darkest days of the telecoms bust. If conditions were less than hospitable on the outside, the same could not be said for the busy halls of the Scottish Exhibition and Conference Centre, where upbeat exhibitors and delegates contributed to the most constructive, forward-looking ECOC since the telecoms industry went into freefall four years ago.

After 18 months of gradual recovery and careful repositioning, it seems that fiber-optic component and subsystem companies are daring to dream again, factoring long-term growth and credible opportunities back into their strategic thinking. That was certainly the line being pushed by Tom Hausken, lead analyst at US consultancy Strategies Unlimited. "Finally, after all these years, we see an uptick in [wireline] capital expenditure; this year it looks like it'll be up by 10 or 15%," he told delegates at KMI's European Conference on Optical Networking Markets, a pre-ECOC seminar in central Glasgow.

That uptick is significant because fiber-optic component revenues are tracking carrier capex, with sales of components in 2005 up significantly on 2004. Hausken added: "So far, it [component revenue] looks like it'll be up by about 13%. Expect steady, repeated growth of that kind in 2006."

Adding to that feelgood factor, the ECOC trade show saw the resurgence of several technologies initiated way back in the heady days of the photonics boom and now finally coming to fruition. For starters, Intel, US, announced that Fujitsu has adopted its full-band tunable laser for use in next-generation 300-pin tunable transponders. According to Bob Zona, director of marketing for Intel's optical-platform division, this deal is repre-



More than 300 companies exhibited at ECOC, including dozens of optical component manufacturers, while the technical conference attracted more than 1000 delegates.

sentative of the increasing demand for tunable lasers across the industry.

The tunable transponders will incorporate Fujitsu's lithium-niobate modulator and Intel's TTX19907 integrable tunable-laser assembly. Zona says that Intel has been working on design-ins with systems vendors over the last 12-18 months. Last year, the projects moved out of the qualification phase and into

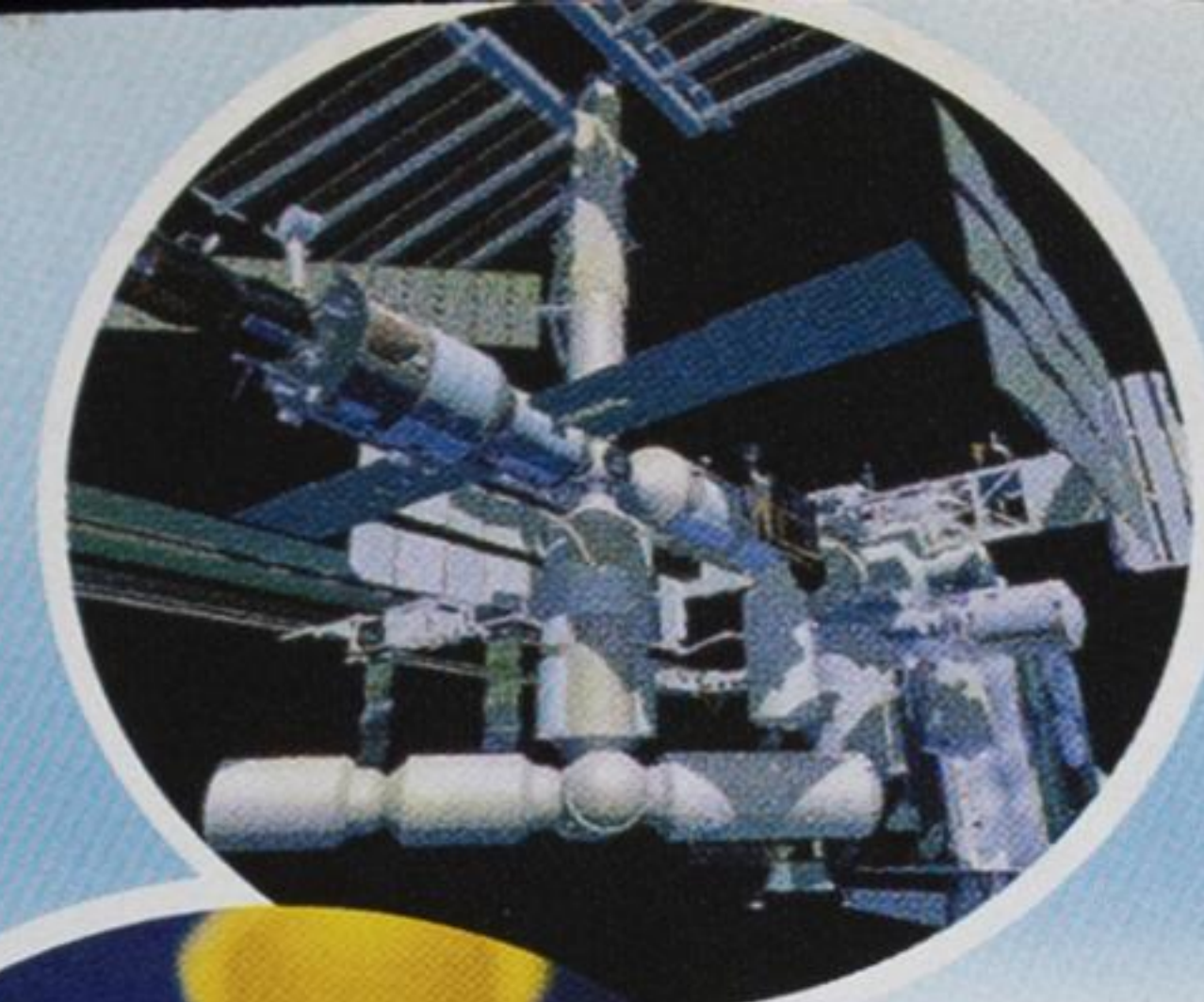
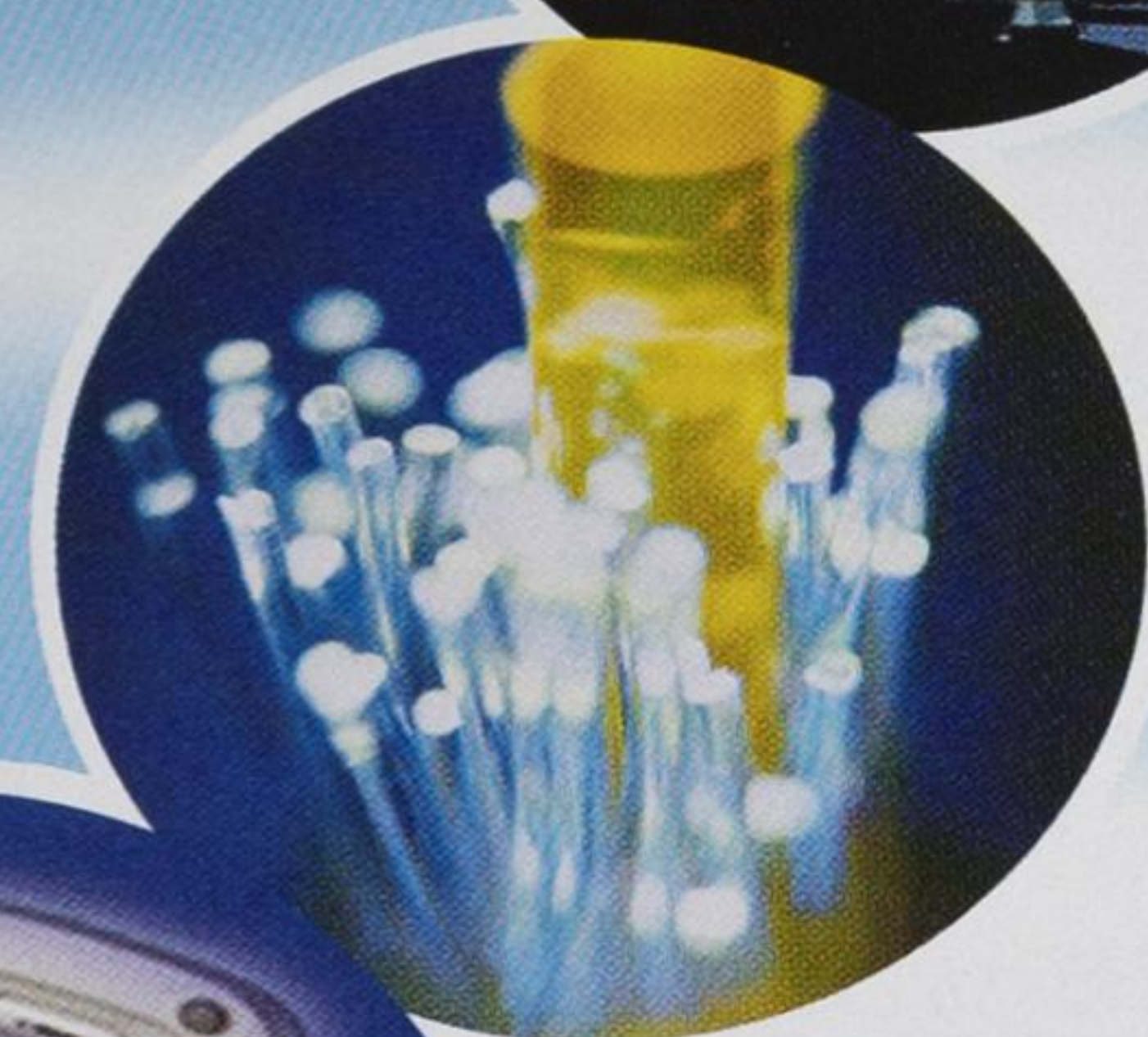
"We see an uptick in [wireline] capital expenditure; this year it looks like it'll be up by 10 or 15%."

TOM HAUSKEN
STRATEGIES UNLIMITED

production, with Zona claiming that the technology is now "ready for primetime". One reason for the increased acceptance of tunable lasers, he says, is the big reduction in the price difference between tunable and fixed-wavelength lasers. Intel's TTX19900 C- and L-band thermally-tuned lasers are available at a unit cost of \$2500. The lower cost was achieved, in part, by the use of innovative packaging to ease the manufacturing process.

Meanwhile, InP foundry and component maker Opnext exhibited a fully tunable 300-pin transponder, the TRV709A. Ed Cornejo, the US vendor's director of product marketing, also noted that the demand for tunable devices is on the up.

According to Cornejo, another technology that is increasing in popularity is 40 Gb/s, driven in part by new deployments of voice-over-IP and IPTV services. Opnext had its



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40 Gb/s 300-pin transceiver on show. The device offers a power consumption of just 20 W, achieved using direct modulation of the laser to lower the cost and the power budget. Opnext's customers are now qualifying its 40 Gb/s products. "It's still a couple of years away in terms of real demand for deployment," Cornejo said. "It'll take price erosion before that happens."

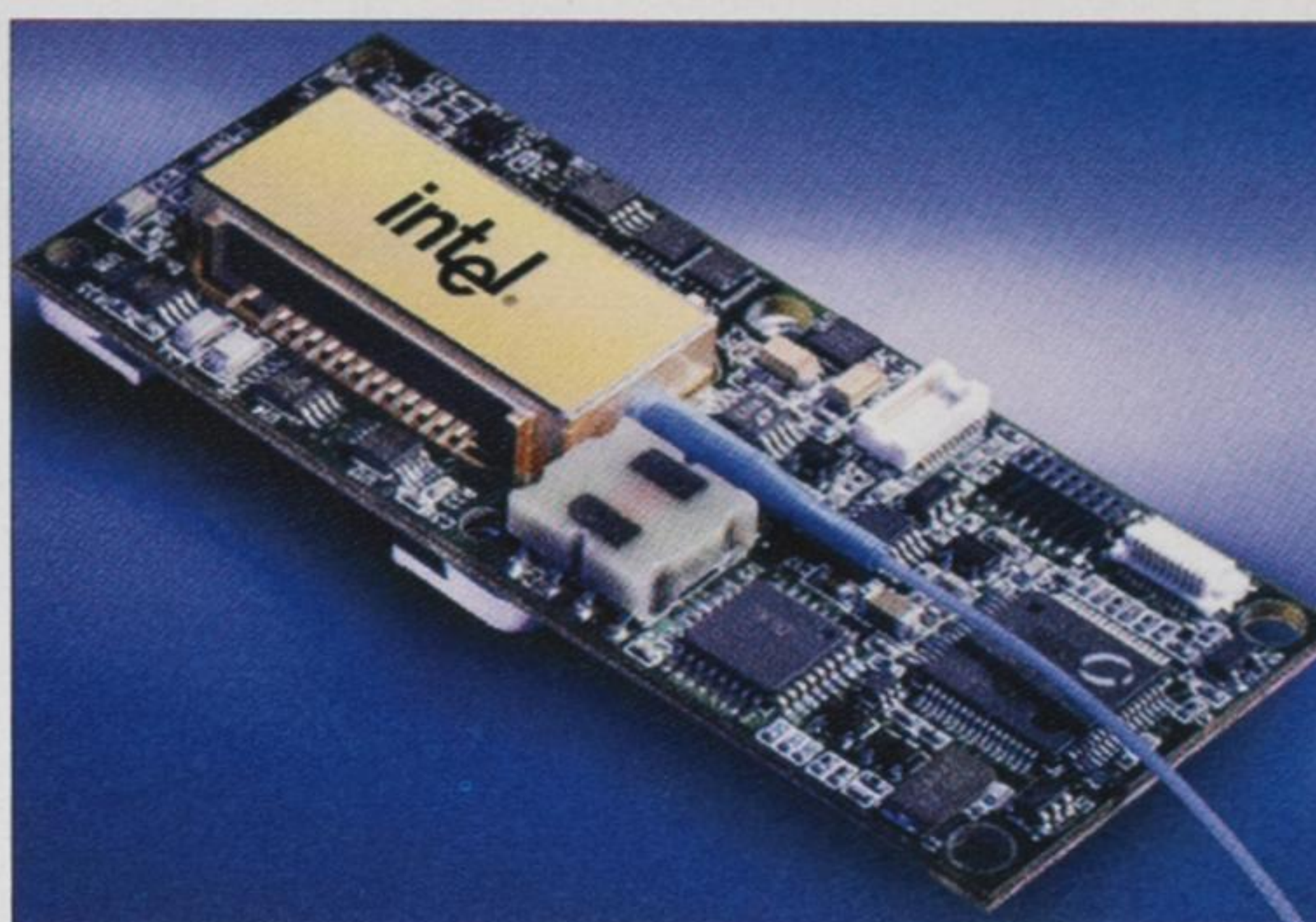
Neil Weston, vice-president of sales and marketing at the Centre for Integrated Photonics (CIP), UK, reckons that the last year has seen a resurgence of interest in 40 Gb/s technologies. "The big component and systems houses are asking for 40 Gb/s devices, while a year ago they were concentrating on 10 Gb/s." At ECOC, CIP was showcasing its latest optical-networking components for 10 and 40 Gb/s applications. Its 2R regenerator, for example, enables the optical regeneration of 40 Gb/s signals. Based on a combination of silica-on-silicon planar waveguides and InP semiconductor optical amplifiers, the device compensates for attenuation, polarization-mode dispersion and other impairments that can cause big headaches at ultra-high-speed data rates.

Clearly, with many of the 40 Gb/s technology issues now solved, it might not be too long before 40 Gb/s platforms – or indeed advanced devices such as tunable lasers – really make their mark in optical networks.

Innovation at ECOC

Hitachi-backed Opnext also revealed details of three new laser diode products for applications ranging from barcode scanning to medical equipment, while in the technical conference its researchers detailed a new short-cavity distributed Bragg reflector laser that should lead to smaller 10 Gb/s modules. The developmental 1310 nm edge-emitter is based on InGaAlAs technology.

Long-wavelength lasers of the vertically-emitting kind provided another talking point in Glasgow, as Danish company Alight announced that it had acquired the dilutenitride VCSEL technology previously developed and owned by Infineon Technologies. Alight has already begun integrating the structures with its own proprietary photonic bandgap approach, which should result in high-power singlemode VCSELs emitting at the longer wavelengths that are crucial for long-distance transmission of data over fiber. Alight is aiming to manufacture the devices commercially using an MBE reactor installed at an unspecified foundry location.



Intel's tunable lasers cover all channels in the C- or L-band, with an optical output power ranging from 7.0 to 13.5 dBm.

Among the other companies to be showcasing long-wavelength VCSELs was Korean chipmaker RayCan, whose 1550 nm and 1310 nm sources are based on InP. The company has traditionally served only domestic customers, but is now planning to sell its VCSELs internationally.

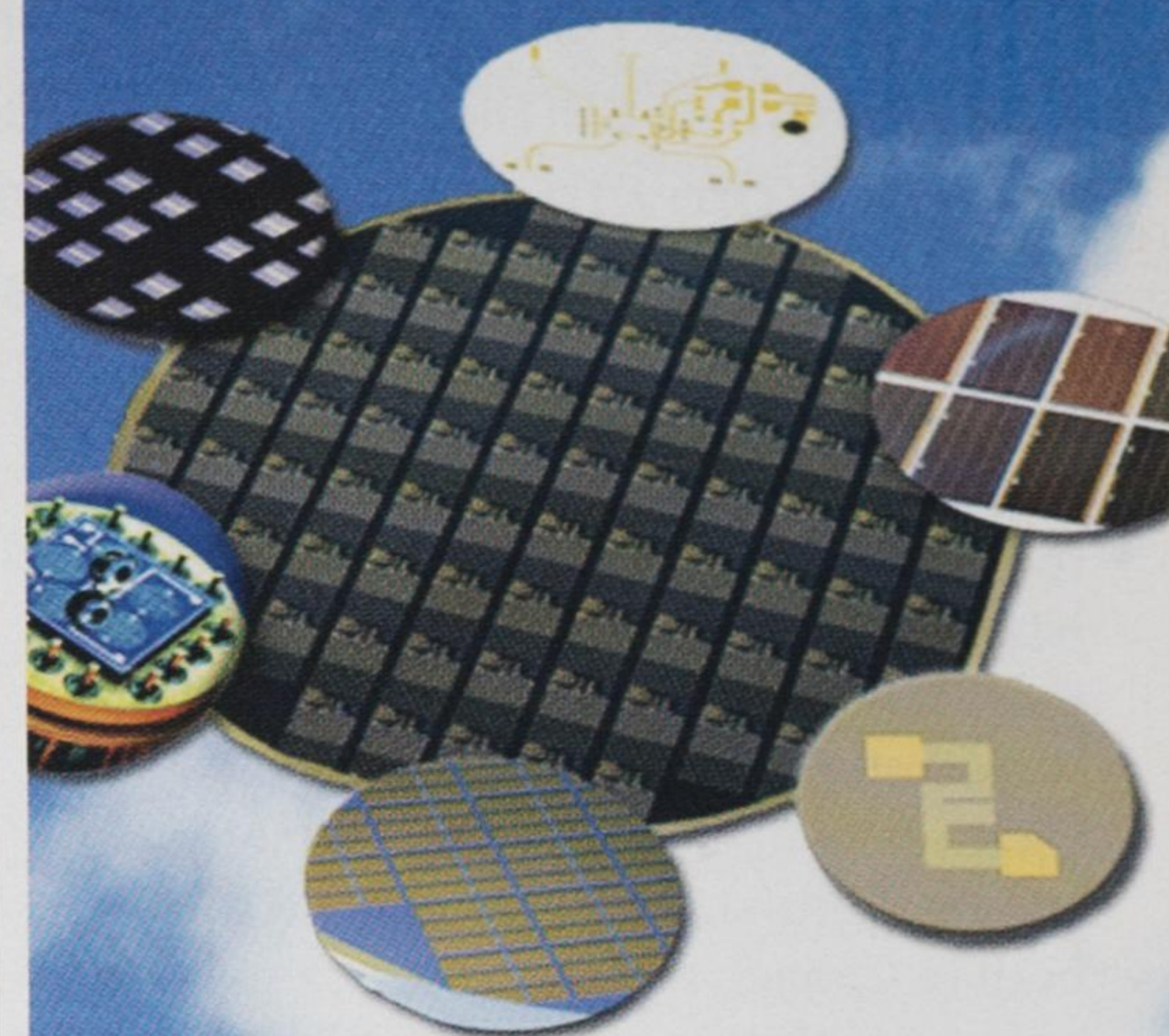
In the technical session on semiconductor laser diodes, research at the Japanese company NTT showed how doping an InP-based buried heterostructure device with ruthenium instead of iron improved some operating characteristics. Doping with ruthenium reduces interdiffusion between the doped and active layers, improving the crystal quality of the quantum wells. This resulted in higher output power, especially at elevated temperatures, said the NTT team.

