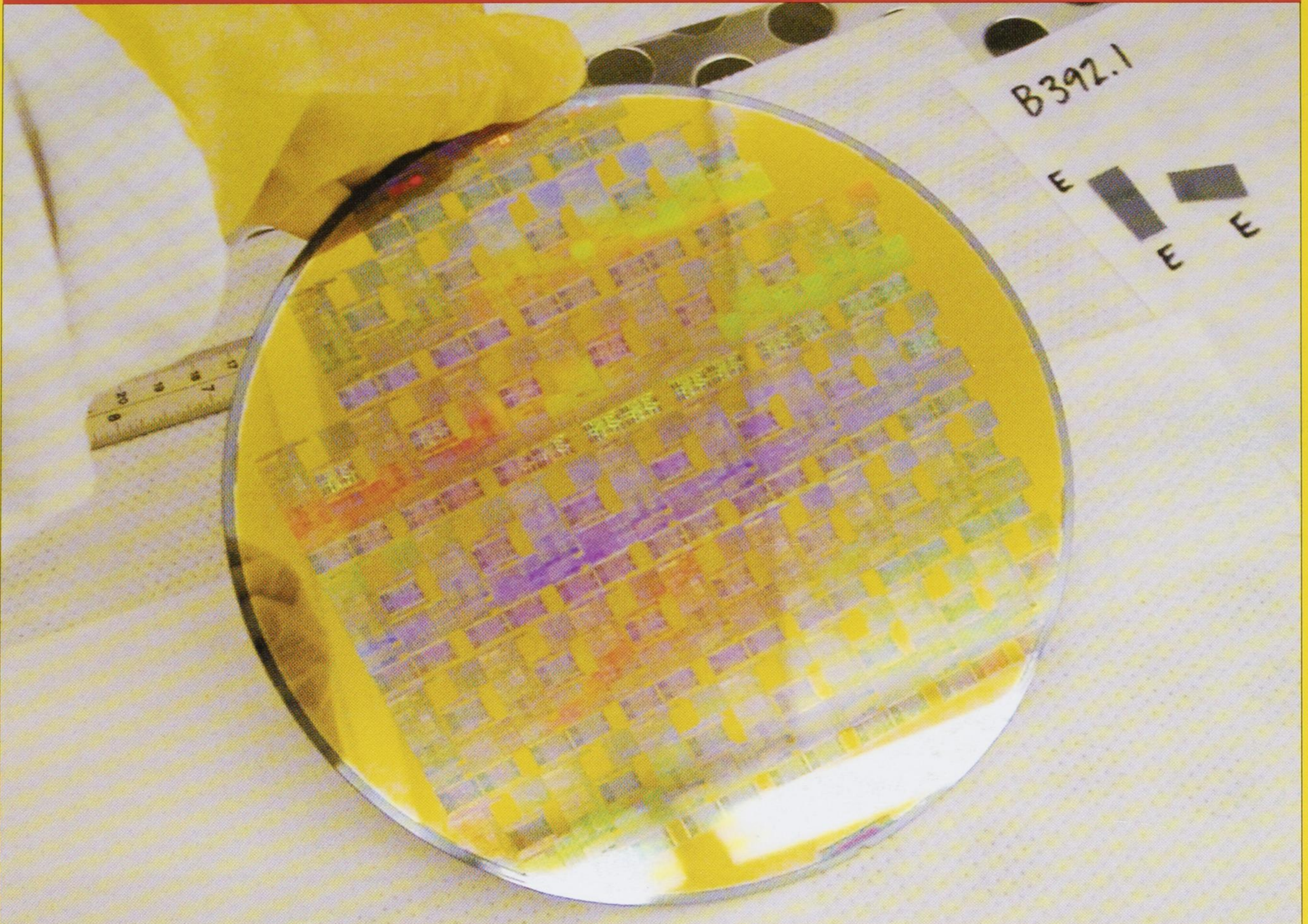


COMPOUND SEMICONDUCTOR

Three-Fives and Silicon Heterostructures

September 2004 Volume 10 Number 8



NEW TECHNOLOGIES