Meanwhile, researchers at Germany's Heinrich Hertz Institute (HHI) described a "curved stripe" 1550 nm distributed feedback laser that allowed uncooled 10 Gb/s operation at 90 °C in a high-yielding process. HHI was also involved in the manufacture of a quantum dot VCSEL structure designed by NL Nanosemiconductor that had a threshold current of just 200 μ A – described as "thresholdless" by the research team. NL Nanosemiconductor believes that the 1300 nm lasers could be useful for 40 Gb/s datacom applications, which it expects to see deployed widely in around five years.

But perhaps the most encouraging aspect of this year's ECOC was this: all of the new product activity, along with the upbeat projections, suggests that ECOC 2006 in Cannes will see the optical communications industry finally freed from its downturn nightmares. ●

A version of this article originally appeared in the October 2005 issue of Fiber Systems Europe. Additional reporting by Michael Hatcher.

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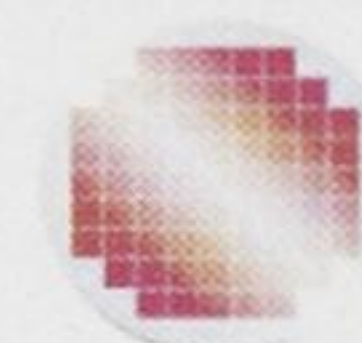
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Photonics foundry reinstat

The Canadian government has invested C\$43 million in building a compound semiconductor fabrication facility that it hopes will drive the growth of start-ups and small businesses. **Richard Stevenson** talks to the facility's director, Sylvain Charbonneau.

The opening of the Canadian Photonics Fabrication Center (CPFC) in Ottawa in May 2005 re-established III-V chip making in Canada, which has been absent since Bookham exported its production line to the UK in 2003.

According to the CPFC's director, Sylvain Charbonneau, the center will enable small- and medium-size enterprises and start-ups, both in Canada and overseas, to grow their business. "If you are just starting and need access to a III-V foundry service, unless you have a large amount of money it is difficult to make a prototype device," he said.

Although Canada is well known for its photonics technology, the loss of local III-V fabrication facilities in recent years has hampered the development of smaller firms. They have been unable to work with the larger fabs in the US, the UK and Asia, which are concentrating on their own products. The CPFC aims to help smaller companies and venture capitalists (VCs) to "de-risk" their investments, although any high-volume orders involving thousands of wafer starts per month would require a bigger foundry.

Infrastructure

The CPFC has its own staff and equipment housed in 40 000 ft² of lab and office space, as well as an 11 000 ft² "class 100" and "class 1000" clean room. The facility has a multi-wafer MOCVD reactor that can produce InP- and GaAs-based epiwafers up to 6 inches in diameter, various deposition systems to produce silica and SiN layers, and lithography, metallization and etching equipment. The CPFC can dice or cleave wafers but it does not offer a packaging service.

"I want to stress that very little research is done in the CPFC. It's development or prototyping, and really manufacturing," said Charbonneau. He believes that research expertise would be lacking if it were not for the CPFC's strong link with the Institute of Microstructural Studies (IMS), of which he is also a director. The IMS has 20 years of experience in developing hardware for information

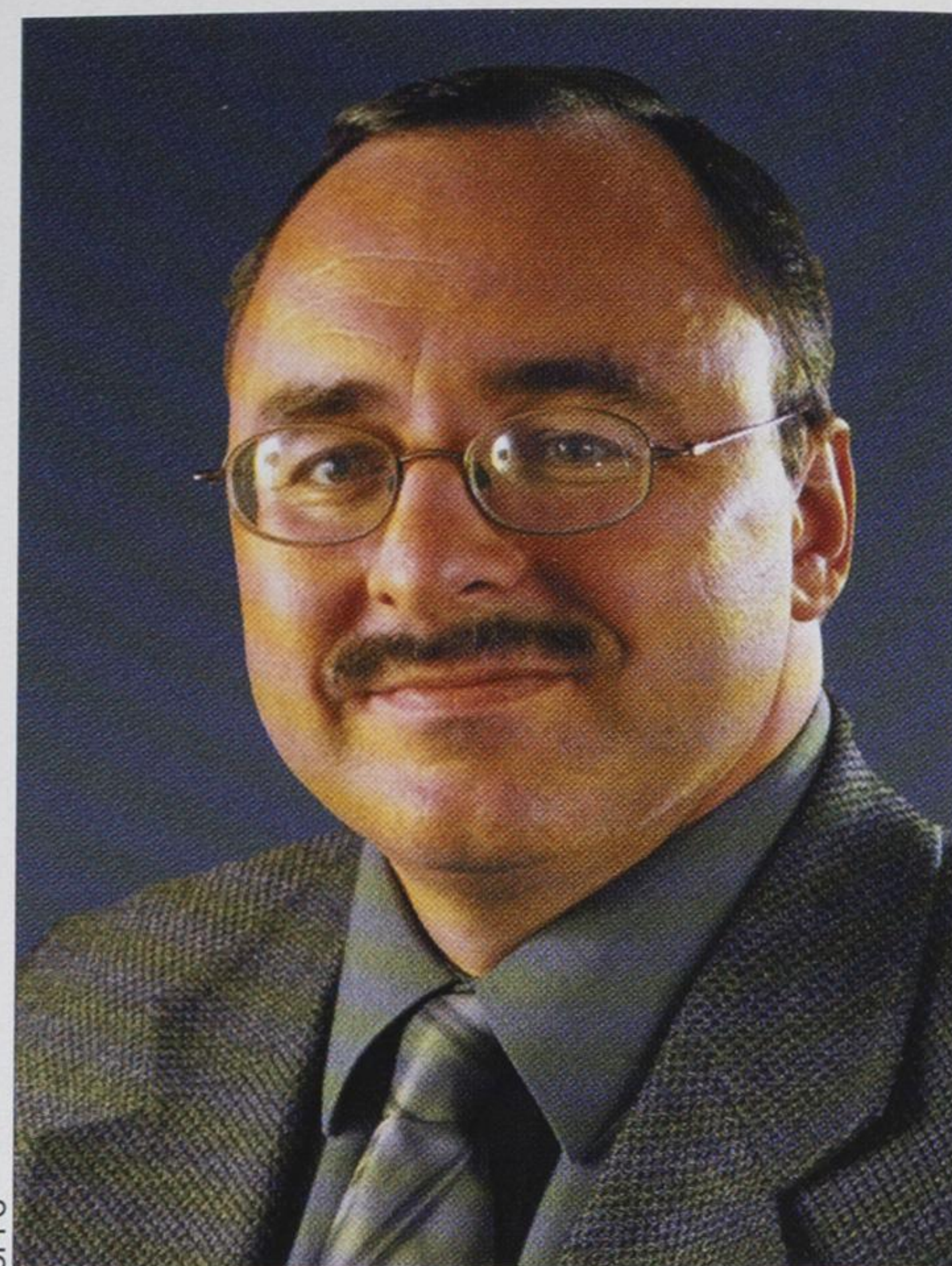
technology, and numerous pieces of equipment are available to CPFC's engineers, including electron-beam apparatus for lithography, a secondary ion mass spectrometer, an Auger X-ray photoelectron spectrometer, and various electron microscopes.

The C\$43 million (\$36.4 million) funding from the province of Ontario and the Canadian government has been used to build the infrastructure and purchase equipment and consumables. "We were quite aggressive in taking advantage of other people's demise," admitted Charbonneau. Five years ago it would have cost more than C\$150 million to build and equip the facility, but the CPFC was able to buy equipment at vastly reduced prices from the firms that exited chip production in the wake of the telecoms bust.

The CPFC has also benefited from hiring former Bookham and Nortel employees, says Charbonneau. He claims that this will enable the facility to distinguish itself from other competitors because these engineers know how to run a commercial fab, while those at IMS are motivated by academic publishing and pushing the frontiers of science. "That's all very nice, but the CPFC is not about that. It's there to push the product out, so you need a certain discipline. If the client needs a certain specification, and that specification is met, the wafer goes. I know you could do better, but that's not what the client is asking. That's the discipline I'm referring to."

As a not-for-profit organization, the CPFC recoups its operating costs by charging for foundry services and licensing its technology. Income also comes from CMC Microsystems, an organization that selects and funds the best proposals from Canadian universities that want devices to be fabricated at the CPFC. Carlton University, Ottawa, which has a strategic partnership with the CPFC, also has separate funding to grow prototype structures at the facility.

According to Charbonneau, the CPFC has also directed efforts at educating VCs about the role of the facility. He explained that many



"It's imperative that such facilities exist here for Canada to be competitive."

SYLVAIN CHARBONNEAU

VCs were "burnt" when firms used their investment to build fabs. "The fabless model makes a lot more sense because VCs don't have to invest large quantities of money just to prove that the idea has commercial applications. With a few hundred thousand dollars you can find out whether the product will have traction with your customers."

Understandably, VCs are far less nervous about investing a few million dollars to develop a product at the CPFC, than investing tens of millions to construct a fab. According to Charbonneau, several million dollars of investment is enough for companies to produce their initial product, have it evaluated by their customers, and then refine it. Once the product has some customers, VCs are more generous with their money and can then fund the production ramp-up, using either CPFC's facilities or bigger foundries.

Although Charbonneau believes that the CPFC would have been beneficial five years ago, when many telecom-based start-ups were being launched, he thinks that it will be even more valuable now. "It's absolutely impera-

ates chip making in Canada



The CPFC is equipped with an MOCVD reactor that can produce InP- and GaAs-based epiwafers, deposition systems, and lithography, metallization and etching equipment.



The CPFC is located in Ottawa, Ontario, on the same campus as the Institute of Microstructural Studies, a research facility that has extensive characterization techniques.

tive that such facilities exist here for Canada to be competitive," he said. He added that there are still quite a few start-ups in Canada and the eastern US, as well as a growing number of small firms working in the environmental, health and energy sectors, that are potential customers. The CPFC's first three customers are developing solar cells, lasers for biomedical applications, and white-light emit-

ters that avoid using GaN LED technology. Since opening, the facility has also produced 1310 nm VCSELs and dense wavelength division multiplexers.

The next few years will determine whether the CPFC can promote the growth of technology companies throughout Canada and return the country to the forefront of innovative photonic chip fabrication.

CPFC draws on IMS's expertise

The CPFC benefits from the expertise available at the Institute of Microstructural Sciences (IMS), which is located on the same campus. The IMS has a track record in exploiting its research for commercial purposes. For example, it developed strained silicon in the 1980s, and this eventually led to the launch of SiGe Semiconductor, a company that posted \$20 million revenue last year.

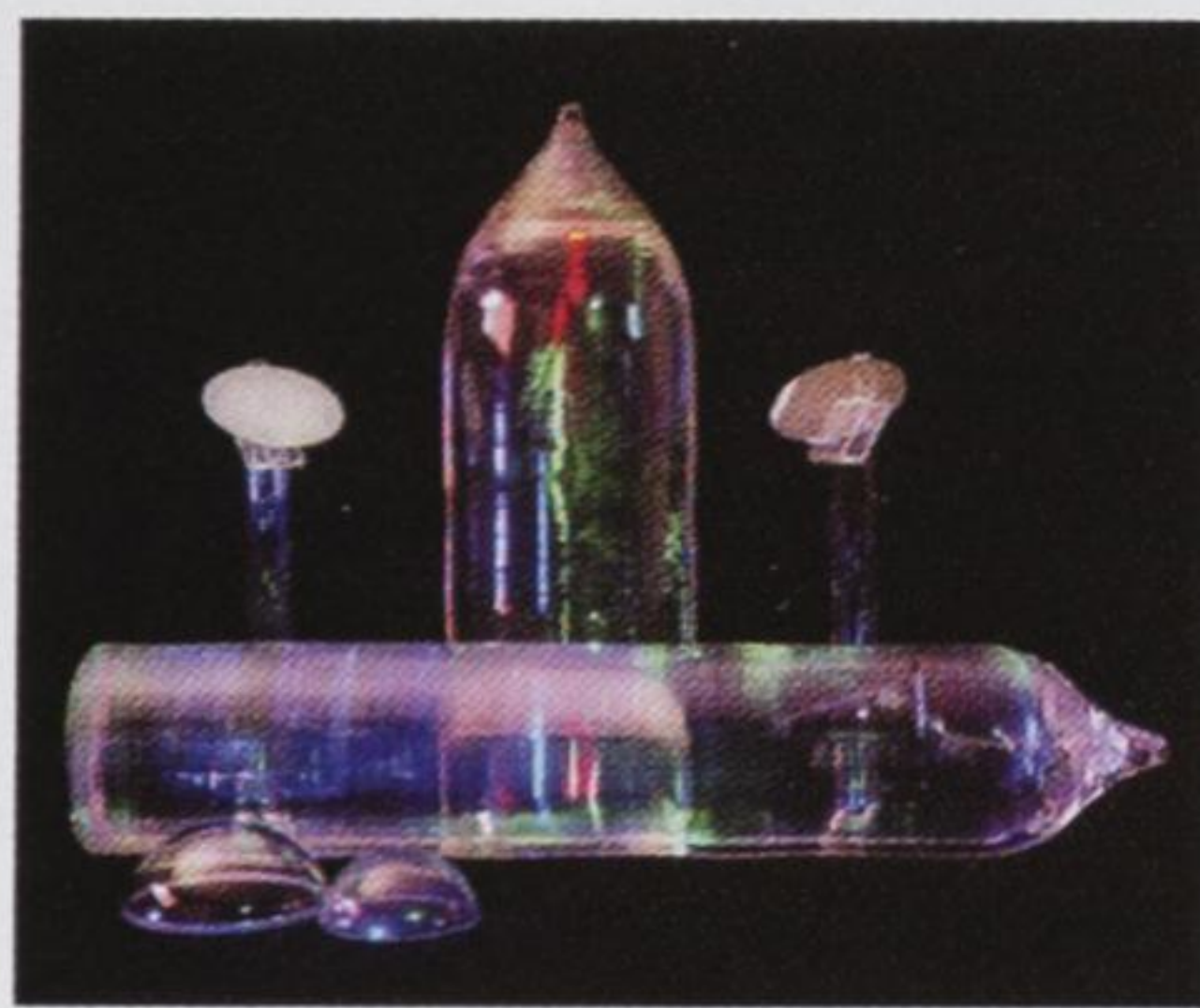
The IMS is carrying out innovative research programs with compound semiconductors, such as the development of dilute nitride lasers. The institute has recently produced the first laser diodes containing a dilute nitride active layer that are capable of room-temperature continuous-wave operation at 1.55 μm – one of the key wavelengths used in optical communications (*Elect. Lett.* **41** 1060).

These lasers use the GaInAsSb/GaNAs material system. This is more difficult to grow than the InGaAs layer that is used for the active region of many dilute nitride devices, because of complexities associated with a fifth element. However, IMS researcher James Gupta explained that incorporating antimonide (Sb) into the active region has its benefits, because this element prevents phase segregation and prevents indium from exiting the quantum well. It also increases the growth temperature window, which improves device morphology.

The IMS team used a 3 inch GaAs substrate to produce lasers with just a 5 nm variation in emission wavelength across the wafer. The high level of uniformity is achieved in an MBE reactor that is optimized by installing a port to monitor the antimonide flux, and an RF plasma source that delivers an argon and nitrogen gas mixture.

Gupta said that although the dilute nitride laser devices now have an output power of only a couple of milliwatts, changes to the waveguide design, including optimized doping levels and the use of graded-index layers, will lead to higher output powers in the future.

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Cree calls the shots at ICSCRM

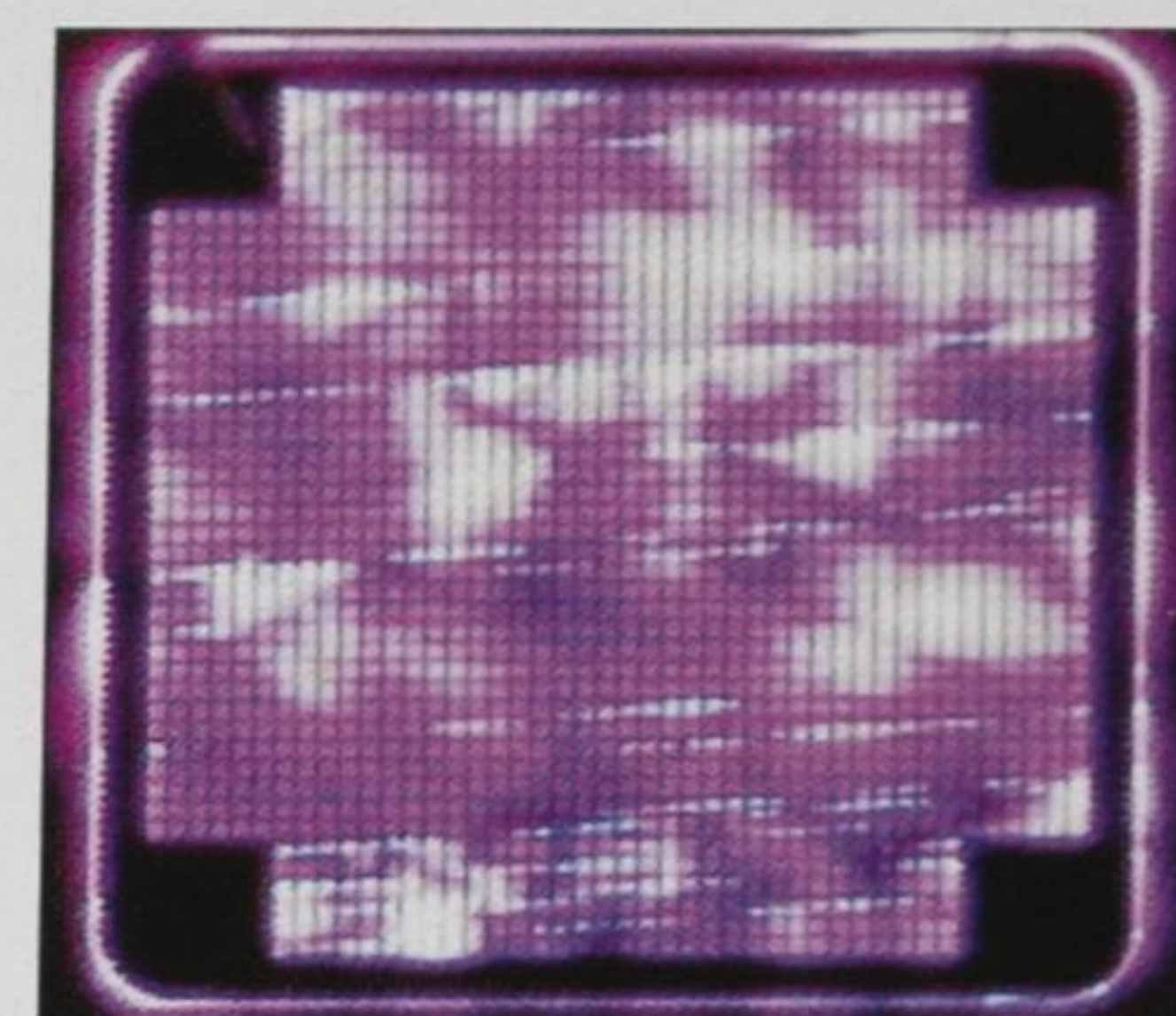
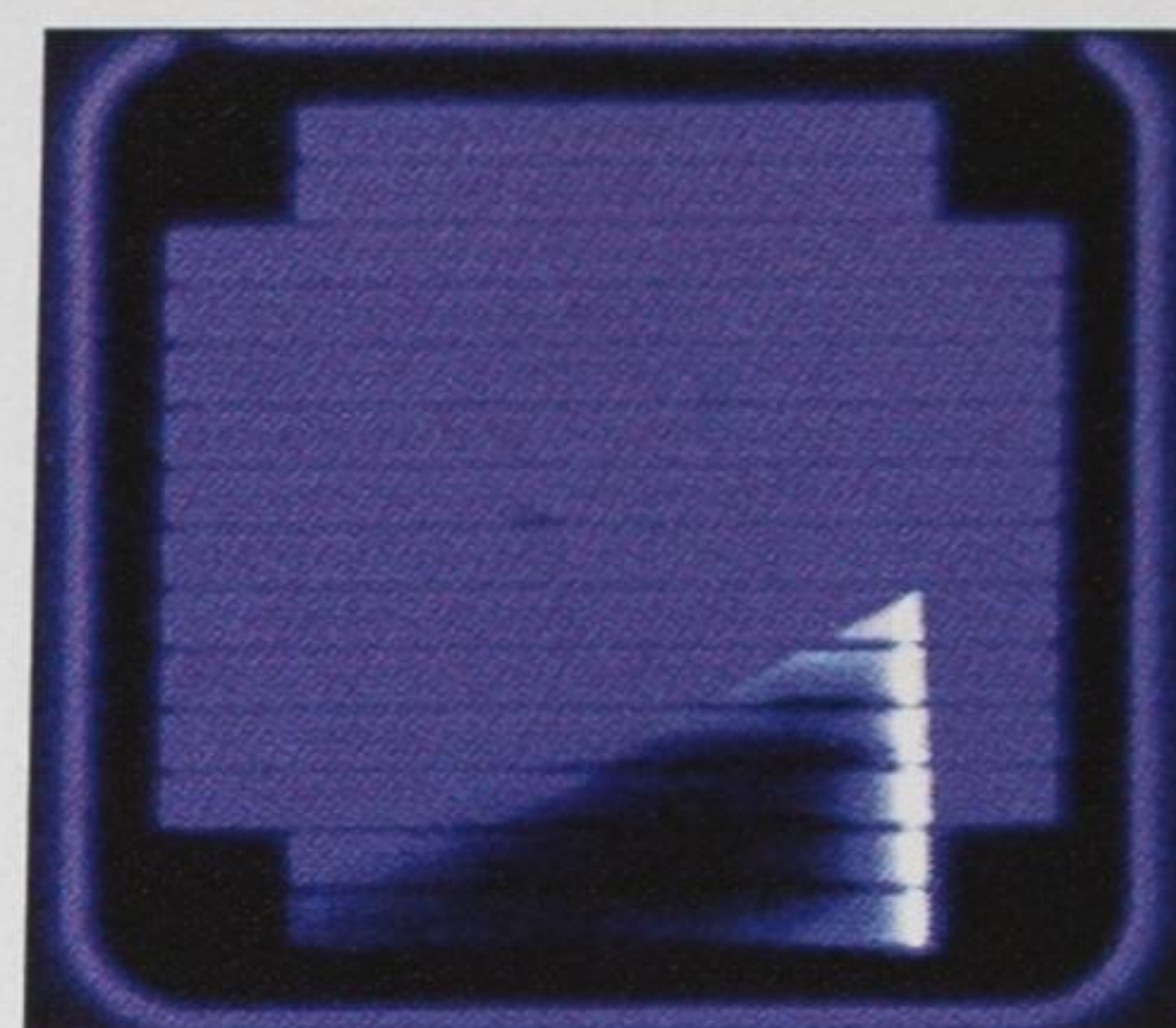
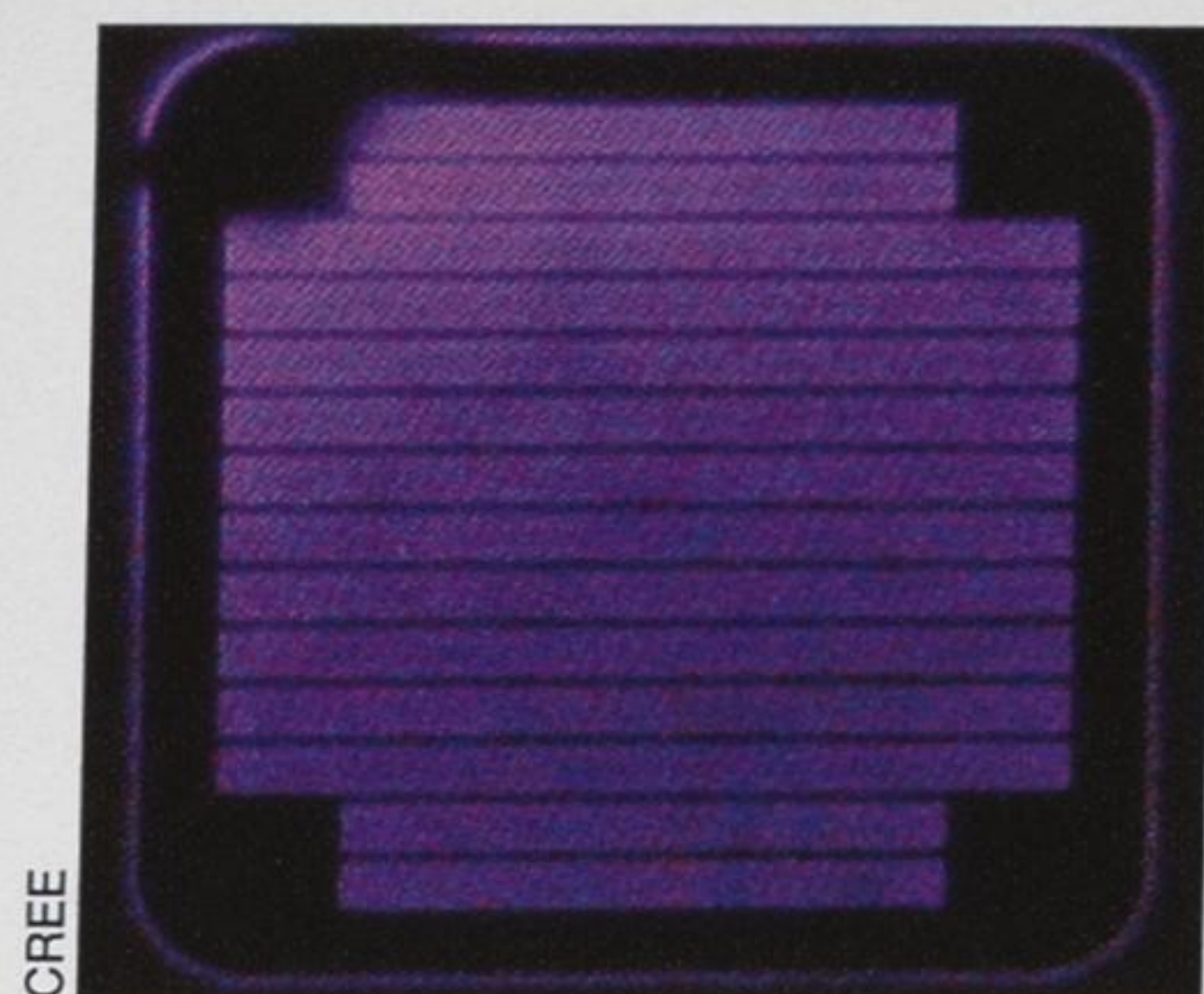
At September's ICSCRM conference Cree launched 4 inch SiC material, demonstrated how to grow high-quality epitaxial layers in larger multiwafer planetary reactors, and revealed improvements in yield that are produced by reducing basal plane dislocations. **Richard Stevenson** reports.

Cree dominated this year's International Conference on Silicon Carbide and Related Materials (ICSCRM) in Pittsburgh, PA, using the event to reveal improvements in SiC substrate production, epitaxial growth, and the performance of various devices. The company was not to be outdone on the social front either, with all 657 delegates invited to a lavish boat party. John Palmour, Cree's director of advanced materials, even managed to rally the community with an enthusiastic, up-beat message to round off the conference – that SiC could deliver global energy savings worth \$35 billion per year if these devices replaced silicon in all switch-mode power supplies and RF applications.

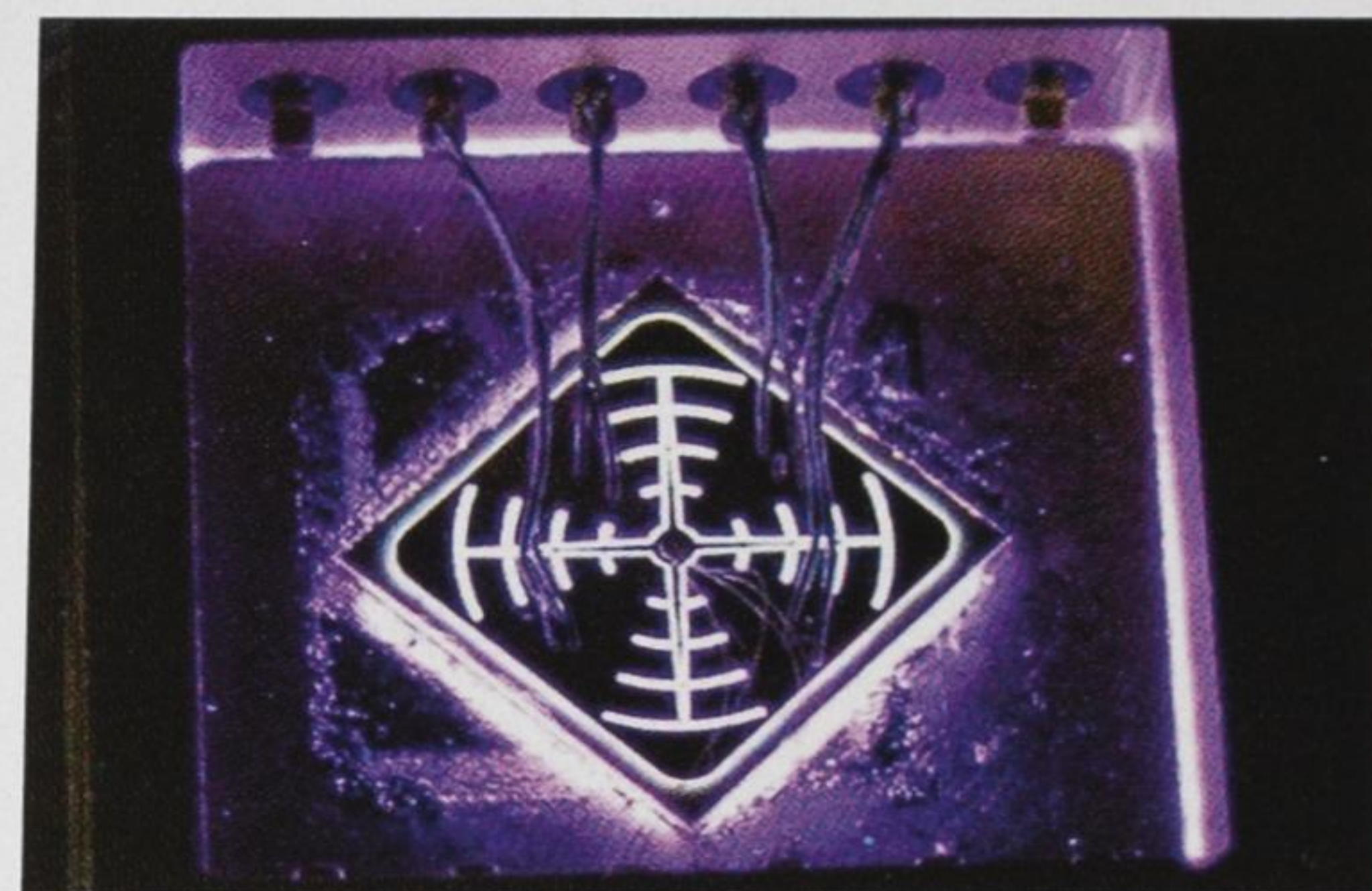
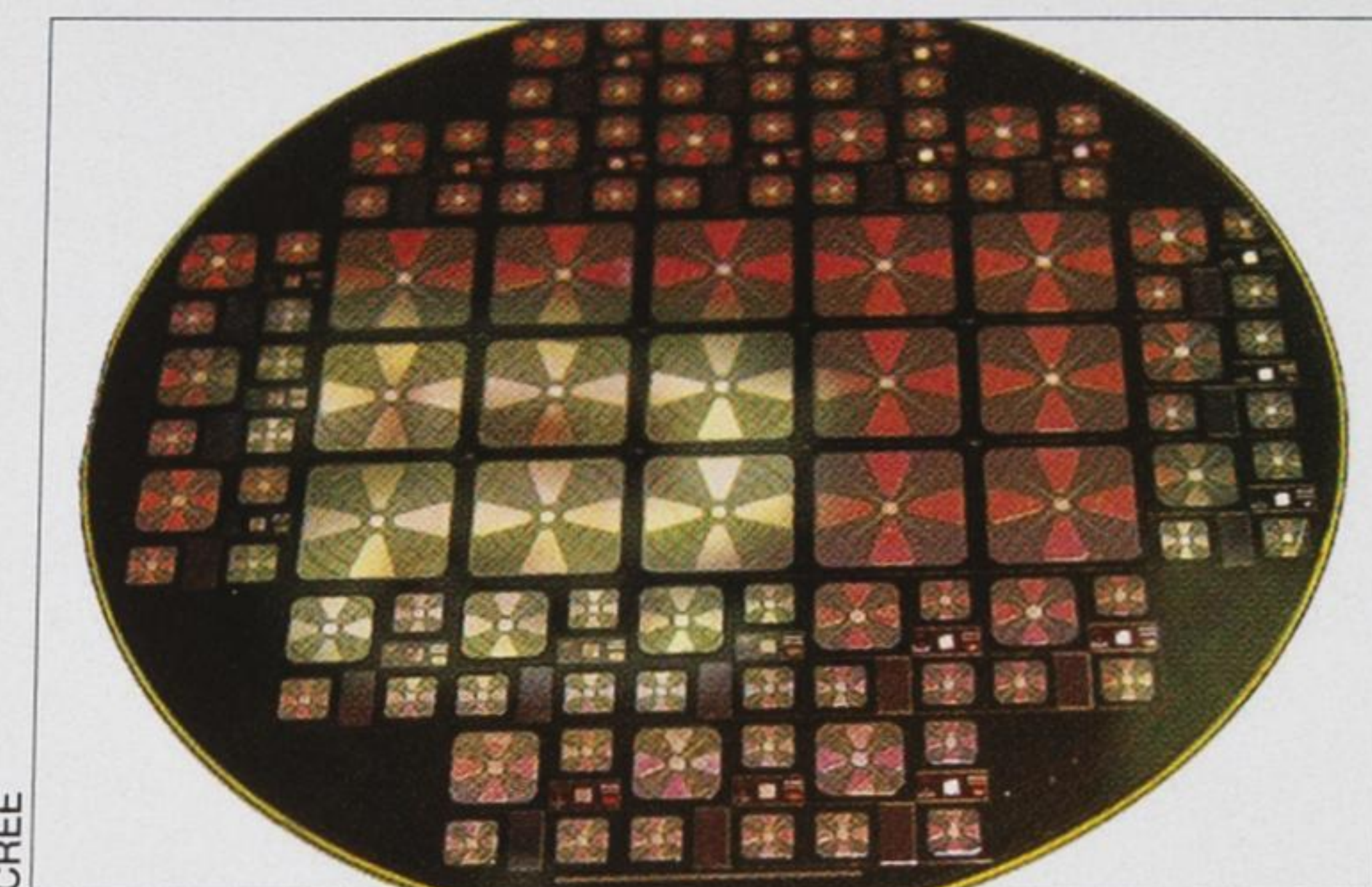
Cree also chose the conference to announce the commercial launch of its 100 mm n-type SiC substrates. According to Adrian Powell, these substrates have an average micropipe density below 20 cm^{-2} and a best value of just 0.7 cm^{-2} , with most of the micropipes located near the wafer's edge. Powell added that Cree's 3 inch material now has an average micropipe density below 2 cm^{-2} , a figure that is still falling, and that the best wafers have only two micropipes.

Affordable 100 mm substrates can only cut the cost of device manufacturing if they can be used in multiwafer reactors that deliver epitaxial layers of sufficient quality and uniformity. Al Burk showed that this is possible with a $8 \times 100 \text{ mm}$ warm-wall planetary reactor, using growth rates of $7\text{--}10 \mu\text{m/h}$. This approach has produced layers on 4H-SiC substrates with nanometer-scale surface roughness as well as uniform thickness and doping.

"We chose a warm-wall reactor because it offers the optimum combination of a hot-wall and cold-wall reactor," revealed Burk, who went on to show the results for a $6.8 \mu\text{m}$ -thick doped SiC layer grown at 1600°C . With a 3 mm exclusion zone the average variation in thickness uniformity for each 100 mm wafer, defined in terms of σ/mean , was 2%, and the difference between the thickest and thinnest wafer was $0.15 \mu\text{m}$. For a 6 mm edge exclusion zone, mercury probe capacitance-voltage measurements revealed an average doping



Cree has made progress in reducing the density of basal plane defects that cause device failure. The center and right-hand images contain areas of white emission that reveal the location of stacking faults formed at the basal plane defects in a SiC BJT's emitter region.



Cree has produced a variety of different-sized thyristors on a 3 inch substrate (left), which can be packaged to deliver blocking voltages of up to 5 kV and conduct up to 200 A (right).

variation across the wafer, measured in terms of σ/mean , of less than 8%, and a wafer-to-wafer variation of $\pm 6\%$. Burk says that these results compare favorably with other published data using reactors with a lower capacity, but he added that further improvements are still required on near-edge layer uniformity and thicker layer morphology. Run-to-run uniformity also requires more investigation.

SiC for WiMAX

Cree's many presentations contained little coverage of its commercial Schottky barrier diodes (SBDs), but Palmour did outline the performance of the newer line of commercial SiC MESFETs. The company is selling 60 W MESFETs for RF applications that require a large bandwidth, such as military radios and jammers, and 10 W MESFETs for WiMAX applications. Palmour highlighted the reliability of these devices and showed that when failure is defined as a 20% change in any parameter, MESFET reliability is 250 years for an

operating temperature of 175°C , and more than 7,000 years for 225°C . "GaN can't even come close to this in terms of reliability," boasted Palmour.

The 60 W MESFETs can be employed in broadband amplifiers to deliver 12 dB from 0.85–1.6 GHz at an average power-added efficiency of 42%, when biased at 48 V. The device linearity is 10 dB higher than that of silicon LDMOS, which ultimately leads to efficiency improvements for wireless base station transmitters.