Strained silicon, antimonides
and quantum cascade lasers

ALSO INSIDE

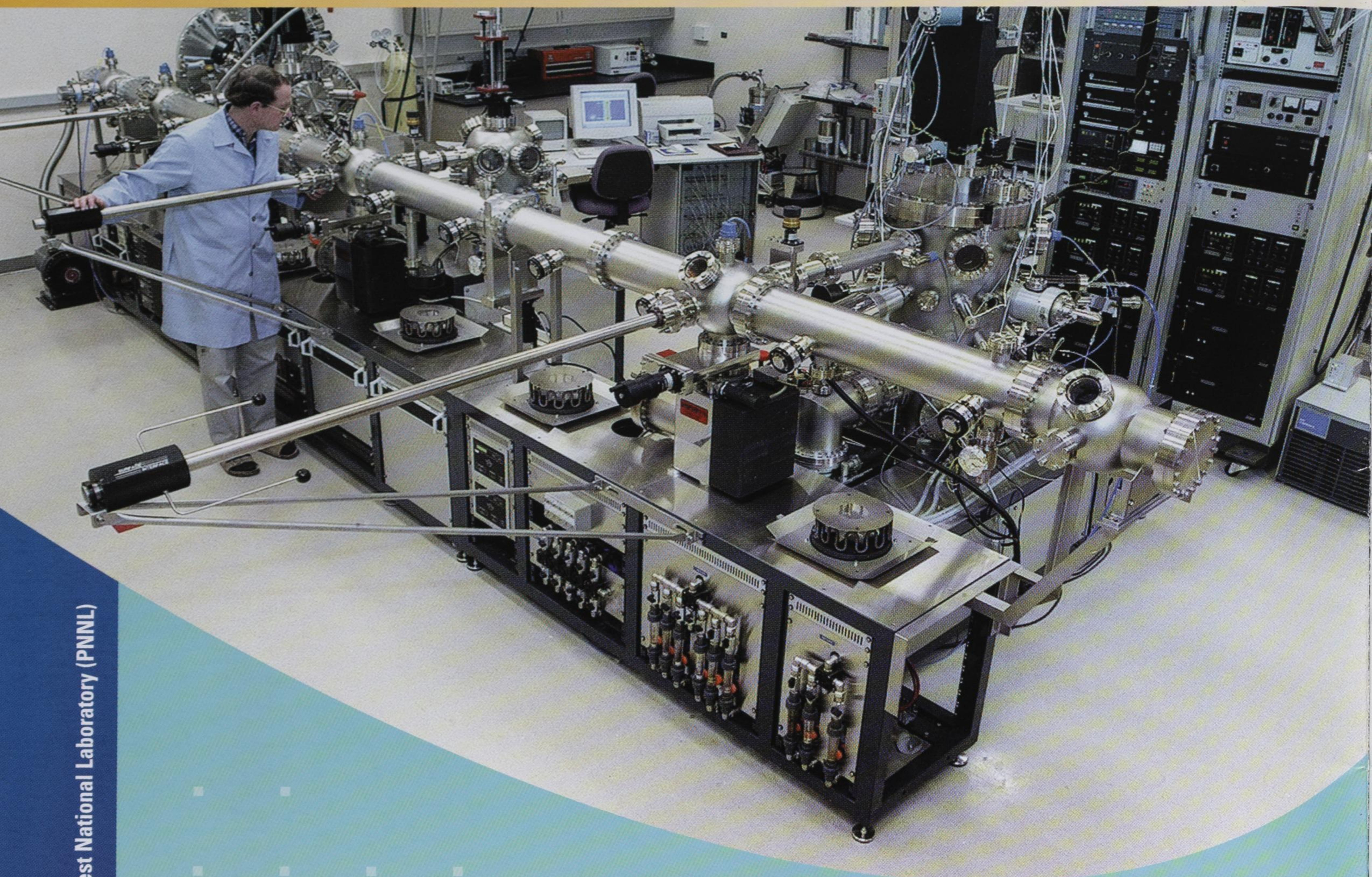
**Cree to expand with
\$300 m investment**