Mrinal Das outlined Cree's development of 4H-SiC PIN diodes. The appeal of these devices is that they offer faster switching and a reduced recovery charge compared with silicon PINs, and they don't require the thick drift layers of SiC SBDs. "One problem preventing insertion into the market place is the drift in forward voltage," said Das. The increase in forward voltage is caused by the growth of stacking faults at basal plane dislocations (BPDs), which reduce the device's active area. →

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Das's colleague Joseph Sumakeris has developed two different approaches to reducing BPD density. According to Sumakeris, although the well known methods of using continuous epitaxial growth and depositing a thicker buffer layer do cut the number of BPDs, another "order of magnitude" improvement is still required. In one approach, called LBPD1, potassium hydroxide is used to etch the surface, then a 30 μm -thick epilayer is grown and the substrate is polished, to achieve BPD densities below 10 cm^{-2} . Das's alternative, LBPD2, produces BPD densities of typically 20 cm^{-2} by hexagonal lithographic patterning of the substrate before growth. Both techniques convert the majority of BPDs into threading-edge dislocations during the initial stages of epilayer growth, which helps stop BPD dislocations spreading into the epilayers.

Das has investigated the influence of both techniques on the yield of 10 kV, 50 A 4H-SiC PIN diodes. Without these approaches, device yield, defined in terms of forward and reverse voltage performance and voltage drift, was zero. The LBPD1 and LBPD2 processes produced yields of 22% and 23%, respectively. Das is now investigating the devices' long-term stability, and initial results obtained by running diodes at 10 A suggest that the potassium hydroxide etch route may be superior.

Exposing silicon's weakness

Cree's Brett Hull outlined the development of PIN diodes that operate at currents of between 2 A and 50 A and a lower blocking voltage of 6 kV, using one of the BPD density reduction techniques. Total wafer yield for 50 A diodes, which measure 8.64 mm $\times$ 8.56 mm, was 62%. This figure is only 7% lower than the yield for smaller 2 A devices, illustrating the progress made in reducing BPD. Hull also compared the switching performance of a 50 A SiC PIN with that of a commercial 4.5 kV, 60 A silicon PIN diode made by Powerex. At 150 °C the SiC PIN showed a 14% decrease in forward power loss and a 10% reduction in reverse recovery time compared with the silicon diode, and at lower temperatures the power savings were even greater.

Cree also detailed the first 1 cm $\times$ 1 cm thyristor chips that can block 5 kV and conduct 200 A. These high-current handlers can be used in flexible AC transmission systems, fault limiters and high-voltage DC transmission with advantages that include reduced cooling requirements and a potentially higher blocking voltage. A future aim, said Anant Agarwal, Cree's manager of power devices,

Delegates expect HEVs to generate SiC sales

The consensus among delegates at ICSCRM was that increasing sales of hybrid electric vehicles (HEVs) will lead eventually to a large market for SiC devices. Today HEVs use silicon devices to convert the DC output from the battery to an AC source for the vehicle's motor, but car manufacturers are expected to turn to SiC-based alternatives that will reduce the size and weight of these converters.

Market analyst Philippe Roussel of Yole Developpement predicts that 4 million electric cars or HEVs will be purchased in 2010, which will generate \$30 million in sales of SiC products. Car makers are



JAMA

HEVs such as the Lexus SUV could become even more efficient if SiC components are used for power conversion.

expecting SiC devices to be implemented in medium volume by 2009, he said. SiC diodes will be used first, but these devices are expected to be replaced with SiC transistors.

The two modules receiving the greatest attention, in terms of deployment of SiC content,

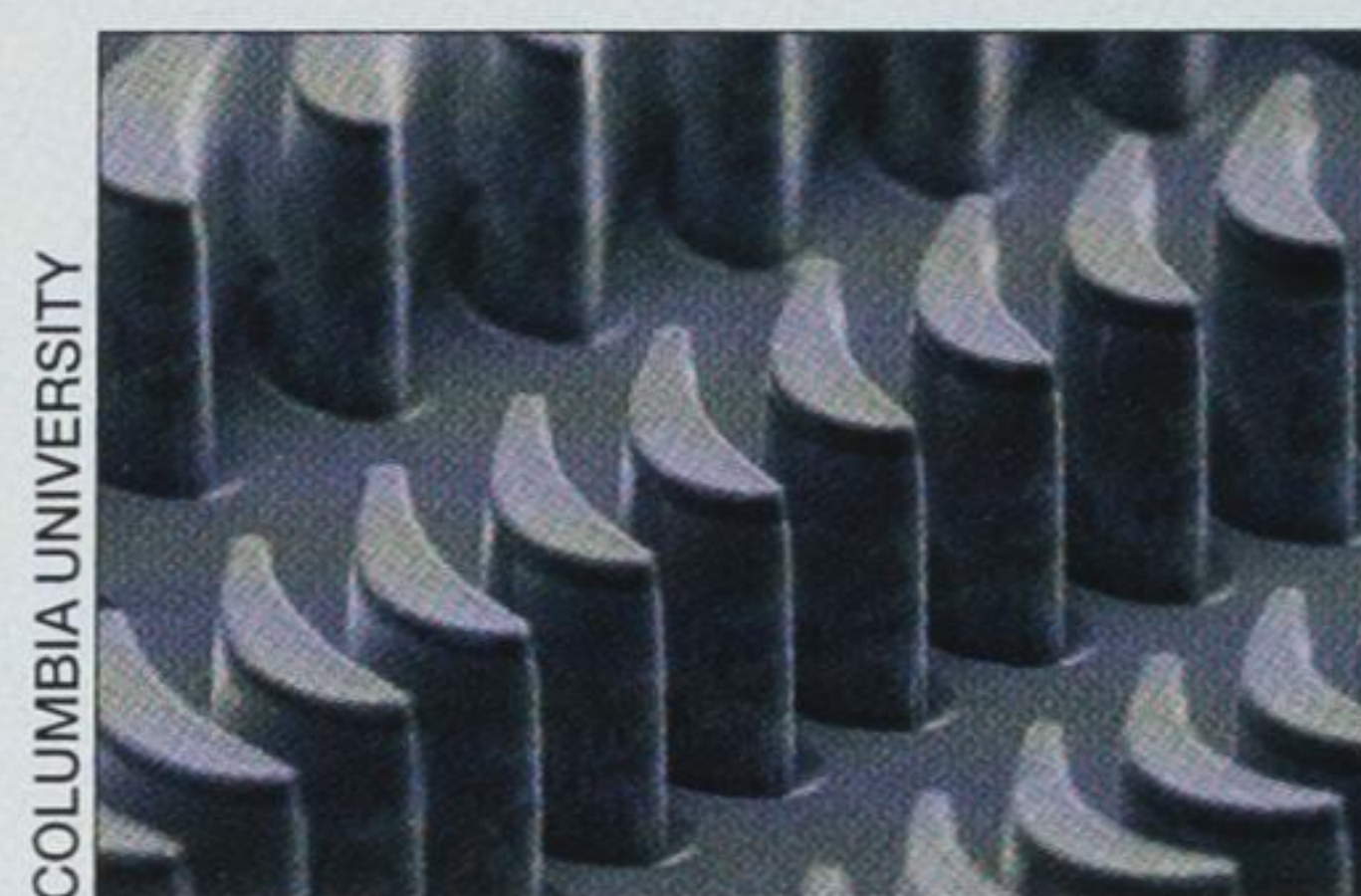
are DC-DC converters and DC-AC three-phase inverters, said Roussel. The requirements for the DC-DC converter include outputs of 12 V, 42 V and a higher voltage of probably 400 V, plus a 3-10 kW power rating, and a 50-100 kHz switching frequency.

SiC could also be used in a DC-AC three-phase inverter that contains the motor and inverter in a single package. The target, said Roussel, is a system that will last for 15 years and deliver at least 55 kW of power for 18 s and 30 kW of continuous power. Additional requirements include current handling of 300 A per motor phase, and at a cost of \$7-10/kW.

Other technical highlights

Impressive devices detailed by non-Cree delegates at ICSCRM included:

- 4H-SiC RF MOSFETs delivering a record 1.9 W/mm at 3 GHz, developed by Gudjon Gudjonsson and colleagues from Chalmers University of Technology, Sweden, and Philips Semiconductors;
- the development by researchers at Cornell University of betavoltaic cells using SiC p-n diodes that convert β -radiation into electrical energy with an efficiency of 3.7%;



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SiC turbine blades can be used to form microelectromechanical systems that operate in harsh environments, as detailed by Laura Evans and Glenn Beheim of NASA.

- a <11-20> 4H-SiC MOSFET with a peak value of 320 cm^2/Vs , produced by

Caroline Blanc and co-workers from the universities of Montpellier and Pretoria, and the Italian Microelectronics Center;

- the first report of RF SiC bipolar junction transistors fabricated on a semi-insulating substrate offering L-band performance, by Ivan Perez of US-based Advanced Power Technology;
- SiC microstructures manufactured by deep reactive ion etching, revealed by Laura Evans and Glenn Beheim of NASA.

is to develop a 20 kV thyristor with high-temperature, high-voltage packaging.

Power factor correction (PFC) circuits can also benefit from SiC. Palmour compared the performance of two PFCs that featured either silicon PINs or SiC SBDs. The devices delivered equivalent efficiency and operated at 80 kHz and 200 kHz, respectively. The SiC version was 38% smaller in terms of area and

volume, and was 44% lighter.

Cree's recent advances – from material quality through to device performance – will no doubt aid the commercialization of SiC-based products. While many of these devices are still in development, in time they ought to impact the company's revenue in much the same way as its already highly successful LED chip operation.

SUPPLIERS GUIDE

SUBSTRATES AND EPIWAFERS

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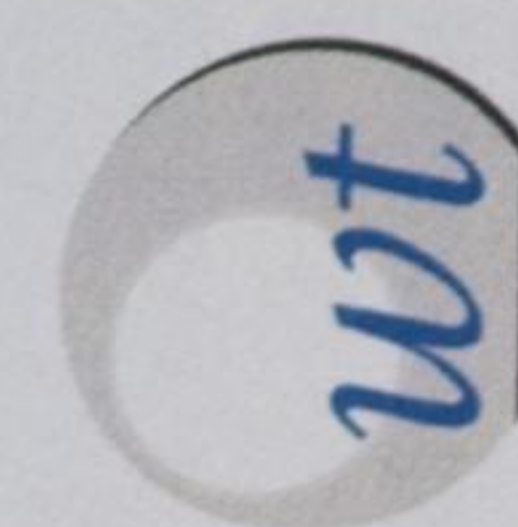
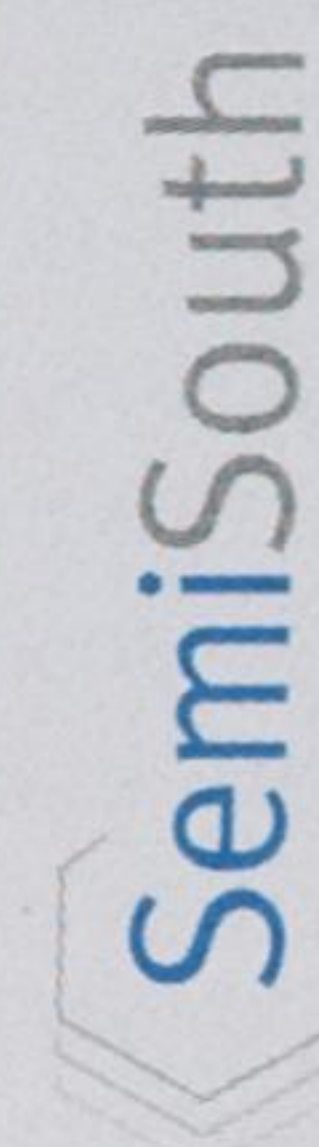
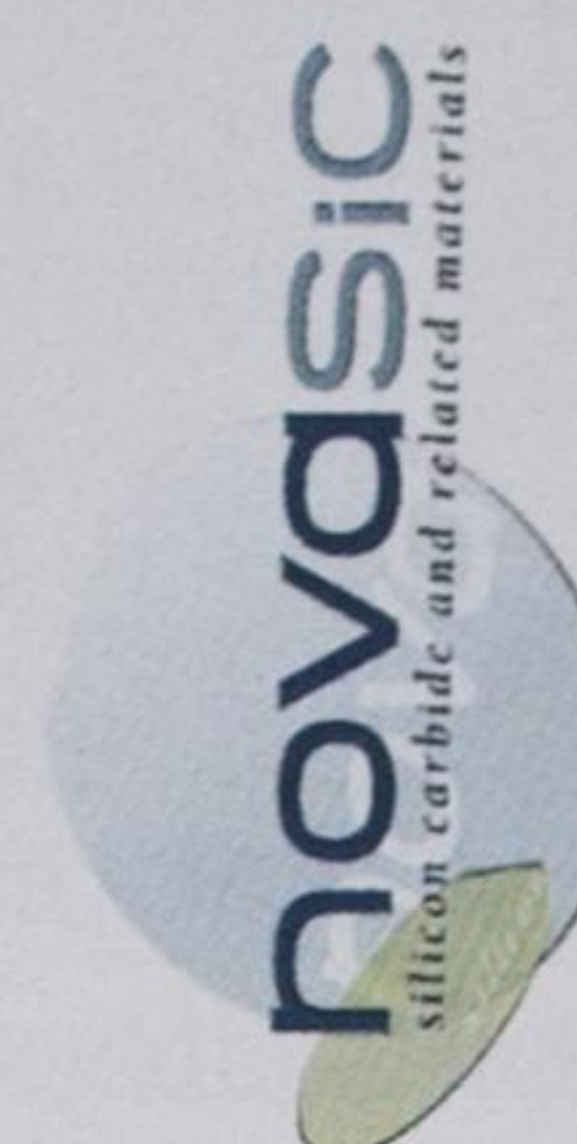
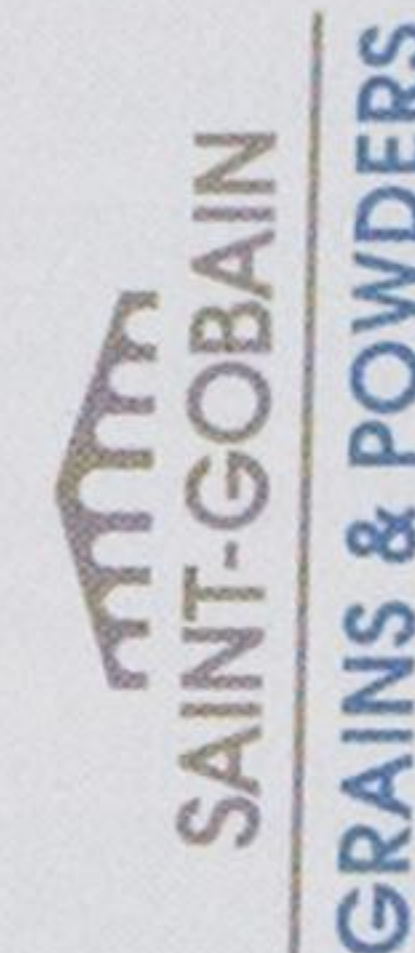
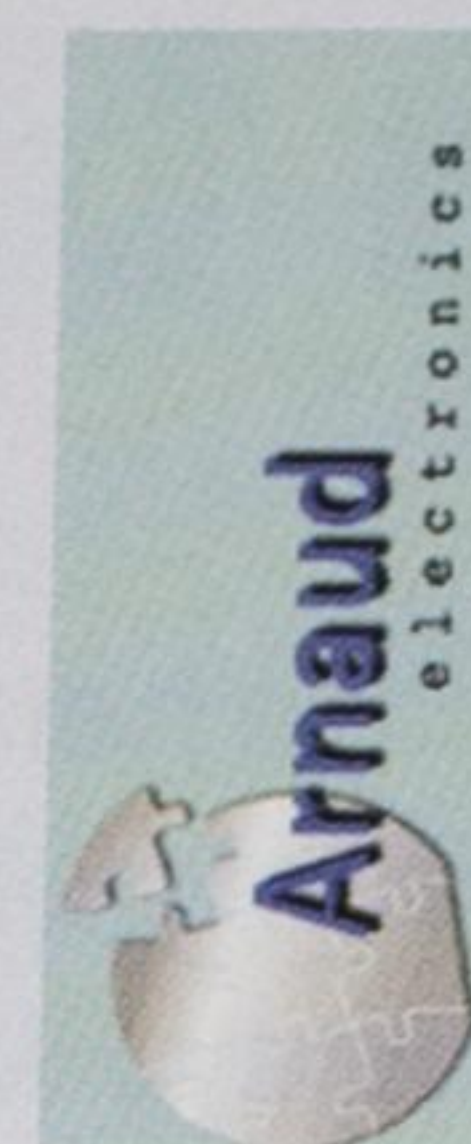
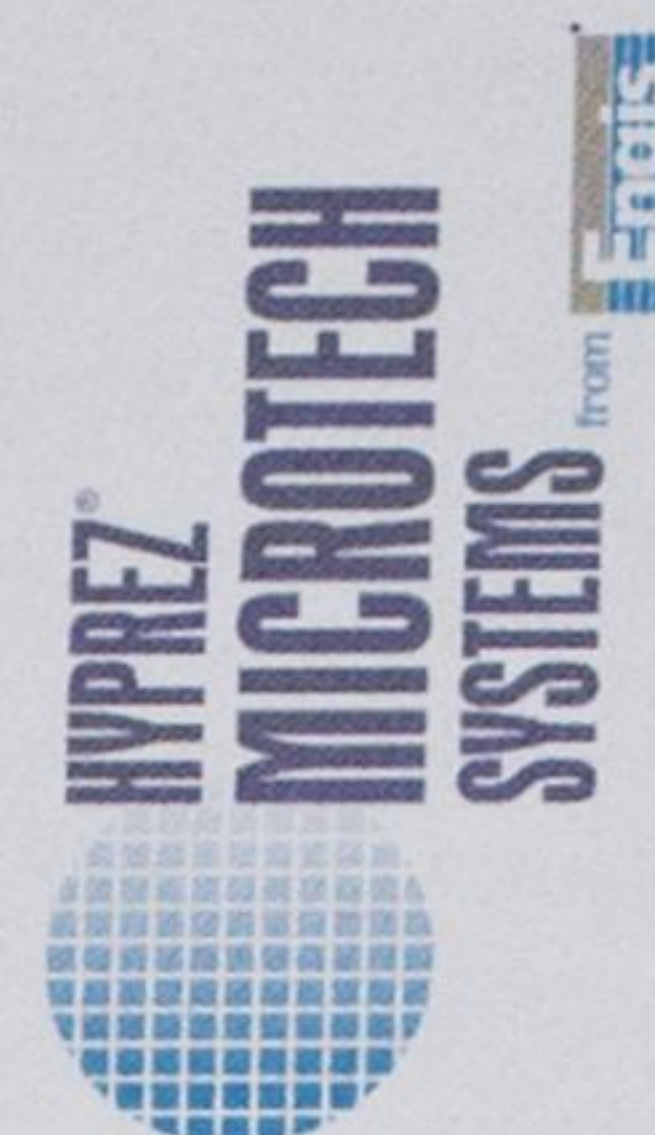
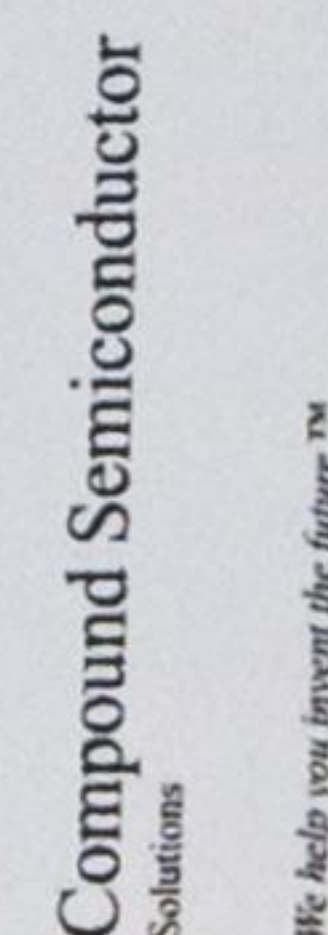
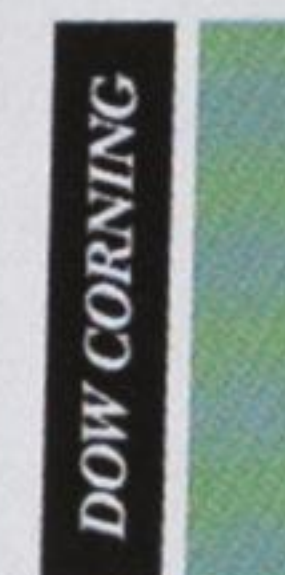
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Substrates and Epiwafers Suppliers Guide

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Picogiga takes polycrystalline approach to SiC substrates

The high cost of SiC substrates is hampering the commercialization of GaN-based RF devices, while silicon's low-cost platform suffers from inferior thermal conductivity. Silicon-on-polycrystalline-SiC substrates are one alternative, say Picogiga's **Jean-Luc Ledys** and Soitec's **Fabrice Letertre**.