**RFIC makers profit
from handset frenzy**

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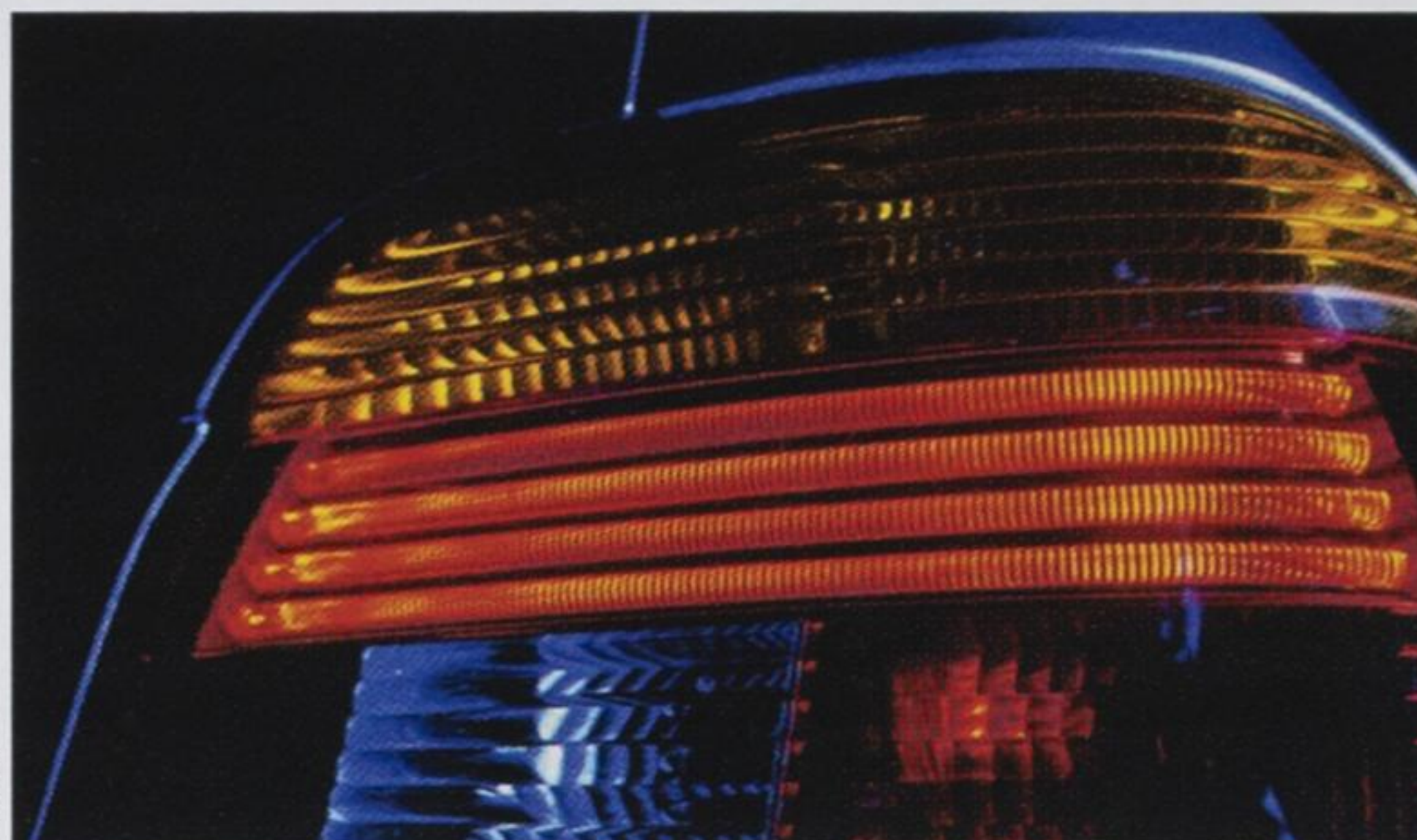
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Three-Fives and Silicon Heterostructures