If GaN HEMTs are to penetrate commercial RF markets such as mobile base station power amplifiers, then production costs must be comparable to those of competing technologies. While GaN HEMTs built on monocrystalline SiC substrates drive high-end performance, cost prevents them from being deployed commercially in 3G or WiMax base stations. Meanwhile, sapphire suffers from undesirable thermal properties and a significant lattice mismatch with GaN.

Cheaper GaN-on-silicon HEMTs manufactured by companies such as Nitronex and Oki Electric are starting to win customers in RF markets, but their performance is limited by the thermal properties of the silicon substrate. Consequently the market would benefit from substrates that have the physical properties of SiC, but which are available in larger sizes and at a similar cost to silicon or sapphire wafers.

Choosing a substrate

For RF applications, the ideal substrate should be electrically insulating, contribute little RF loss, and provide a seed layer that is sufficient to grow a high-quality active layer. It should also deliver high thermal conductivity, so that heat generated by the transistor is dissipated efficiently. This thermal management ensures long-term reliability and enables the device to maintain its maximum output power.

These criteria are being addressed by Soitec Group and its specialist GaN division, Picogiga International. Soitec has developed four substrates to deliver cost-effective seed layers that can be used to grow low-defect-density GaN HEMTs. These are GaN-on-silicon, SiC-on-insulator (SiCOI), GaN-on-insulator (GaNOI), and silicon-on-polycrystalline-SiC (SopSiC).

To produce GaN-on-silicon wafers, Soitec uses high-resistivity silicon (HRSi) substrates. This material is highly affordable, available in diameters of up to 6 inches, and offers the cheapest route to manufacturing GaN HEMTs.

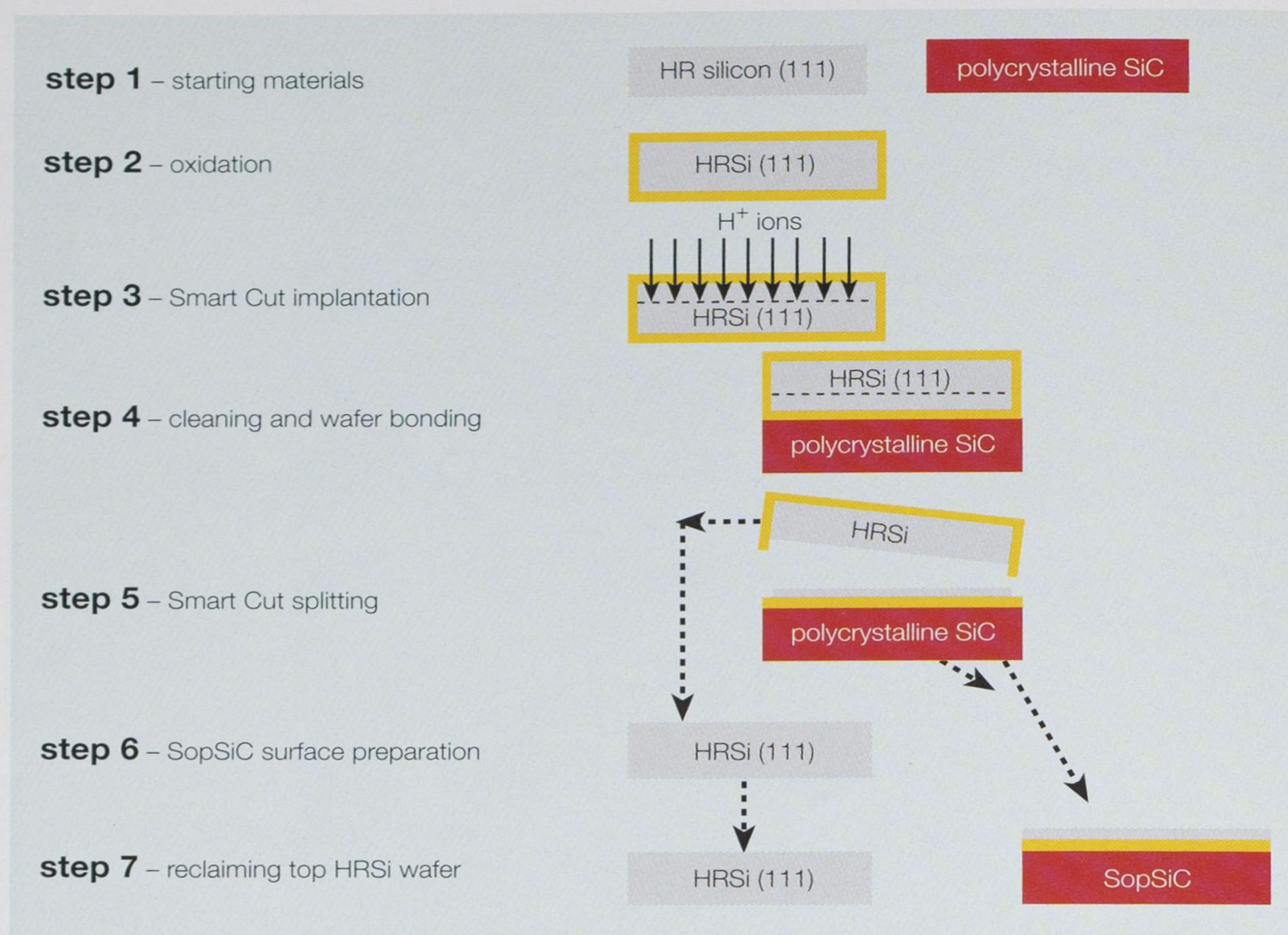


Fig. 1. Soitec's Smart Cut technology is used to produce a silicon-on-polycrystalline-SiC (SopSiC) substrate. The process includes thermal oxidation, hydrogen ion implantation into the high-resistance silicon (HRSi) substrate, surface preparation, and wafer bonding between the HRSi and polycrystalline SiC substrate. Thermal treatment can then split the silicon film to leave a SopSiC structure. This wafer receives additional treatments that stabilize the structure and prepare the silicon surface for subsequent III-nitride epitaxy.

Soitec's patented MBE epitaxial growth method enables GaN to be deposited directly onto silicon despite the lattice mismatch, while maintaining an acceptable level of defect density. However, this substrate's thermal conductivity limits device performance and so it is not ideal for high-power applications.

The other three types of substrate are produced by combining MBE-based epitaxial growth with a proprietary Smart Cut layer-transfer and wafer-bonding technology (figure 1). The process has been used to produce robust 4–12 inch diameter silicon-on-insulator wafers in high volumes for more than 10 years.

The multilayer structure of the wafers enables the seed material on the substrate's front side and the carrier material on its back side to be optimized independently.

At the moment SiCOI and GaNOI wafers are limited in size because large-diameter GaN and SiC substrates are not available, but in time bigger versions will reach the marketplace. These wafers are formed by taking thin slices of either SiC or GaN from bulk substrates, and then bonding these layers to insulating material.

The SiCOI wafers, whose base substrates are made from oxidized silicon, offer affordable

templates that deliver a GaN crystalline quality that is equivalent to GaN films grown on SiC, as well as a substrate holder that has better handling characteristics than bulk SiC.

The GaNOI substrates enable the homoepitaxial growth of very high-quality GaN films. However, this technique is restricted by the shortage of high-quality GaN bulk material: only nine vendors exist worldwide and prices are high. There are also difficulties associated with preparing the GaN surface before bonding. The Smart Cut process requires the GaN's back side to be polished to a mirror-like flatness so that the wafer can bond to the substrate holder, but it is not yet possible to achieve this with a process that is suitable for volume manufacturing.

SopSiC: the Smart Cut approach

One promising alternative to using bulk silicon substrates in the manufacture of GaN HEMTs are SopSiC substrates. Soitec's Smart Cut technology can be employed to produce large volumes of SopSiC wafers up to 6 inches in diameter, and could therefore enable GaN HEMTs to be produced cost effectively. The starting materials for SopSiC substrates are a polycrystalline cubic SiC substrate and an HRSi (111) wafer produced by the Czochralski technique, both of which are available in sizes ranging from 2 to 12 inches.

The morphological properties of the HRSi (111) seed layer have been investigated extensively. High-resolution X-ray diffraction and Raman spectroscopy measurements have revealed that the silicon layer has a crystalline quality and stress levels similar to those of bulk silicon. The layer also exhibits excellent thickness uniformity (figure 2) and an "angstrom range" surface roughness that is ideal for GaN epitaxial growth.

Polycrystalline SiC is highly resistive ($>10^5 \Omega\text{cm}$), and has thermal and mechanical characteristics that are comparable to those of single-crystal SiC. It has a thermal conductivity of 3 W/Kcm that even surpasses the conductivity of GaN (table 1). Polycrystalline SiC can be produced by chemical vapor deposition, and the material has been widely used for microelectronic applications where it serves as 2–12 inch dummy wafers. It costs only two to three times as much as silicon, its resistivity can be easily tuned from $1.5 \times 10^{-2} \Omega\text{cm}$ to $1 \times 10^9 \Omega\text{cm}$, and RF losses can be adjusted to be as low as those of GaAs substrates.

Thermal simulations of the junction temperature of GaN transistors fabricated on various substrates suggest that SopSiC will deliver

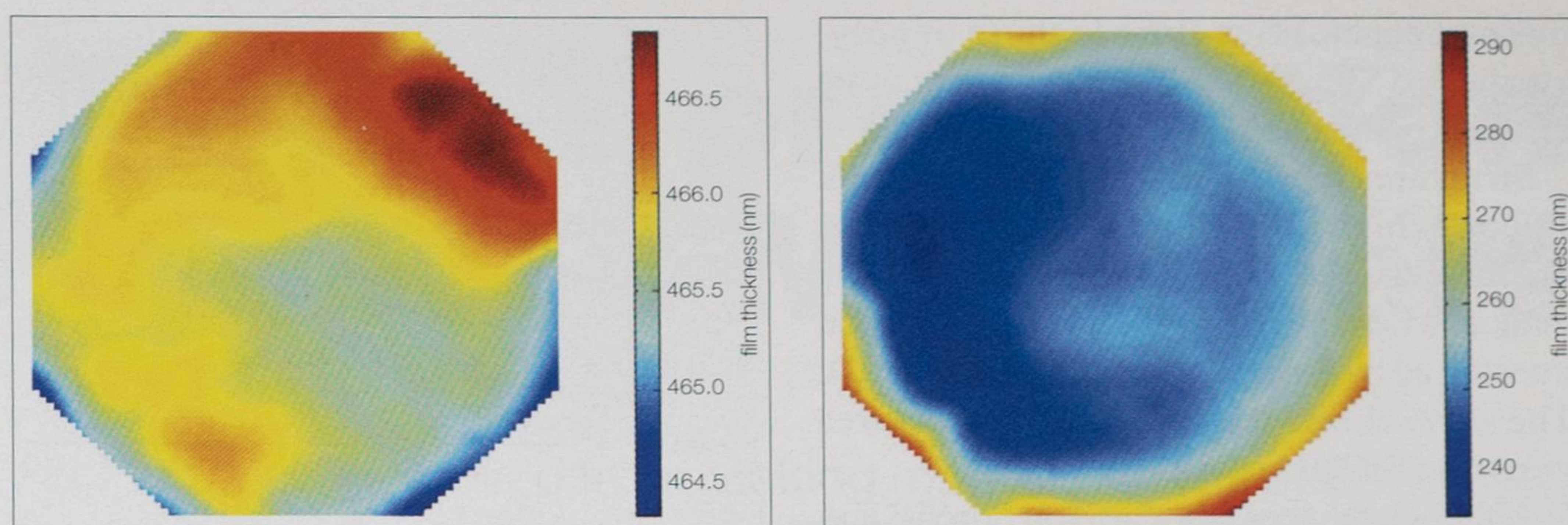


Fig. 2. Ellipsometry measurements on a 4 inch SopSiC wafer reveal the high degree of film thickness uniformity for the silicon film (left) and the buried silicon oxide layer (right).

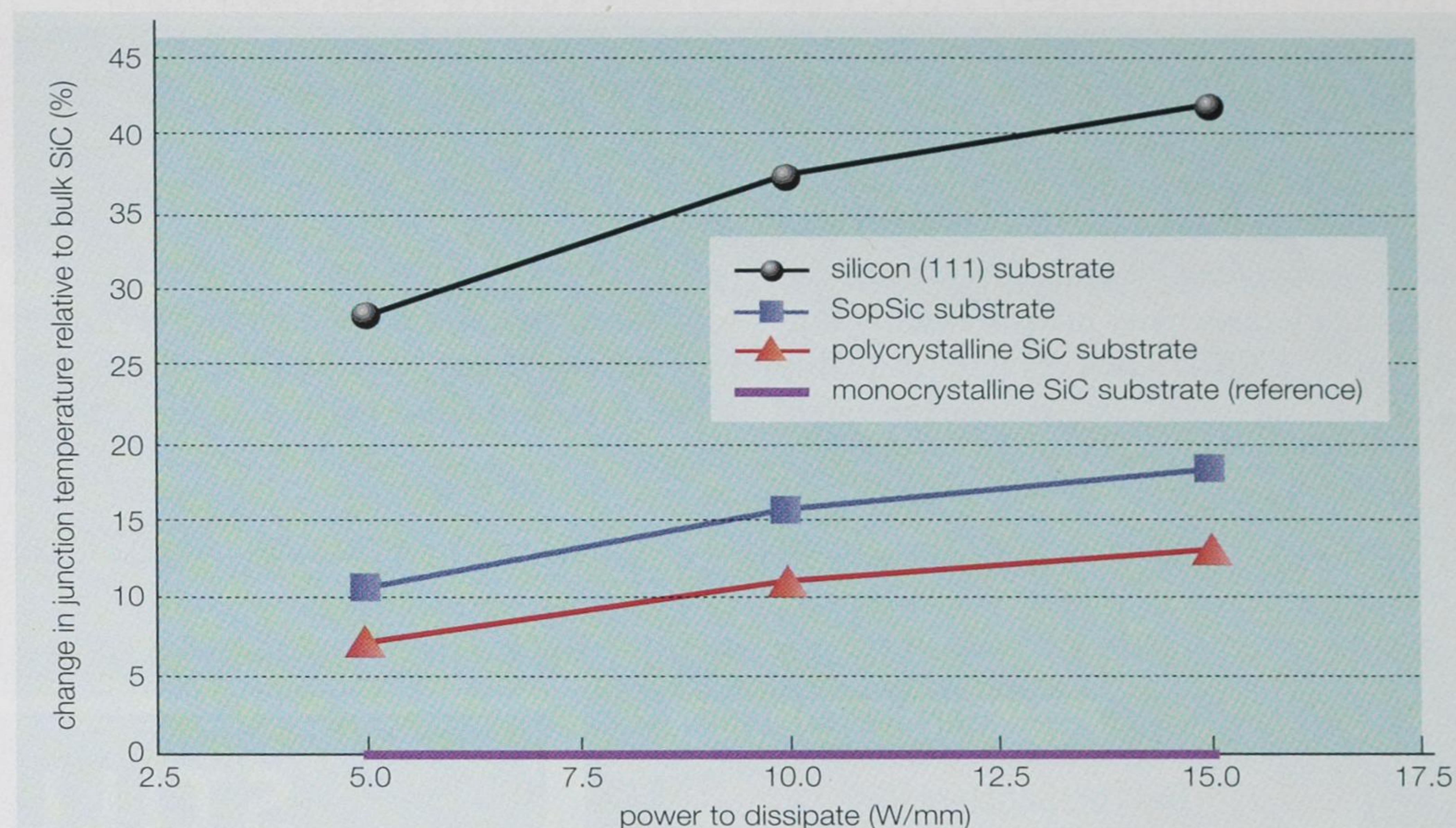


Fig. 3. The results of a simulation of junction temperature as a function of substrate type. If GaN HEMTs are grown on SopSiC substrates instead of SiC material, then the junction temperatures rise only slightly while production costs are significantly reduced.

Table 1. Substrate options for GaN HEMTs

Substrate	Area diameter (mm)	Thermal conductivity (W/Kcm)	Resistivity (Ωcm)	Availability	Price/area (a.u.)
HR Si (111)	100	1.5	10^{-3} – 10^4	excellent	1
SiC	50	3–4	10^4 – 10^8	low	200
Sapphire	100	0.5	$>10^8$	good	4
GaN/AlN	50 / –	2.1 / 3	? / $>10^8$	very low / –	?
Polycrystalline SiC	300	3	10^{-2} – 10^9	excellent	2–3

Table 2. HEMT structure characteristics on various substrates

Substrate type	Sheet resistance (Ω^2)	Mobility (cm^2/Vs)	Sheet carrier density N_s (cm^{-2})	XRD (002)* (FWHM)	Defect density (cm^{-2})
Si**	250 ~ 320	1800 ~ 2100	$\sim 1 \times 10^{13}$	700	3×10^9
SopSiC**	250 ~ 320	1800 ~ 2100	$\sim 1 \times 10^{13}$	700	3×10^9
SiCOI**	250 ~ 320	1800 ~ 2100	$\sim 1 \times 10^{13}$	300	1×10^9
SiC***	280 ~ 320	1500 ~ 2300	$\sim 1 \times 10^{13}$	150/250	1×10^9

* X-ray diffraction (full width at half maximum)

** substrates from Picogiga International

*** substrate from other suppliers

thermal capabilities close to those of polycrystalline SiC, and will dissipate heat more efficiently than bulk silicon (figure 3).

Structures fabricated on SopSiC and bulk silicon exhibit fairly similar results, indicating that the seed layer dominates the performance, whether it is in bulk form or has been transferred by Smart Cut technology (table 2). The same observations occur for structures grown on SiCOI and SiC substrates.

Although devices fabricated on SopSiC and SiCOI are still to be fully characterized, initial results suggest that the back side appears to have little influence on the RF and DC characteristics, although it strongly influences the device's thermal properties. Recent publications (see further reading) also suggest that GaN devices grown on SiC can deliver similar RF and DC results to devices grown using silicon seed layers. Although X-ray diffraction and defect-density measurements suggest that the GaN/AlGaN crystalline quality is higher on SiC substrates, the improvement seems to be insufficient to deliver gains to RF and DC parameters.

Consequently, any advantages introduced

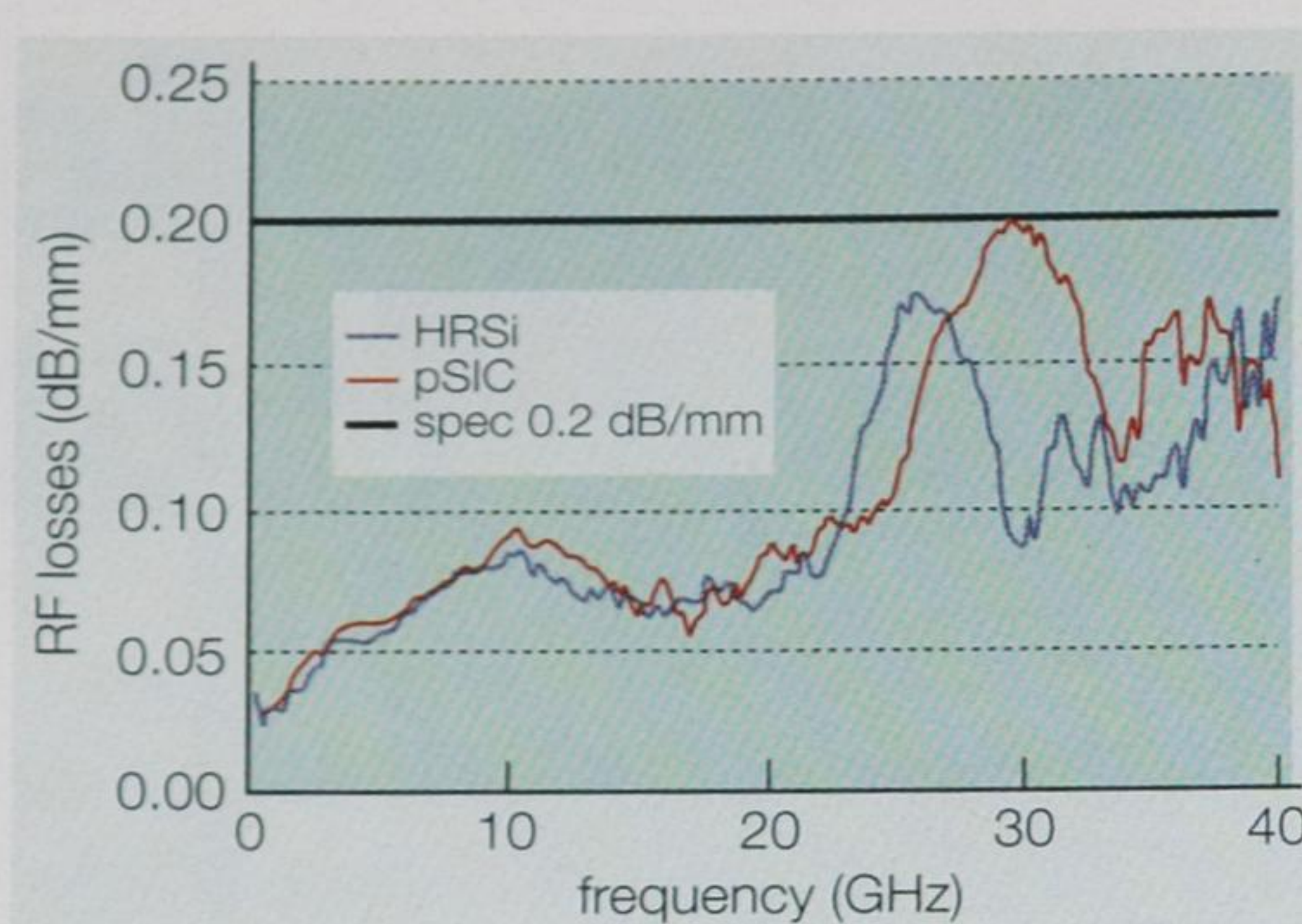


Fig. 4. Polycrystalline SiC (pSiC) and high-resistivity silicon (HRSi) can be engineered to reduce their RF losses below that of GaAs, enabling the substrates to be suitable for X- and S-band radar applications.

by the back side material in a Smart Cut substrate, such as the thermal conductivity advantages offered by porous SiC over silicon, will only improve the behaviour of RF power devices in terms of maximum operating power, operating temperature and reliability. These gains will help to close the gap with devices built on SiC in a cost-effective way.

However, special care is required to prevent

multilayer substrates from adversely affecting the device's RF behaviour. HRSi and polycrystalline SiC can be engineered to reduce their RF losses to levels below those of semi-insulating GaAs substrates for frequencies of up to 40 GHz (figure 4). This refinement enables GaN HEMTs produced with Smart Cut technology to cover a range of applications including radar (X and S band), satellite communications, 3G mobile communications infrastructures, and WiMAX base stations. ●

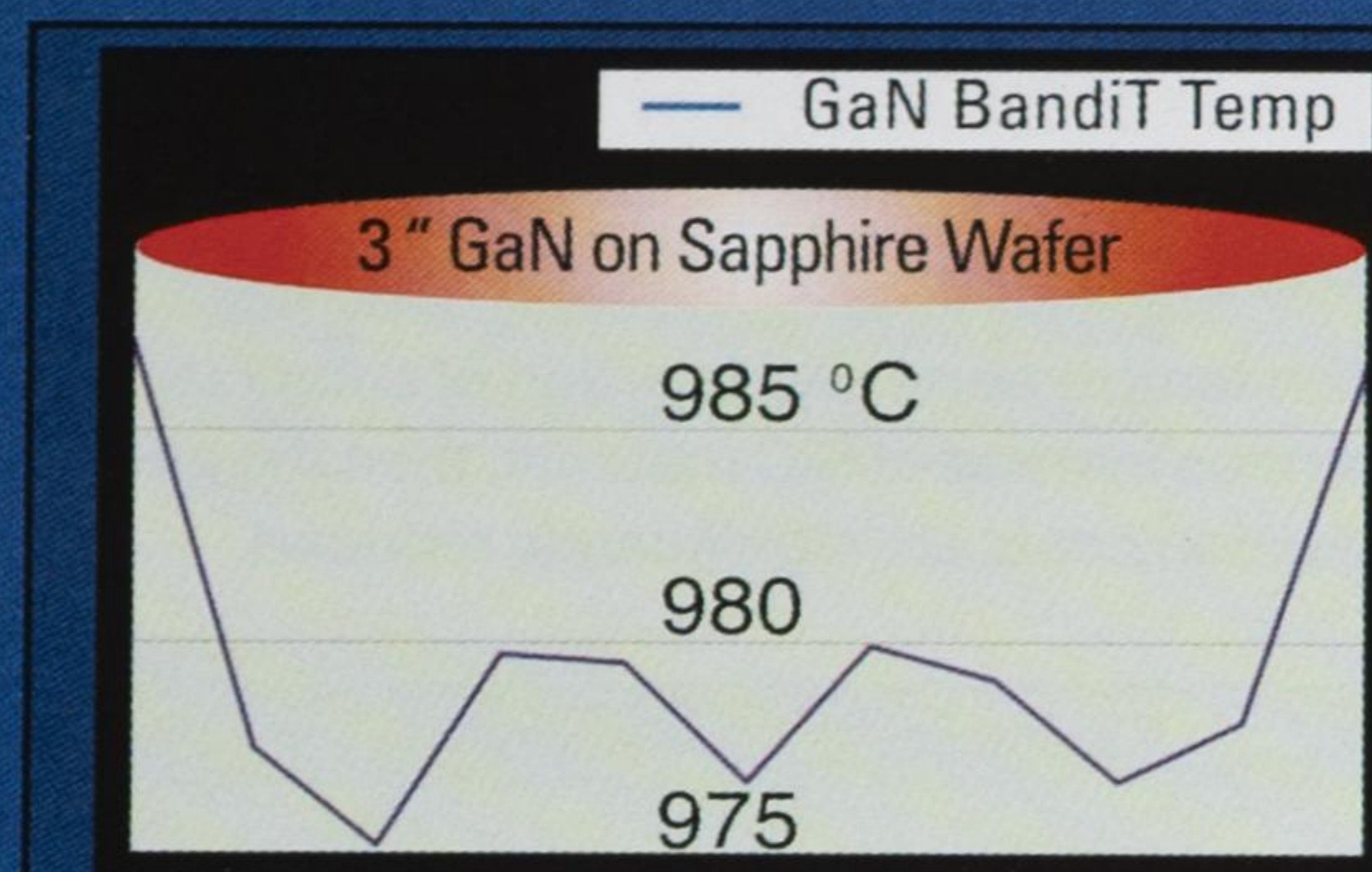
Further reading

H Lahreche *et al.* *Materials Science Forum* **457-460** 1621.

D C Dumka *et al.* 2004 *Electron. Lett.* **40** 1023.

F Letertre *et al.* 2005, 207th ECS Meeting, Quebec.

Jean-Luc Ledys, chief operating officer of Picogiga International, and Fabrice Letertre, R & D manager at Soitec, acknowledge the contributions of Philippe Bove, Robert Langer and Julien Thuret of Picogiga, and Bruce Faure and Alice Boussagol of Soitec.



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GAAS MANUFACTURING

Filtronic's PHEMT production rockets to meet RFMD orders

The 6 inch GaAs production facility at Filtronic has moved from making monthly losses of \$2 million to becoming a near-profitable operation, thanks to huge orders for PHEMT switches from RF Micro Devices. **Richard Stevenson** visits the Filtronic fab at Newton Aycliffe, UK.



Filtronic makes some 10 million PHEMT switches per month at its Newton Aycliffe fab, which is working round the clock to meet demand.

UK-based wireless subsystem manufacturer Filtronic is now fabricating 1000 6 inch PHEMT wafers per month to satisfy orders from RF Micro Devices (RFMD). This is a tenfold increase in the production of PHEMTs over the last eight months. The transistors, in the form of passivated die, are being used in antenna switches that are integrated with RFMD's HBT-based power amplifiers to create handset transmit modules.

Until recently Filtronic's GaAs fab had been hugely under used since its high-profile opening in 1999 by UK Prime Minister Tony Blair. However, this year's increase in production has given the company a 30% share of the GaAs handset switch market.

"The company was selected by RFMD because of the competence and dedication of all of its technical people, its capacity, and the quality of its foundry," explained John Roulston, Filtronic Group's chief executive officer. The company's Integrated Products division began sampling PHEMT switches to RFMD over two years ago, and last year 100–120 PHEMT wafers were shipped each month. This year output has shot up exponentially, and RFMD expects the ramp of

transmit modules to be among the fastest product launches in its history (figure 1).

"Filtronic has introduced a '24/7' operation and added a number of staff to meet that ever-increasing demand," said Roulston. The fab is now close to its current capacity and production is limited by equipment rather than cleanroom space, as today the company is using only one-third of its 100,000 ft² cleanroom space. However, capacity will be increased in March 2006 when Filtronic will install a second multiwafer MBE reactor and additional tools that will double output to around 25,000 wafers per year. According to Roulston, annual capacity could even reach 30,000 wafers. This could be achieved partly by reducing in-line measurement and inspection processes, which is possible when experience in volume manufacturing grows.

Although RFMD is also capacity limited at the moment, it will take all of the PHEMT wafers that Filtronic can produce. Roulston admits that Filtronic may be unable to supply RFMD with all of the material it needs until upgraded capacity has been installed, but he says that the two companies have a good relationship and share each other's success.



The production of PHEMTs has been ramped this year. The dip in August was due to scheduled maintenance at the fab.

Most of the PHEMTs manufactured for RFMD are produced at Filtronic's Newton Aycliffe site, which was acquired from Fujitsu in 1999. However, one-fifth of the epitaxy has been outsourced to one European foundry, and another European company is being considered as a second source. "Using external epitaxial services reduces the risks for fulfilling PHEMTs orders," explained Roulston, although he added that outsourcing is more expensive than producing material in-house. It will be May 2006 before Filtronic qualifies the material from its additional capacity, but

GAAS MANUFACTURING

Filtronic's PHEMT process

Filtronic takes about three weeks to produce a PHEMT switch.

The process begins with epitaxial growth of the transistors using a Veeco Gen 2000 MBE reactor with a 7 × 6 inch capacity. According to Roulston, the reactor, which is only used to grow PHEMT material, delivers a 98% yield and produces devices with very high mobilities.

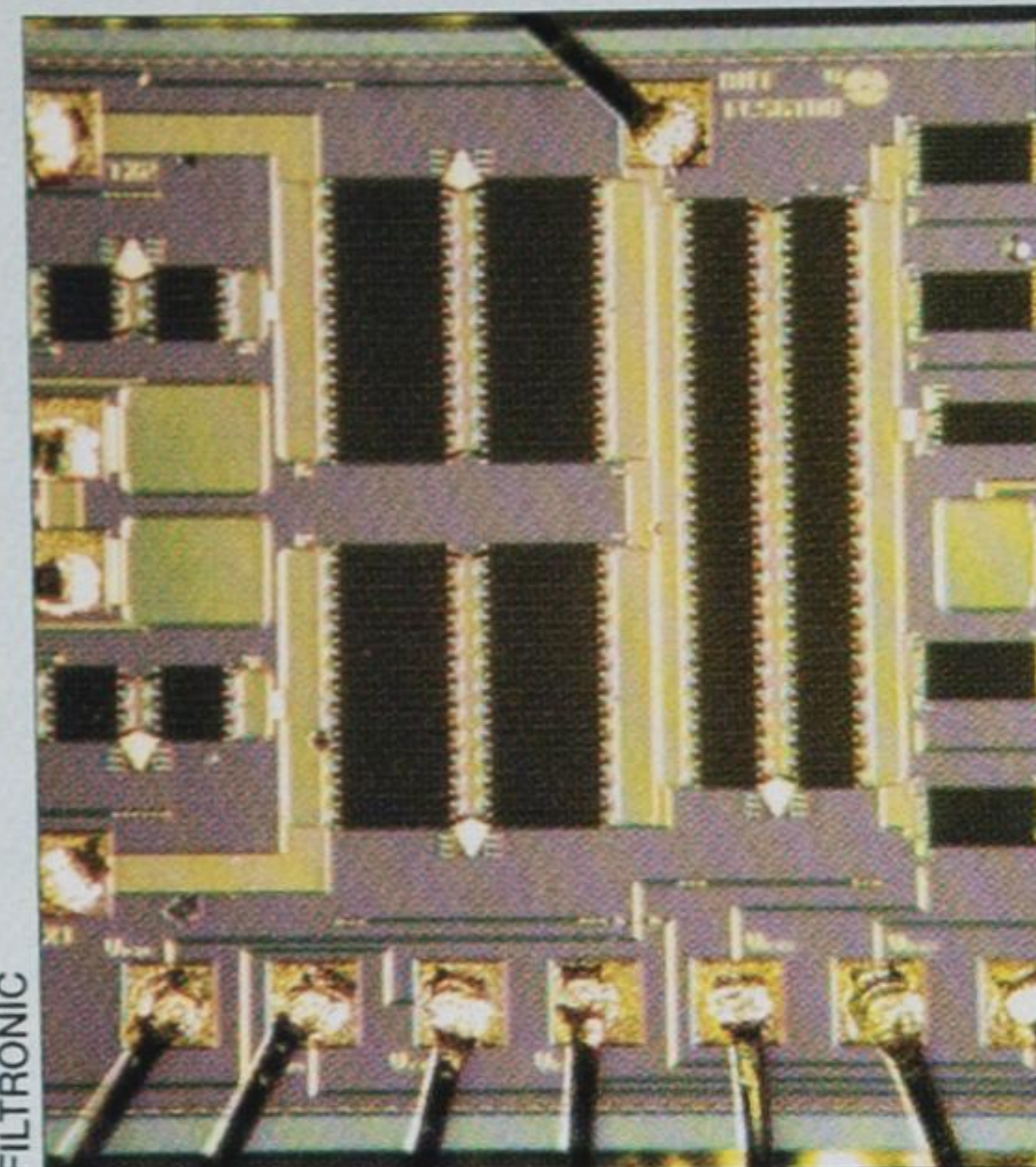
The company has assessed the performance of 6 inch GaAs material from four suppliers and has selected Hitachi and Freiburger material

for production.

Several processes are used to convert epitaxial wafers into the PHEMTs that are then shipped to customers in the form of isolated unpackaged chips attached to a plastic backing.

Manufacture involves nine mask steps, which are carried out using stepper technology used by the silicon industry. This delivers high-quality features even at the wafer's edge.

Ion implantation follows, along with the formation of ohmic contacts, the etching of recess



Filtronic's range of PHEMT devices includes this single-pole six-throw switch.

areas, and the deposition of first the gate and then bonding pads and interconnects.

The last two steps involve growing a thick encapsulating nitride layer, and finally thinning the backside of the wafer.

Before the PHEMTs are shipped, the chips undergo 100% on-wafer testing. "Test times are significant," said Roulston. New equipment that can assess the chip's performance more quickly has been installed in an attempt to speed up the testing process.

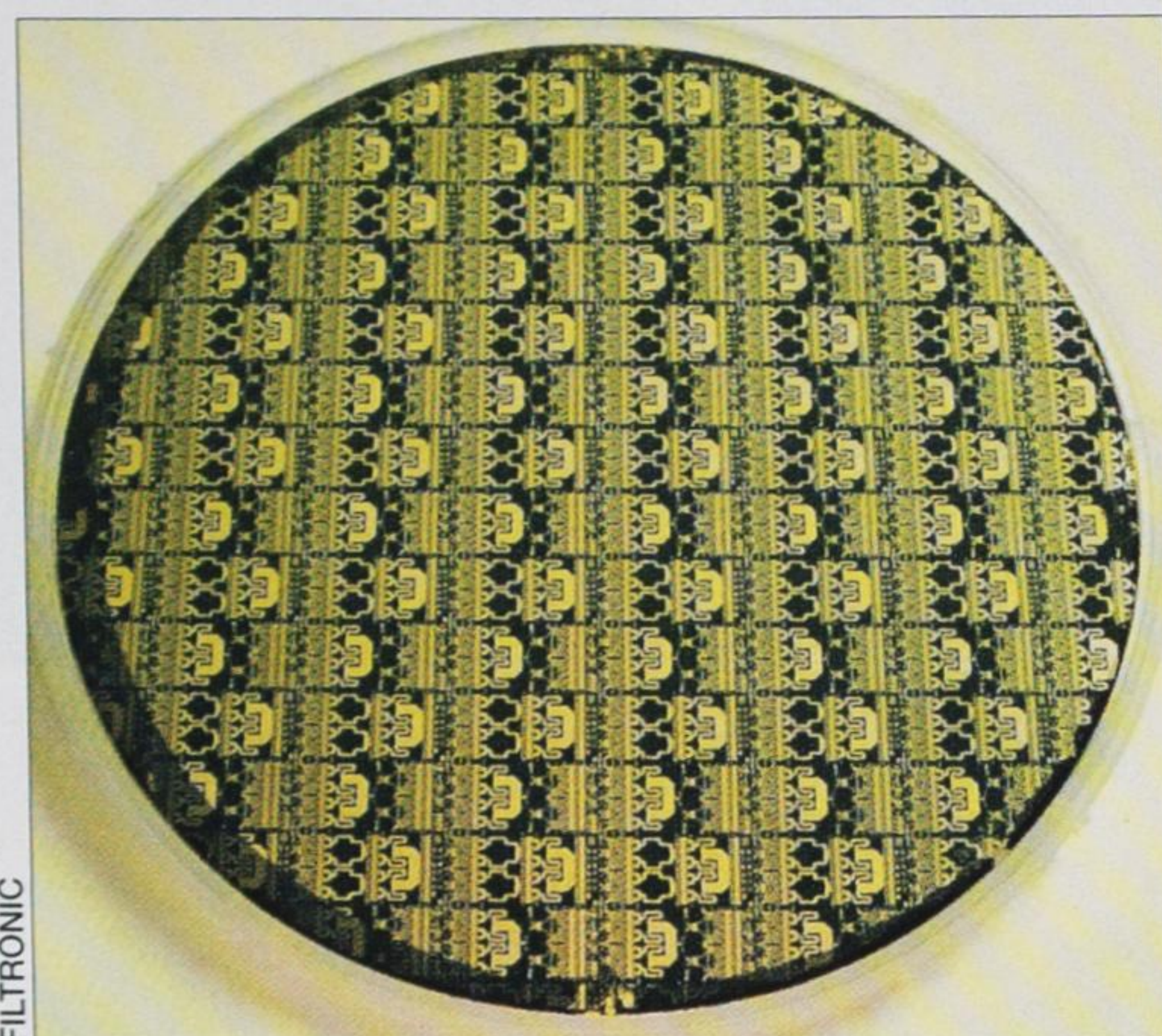
in the meantime it can use wafers from stock to help meet any further increases in demand from RFMD.

Filtronic's sales of PHEMT wafers could produce an annual revenue in the range of \$50–60 million. Since each 6 inch wafer features between 10,000 and 12,000 PHEMT devices, once Filtronic has upgraded its capacity it will be able to produce at least 300 million antenna switches every year. This volume equates to around one-third of the total available – a level of penetration that Roulston believes is possible. And further growth is likely. "Nokia predicts that by 2008 global handset sales will have risen from around 750 million to 1 billion annually, and that each phone will contain 11 antennae and an increased PHEMT content," said Roulston.

Filtronic is debt free following the disposal of its handset antenna business earlier this year, and sales of PHEMT switches will help to bolster the company's financial standing. In the fiscal year ending 31 May 2005, Filtronic's Integrated Products division contributed £45 million (\$80 million) to the total revenue of £263 million, and this fiscal year sales are expected to hit £62 million, with more than half of this revenue generated from PHEMTs.

Second customer

Although Filtronic is now benefiting from a preferred supply agreement with RFMD, the company is also sampling its PHEMTs to other manufacturers. "We're very close to signing a second deal," said Roulston. The potential contract is not with Skyworks, which uses a vertically integrated approach to produce its modules.



Filtronic also produces MMICs on its 6 inch GaAs line for use in cellular base stations.

With Filtronic now generating significant revenues from PHEMT switches, it is possible that other GaAs transistor manufacturers will try to encroach upon its business. "Eventually people will reverse engineer our products," said Roulston. However, he believes that the PHEMT switch market is too small to warrant the investment required to construct a fab that is as good as Filtronic's, and that this product will provide the company with a good revenue for several years.

For that revenue to increase, Filtronic will have to maintain its prominent position despite challenges from alternative technologies. The company reached its dominance by replacing PIN diodes, which were widely used when handsets operated in fewer bands. Although these diodes are cheap, the technology is not suitable for the latest phones because the large number of diodes required draw a high current from the battery and reduce talk time.

MEMS technology is one of the threats to PHEMTs for the antenna switches market. These devices are already being used by Samsung, but according to Roulston there are downsides because their moving parts can stick together, and their lifetime is affected by fatigue. Despite these issues, Filtronic is also investigating the use of MEMS-based technology, in partnership with the engineering department at Durham University, UK, even though it is confident that PHEMT-based switches will dominate the handset market.

Roulston believes that Filtronic's business is not under threat from SiGe-based switches, because these devices cannot meet intermodulation specifications at a high enough efficiency. HBTs are also unsuited to the application because the antenna switch is located after the power amplifier, and the HBT cannot deal with such high power levels.

Roulston is not alone in declaring an optimistic outlook for Filtronic's business. "With the new management team delivering on different fronts, Filtronic is now a stronger, more focused, less risky business," says UK-based research firm Clear Capital. The analysts say that the Newton Aycliffe fab, which has drained £1 million per month from Filtronic for many years, is now on the road to profitability, and that the guidance offered for the GaAs production line is the most reliable ever given.

Profitable manufacturing at this site would certainly be welcomed by the UK compound semiconductor community, which lost the Caswell 6 inch GaAs line last year. Filtronic is the UK's only 6 inch wafer production line, and the fanfare that accompanied its 1999 opening is now finally becoming justified. ●

3G and CMOS migration set agenda for Chinese handsets

As the Chinese market for cell phones goes from strength to strength, **Michael Hatcher** finds out which RF chip suppliers are making inroads into the local Chinese brands and asks whether a recent design win by CMOS power amplifier maker Silicon Laboratories is a sign of things to come.

China is where it's now at for cell-phone manufacturers. Leading vendor Nokia, of Finland, said in its most recent earnings call that it had witnessed an increase in shipment volume of about 87% compared with the equivalent period in 2004.

But while the top global brands have enjoyed recent success in penetrating the world's single biggest handset market (350 million subscribers and 100 million cell phones bought annually), it is typically the local cell-phone makers that have dominated sales in China.

Visit a cell-phone store in Beijing and you will most probably see five Chinese-branded phones for every Nokia handset. The leading local brand name is Ningbo Bird, which became one of the top 10 global handset vendors for the first time in 2004. The Chinese company was ranked in eighth place by analyst firm IC Insights in its review of the market, ahead of the Japanese heavyweight electronics firms Panasonic and NEC.

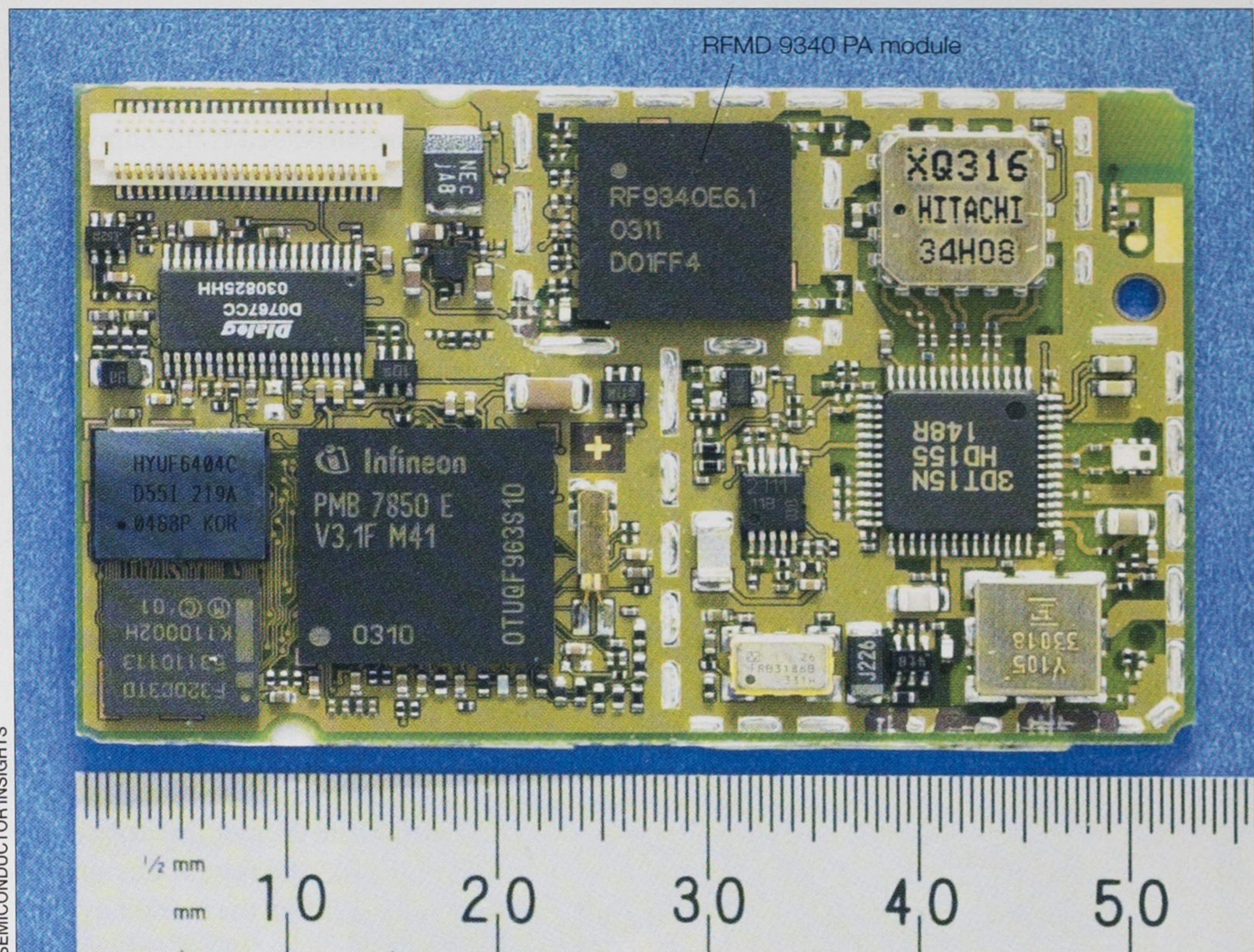
Bird, as the brand is known, is also keen to penetrate outside of its local market, and the company claims to have exported 3 million handsets in 2004, equating to one-fifth of its total shipments of 15 million.

Bird's local rivals include Amoi Electronics, TCL Corporation and Lenovo Mobile. The latter is a subsidiary of China's leading PC maker, which is best known in the West for acquiring IBM's PC business in late 2004.

Tear-down analysis

Cedric Paillard and colleagues at the research firm Semiconductor Insights recently performed a tear-down analysis on seven of China's top-selling, locally made cell phones to establish any differences in construction and supply lines between the domestic industry and that of the rest of the world.

Paillard looked at five phones from Ningbo Bird, and one each from TCL and Amoi. "Bird is the biggest domestic brand, and also produces one of the most advanced phones in



RFMD's power amplifiers feature heavily in Chinese handsets, including this Ningbo Bird A150, a high-end domestic phone stripped down by Semiconductor Insights. Market shares are more evenly spread between chip suppliers in Chinese-branded cell phones.

terms of the [chips] inside," he said.

According to him, the power amplifier (PA) and antenna switch are largely provided by GaAs chip manufacturers. PAs from RF Micro Devices (RFMD) featured in one of Ningbo Bird's top phones, the A150, and Skyworks Solutions PAs showed up in two of the seven handsets analyzed (see table).

But owing to the nature of price competition in China many older chip solutions are still being used, with power management units from Agere and Philips also found in some of Bird's most popular phones.

"Rather than trying to redesign something for the Chinese market, many manufacturers will put a lot of [other] devices around a

standard PA to make it match," said Paillard. "Despite the large size of the Chinese market, it's still not really big enough to justify the development of a specific PA solution."

China's migration to 3G services is of enormous strategic importance to RF chip manufacturers, and one that is complicated by the Chinese authorities' backing of the home-grown network standard TD-SCDMA. While the development of handsets based on TD-SCDMA is thought to be lagging behind that of the network architecture, this could change following an agreement between Nokia and local service provider China Putian to collaborate on the rollout of 3G networks based on both the Chinese standard and on the more

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conventional wideband CDMA protocol.

The two companies have formed a joint venture company that plans to sell network systems in China as early as 2006, and Nokia's unrivalled expertise in handsets will undoubtedly ensure that cell-phone technology soon matches that of the network.

According to Paillard, China may well end up falling into line with much of the rest of the world by adopting W-CDMA for cost reasons. He likens today's 3G network situation to that previously seen in the wireless LAN sector, where the Chinese government originally wanted to roll out its own system for reasons of security. That plan was eventually dropped because it was deemed to be uneconomic.

"I wouldn't be surprised if the same thing happened with TD-SCDMA," Paillard told *Compound Semiconductor*. "I'm not saying that it [TD-SCDMA] won't happen, but you increase significantly your cost of development if you're not in line with other large markets."

"You can see that with the domestic Chinese phones we have analyzed. They tend to use as much as possible from what is available in other markets. No company has designed a specific chip for the Chinese market." Paillard added that semiconductor chip manufacturers might well band together to lobby for 3G harmonization, as happened with WLAN.

Silicon PA deal

While GaAs companies are likely to benefit as Chinese consumers migrate to higher-end phones that utilize the greater linearity of the compound material, one recent design win may hint at a future shift in the market dynamics towards CMOS.

That came in late September, when fabless chip designer Silicon Laboratories announced that both its transceiver and its CMOS-based PA would feature in a line of handsets made by Lenovo Mobile. Silicon Laboratories says that its Si4300, which is manufactured at the huge TSMC foundry in Taiwan using a standard 0.35 μm process, is the first GSM PA

"Despite the large size of the Chinese market, it's still not really big enough to justify the development of a specific PA solution."

CEDRIC PAILLARD
SEMICONDUCTOR INSIGHTS

Tear-down analysis

Brand	Handset model	PA supplier
Amoi	Rosemary F90	Agere
Ningbo Bird	V5100	Philips
Ningbo Bird	S788	Philips
Ningbo Bird	A150	RFMD
Ningbo Bird	A130	Skyworks
Ningbo Bird	S689	Skyworks
TCL	898	Wavecom

Source: Semiconductor Insights

solution to be implemented in CMOS.

Lenovo may not yet be a major player in the handset market, but, as Paillard pointed out, any supply deal with a Chinese manufacturer could be construed as significant, and now that Silicon Laboratories is designed into Lenovo's phones it is likely to stay there for some time.

Silicon Laboratories may have had to bargain hard for its position with Lenovo, but the development could be a sign of things to come – at least in the long term. "A significant amount of work is going into CMOS-based power amplifiers," said Paillard. "I think that GaAs chipmakers have a bigger problem than just worrying about TD-SCDMA – they should be worried about their transition plan to CMOS in general."

Paillard believes that many of the major semiconductor companies with their sights set on the RF market are looking at 2010 as the likely time for a shift towards the use of CMOS in digital PAs, through 90 nm or 130 nm silicon processing techniques.

Some firms are targeting the RF sector more aggressively, believing that the switch could occur as soon as 2007, and one company is expected to produce a full CMOS PA for WLAN applications next year. "It is the 'power-amplifier-only' guys that I am most worried about," warned Paillard, "because they do not necessarily have the strength on the baseband or transceiver side."

GaAs is certainly in the ascendancy when it comes to the design of PAs, and leading manufacturers such as RFMD are aggressively ramping the production of transceivers and full transmit modules. But ultimately the PA stage could become swallowed up in a single CMOS solution manufactured by a silicon giant such as Texas Instruments. "I think in 2010 you could see that," concluded Paillard.

Semiconductor Insights' report on Chinese handsets is available now. Visit www.semiconductor.com for details.

Cautious Aixtron drops sales guidance

MOCVD equipment supplier Aixtron has reduced its revenue guidance for fiscal 2005 by around 10% to €140 million (\$165 million), and says that it expects customer equipment spending to remain weak until early next year.

Revenue in Aixtron's third fiscal quarter for 2005 was €29.1 million, down 35% sequentially, with its new silicon business contributing €9.2 million to the total.

During that period, the Aachen, Germany, company's compound semiconductor business posted sales of only €19.9 million, down €8.9 million sequentially, and €10.1 million lower compared with last year.

Company CEO Paul Hyland summed up the prevailing mood of caution: "Aixtron's business in the third quarter and the first nine months of 2005 continued to be affected by generally low levels of customer capital spending, resulting in lower order intake and total revenues."

The company also recorded a €7.1 million loss for the third quarter, with cash and cash

equivalents on its balance sheet dropping by €14 million to €31.5 million, while orders also declined from €28.4 million in the second quarter to €24.9 million.

Despite being somewhat buoyed with the contribution from Aixtron's new silicon semiconductor equipment business, there was no denying the negative sentiment surrounding compound semiconductor equipment sales: "The compound semiconductor market continues to be very difficult, with many customers reluctant to commit to capital expenditure programs in the current climate," said Hyland. "There is no question that compound semiconductors will be at the forefront of key enabling technologies for the foreseeable future. However, at this particular point in time, we are at a crossroads of several market dynamics."

The CEO believes that a decline in the selling prices of devices has culminated in significant customer consolidation recently. That process has also delayed the introduction of

some new customer products.

"Once these market adjustments have been made and the predicted new display backlighting, mobile phone camera flash, and automotive applications begin to emerge, we expect to see renewed growth return to this sector. However, this will not be before next year."

Expectations of relatively low capital expenditure in the compound semiconductor industry for the near future prompted the cut in revenue guidance and saw 10% knocked off the Aixtron share price.

Despite the hefty cut in its sales guidance, Aixtron has not adjusted its expected annual loss, which is still predicted to be between €10 million and €15 million.

● Californian nitride device start-up Blue Photonics has installed a Close Coupled Showerhead GaN reactor supplied by the Aixtron subsidiary Thomas Swan. The 19 × 2 inch production reactor will be used to make high-power transistors as well as blue laser diodes and LEDs.



Executive Production Managers (EPI)/(Chip Processing) Hong Kong and southern China

Executive Production Manager(EPI)

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Job Description: Manage the production of HB LED under the direction of CTO.

Requirements:

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- 2) Sound theoretical and practical background of LED device structure is required.
- 3) Leadership and experience in management of LED Production line.
- 4) Good communication skill and professionalism attitude.
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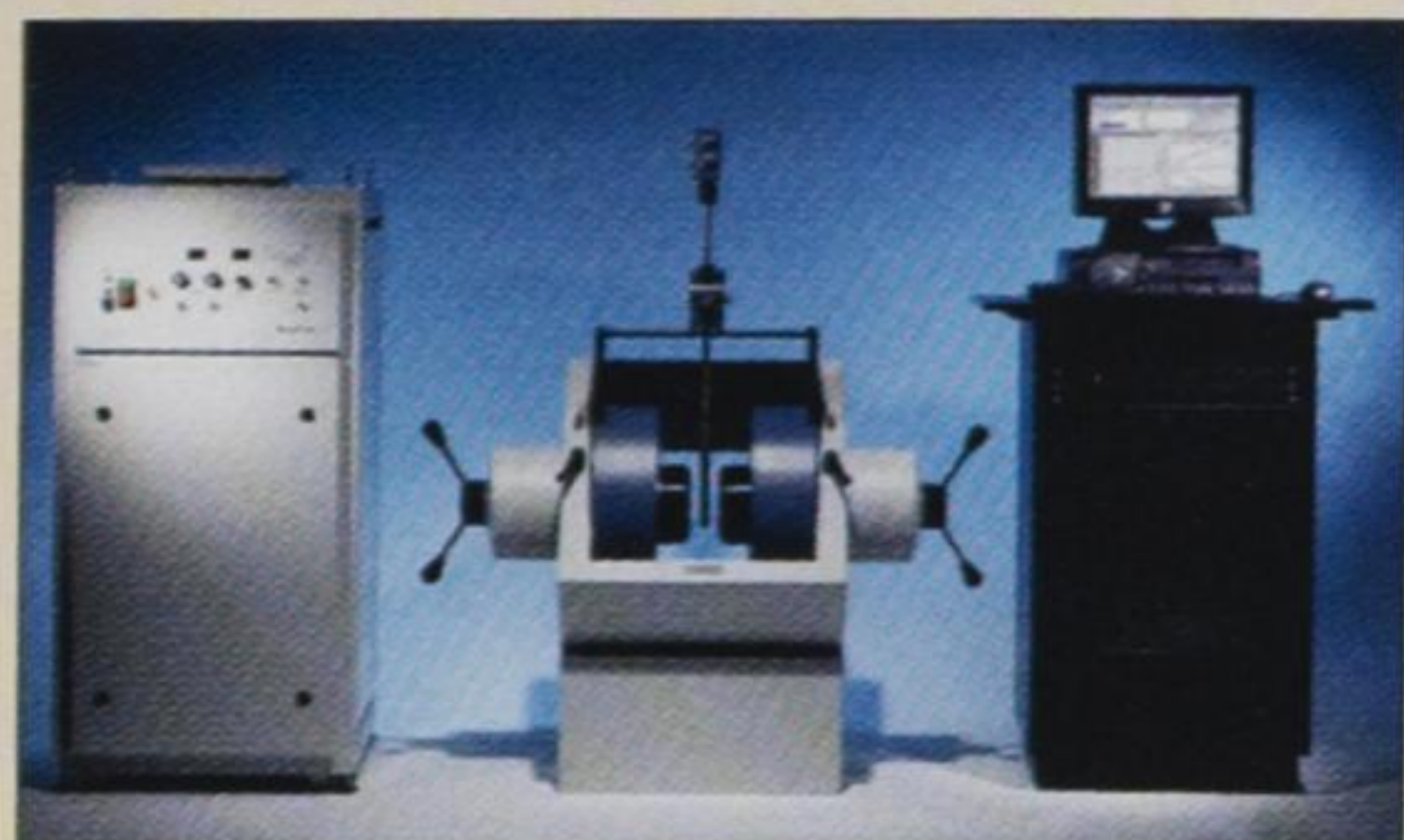
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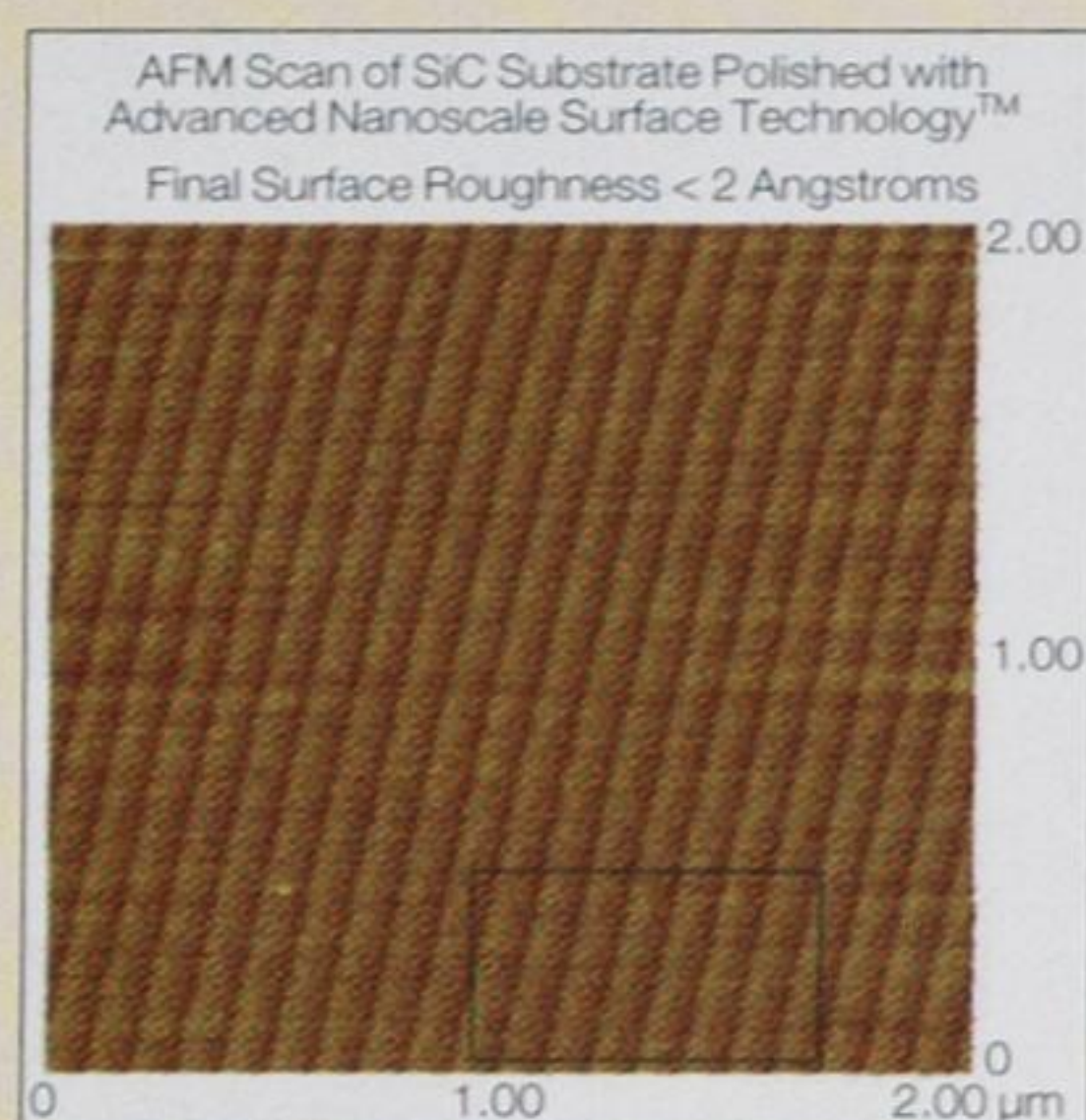


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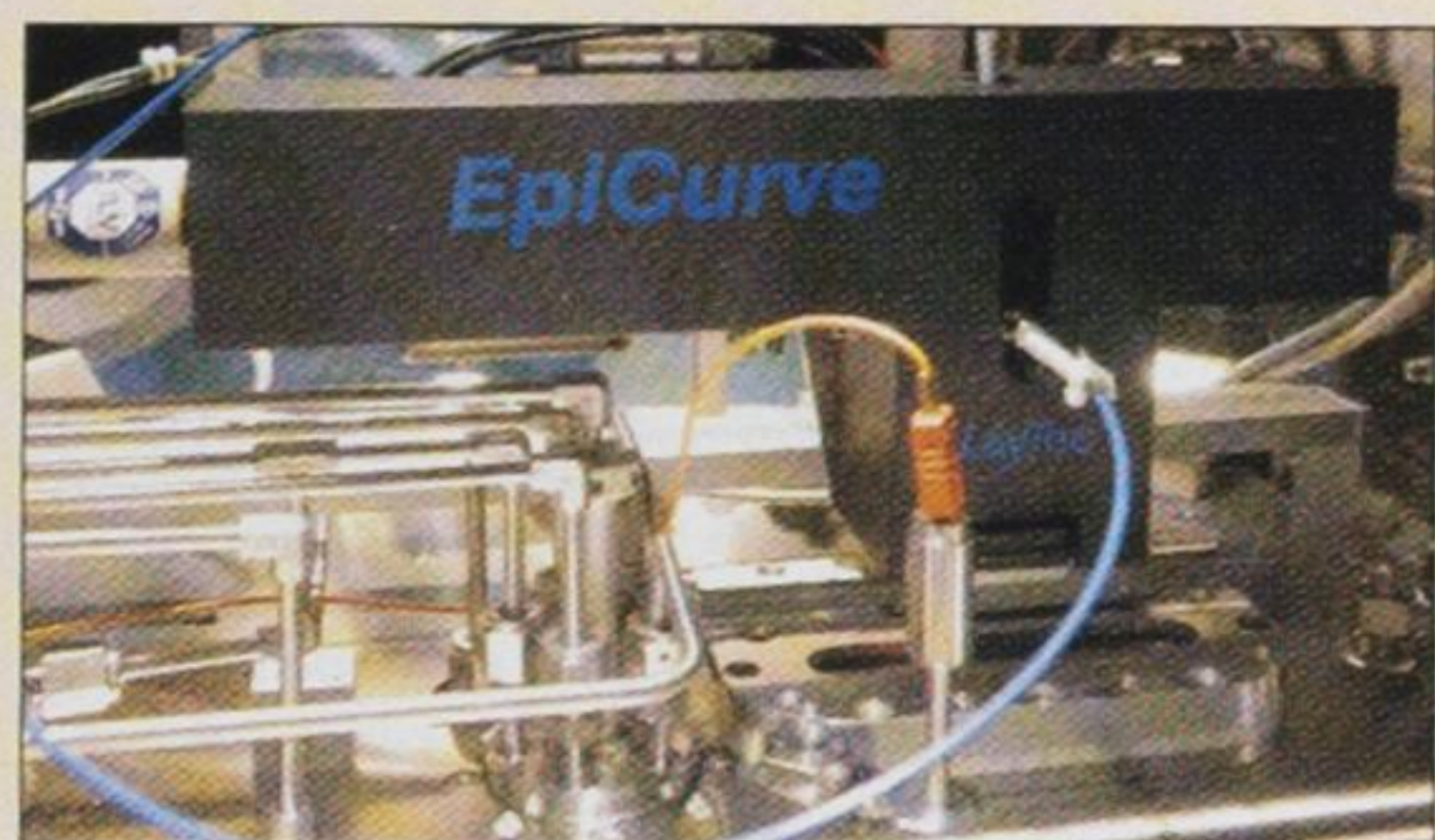


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LayTec has developed a new *in situ* curvature sensor for production-line MOCVD: **EpiCurve**. EpiCurve is the first *in situ* sensor that combines wafer bowing measurements with reflectance and emissivity-corrected pyrometry, allowing an accurate online surface temperature measurement and growth rate analysis! **EpiCurve** can be used in single- and multi-wafer reactors and even with planetary rotation, as well as on transparent and low-reflectance substrates. It provides all the parameters necessary to optimize yield and minimize bowing-related inhomogeneities in GaN LED production and many other applications.



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Optimistic AXT reduces staff at Fremont facility

AXT claims to have made significant progress in identifying and rectifying the surface morphology problem that has plagued its substrates over the past two years.

The Californian firm says that its latest material is being tested by major customers, and that initial results have been positive.

"Our customers will continue to test larger quantities over the next several months to ensure that we can deliver high-quality products on a consistent basis," said company CEO Phil Yin during AXT's earnings release for the

third fiscal quarter 2005.

The company posted sales of \$6.2 million for the recent quarter, up \$0.2 million sequentially but down 28% year-on-year.

GaAs substrates contributed \$5.4 million in revenue for the third quarter, while InP wafers and raw materials added \$0.2 million and \$0.6 million, respectively. An improvement in gross margins reduced the sequential quarterly loss by \$1 million to \$2.3 million.

AXT will also reduce the head count at its Fremont facility, which stands at 58, by at least 20.

Veeco, Riber say worst is over

Deposition equipment supplier Veeco Instruments believes that the market for MBE and MOCVD tools will soon improve.

While total company revenue in the quarter ended September 30 came in at just over \$100 million, only 10% of that figure was generated from sales of epitaxial equipment. That proportion compares unfavorably with the first nine months of the current fiscal year overall, when sales of MBE and MOCVD machines represented some 15% of revenue.

Demand for the US supplier's deposition tools has also declined markedly from last year, with CEO

Edward Braun commenting that a companywide improvement in sales had been offset by the weak compound semiconductor sector. Braun added that he believed the dip in demand had now bottomed out, and that Veeco expected to see a better performance from the division in 2006.

Meanwhile, MBE equipment supplier Riber revealed total sales of €9.3 million (\$11.2 million) for the first nine months of 2005, an 82% increase on the same period last year. Overall, the France-based company has witnessed a 40% increase in orders compared with the same period last year.

In brief

● **Intel Capital**, the venture investment wing of the world's top silicon chip manufacturer, has invested an undisclosed sum in UK-based chemical precursors supplier **Epichem**.

The funds will be used to accelerate the development of novel chemicals, specifically relating to the areas of low-temperature silicon epitaxy, strained-silicon devices, low-k

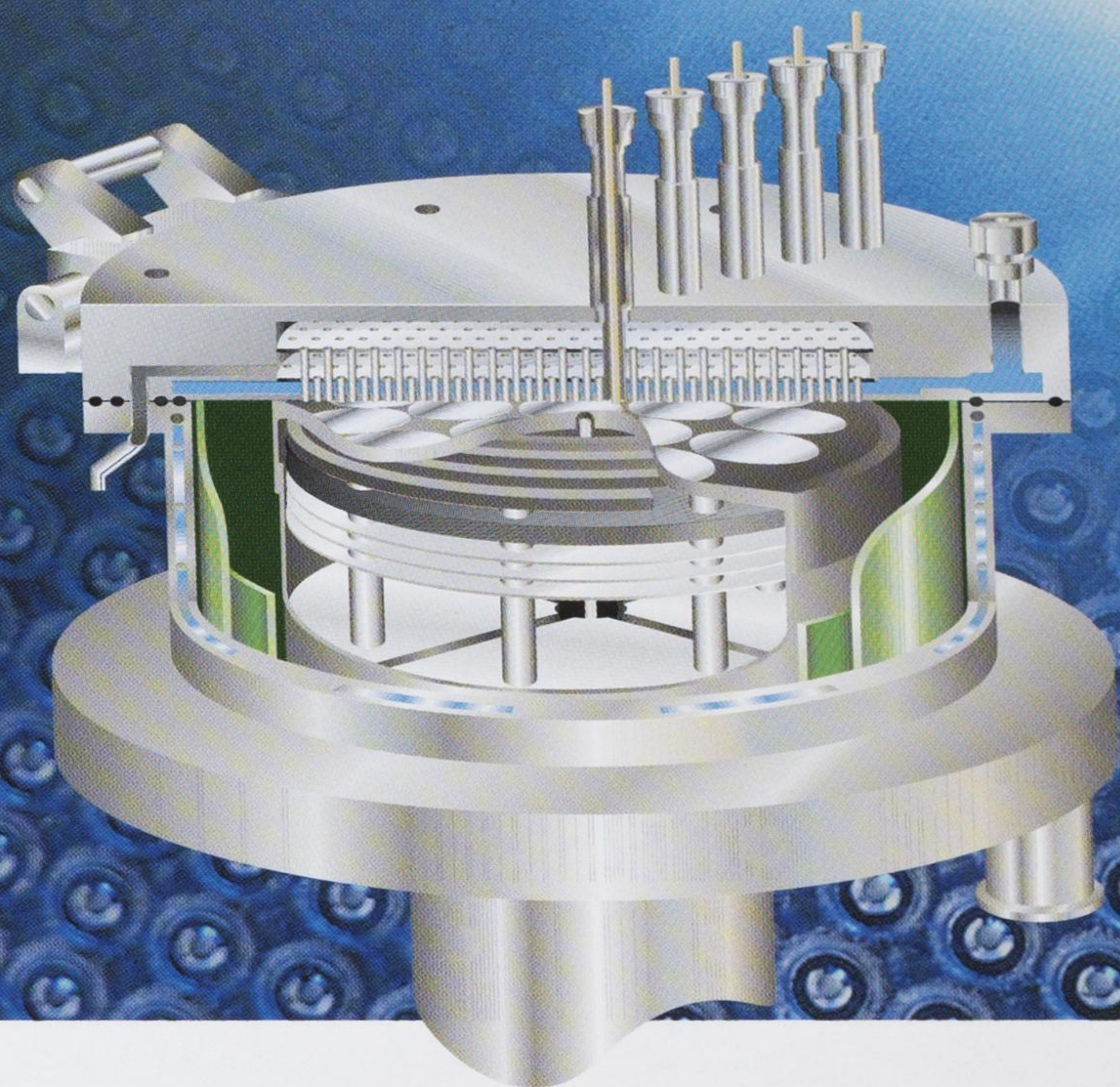
dielectrics and barrier layers.

● Rising orders for HBT circuits increased **Kopin's** revenue from its III-V division by \$0.9 million sequentially, and \$1.8 million year-on-year, to \$10.8 million, in the most recent quarter. However, the company does expect overall sales to fall to \$23-25 million in the fourth quarter owing to end-of-year seasonality.

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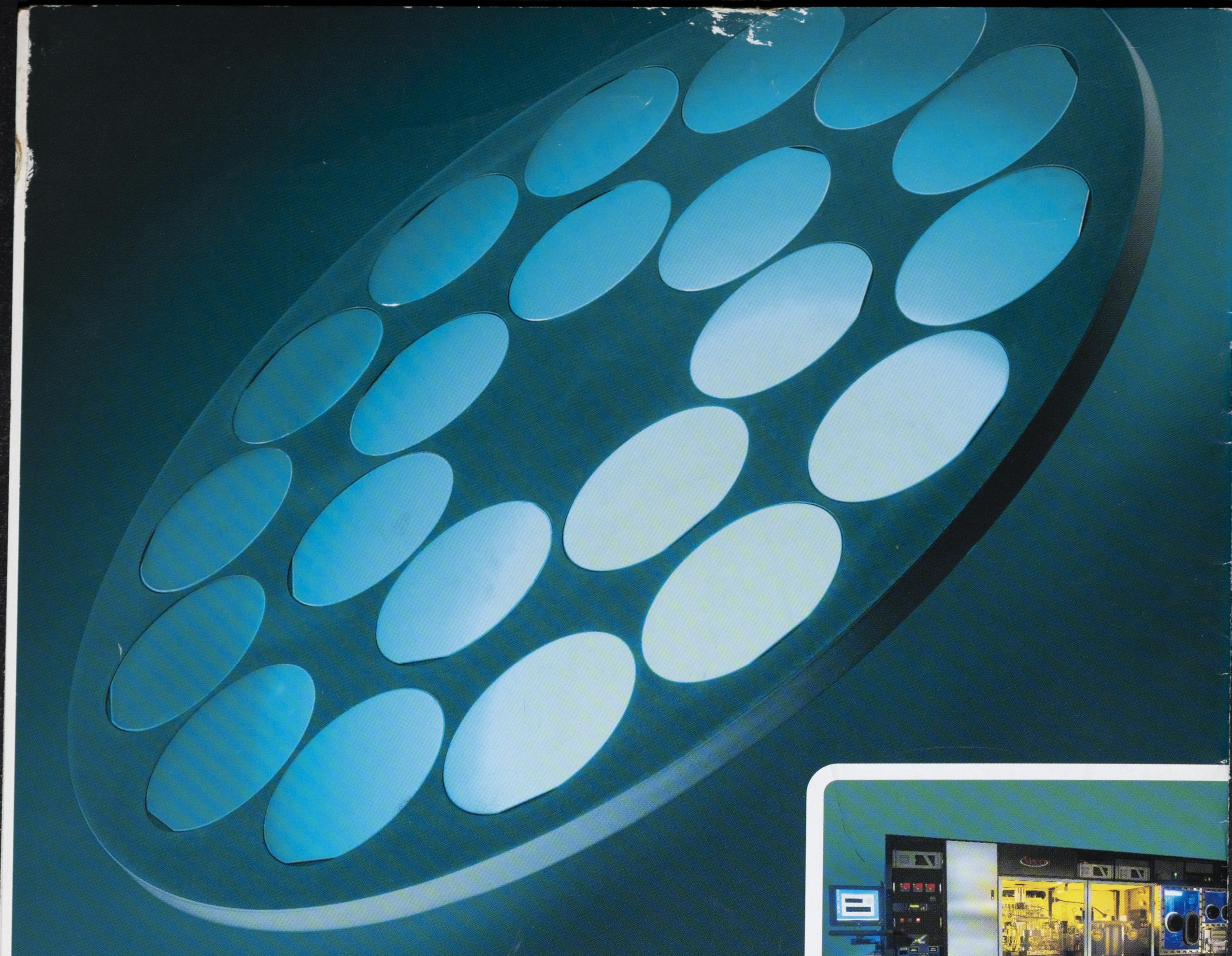
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