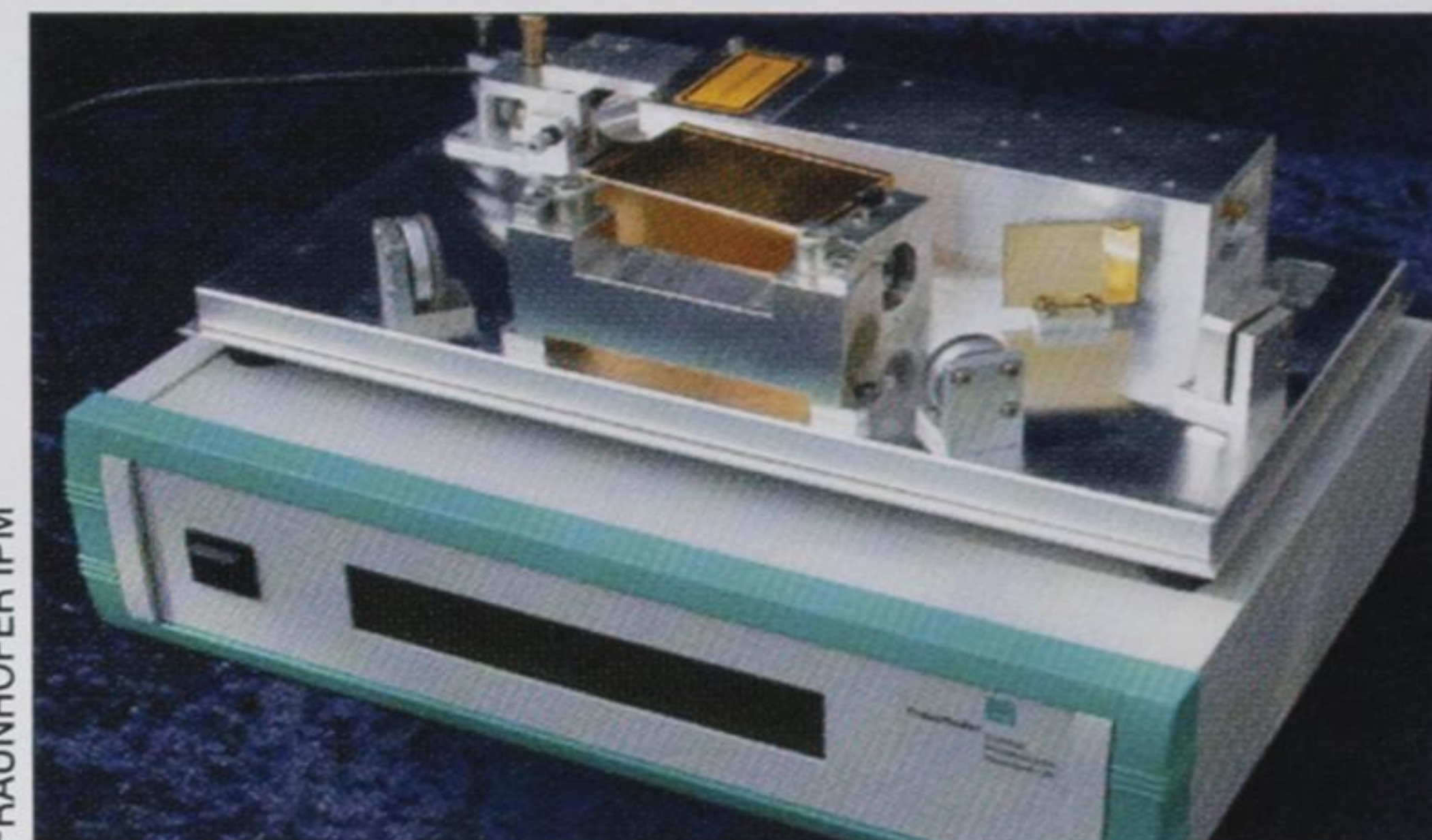
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On the cover: A finished 200 mm (8 inch) strained-silicon wafer with 20% germanium content in the SiGe layer beneath the strained layer – see p18.
Credit: AmberWave Systems.

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Convergence: from consumer electronics to Monterey Bay



“Convergence” is one of those buzzwords that has been talked up for the past few years, particularly by marketers urging us to sign up for broadband Internet access, bundled together with television and telephone services.

Now we’re beginning to see a different kind of convergence at the hardware level, with III-V devices playing a crucial role in various functions. To gauge the potential impact, you need only look at Sony’s new range of televisions featuring LED backlights from Lumileds.

High-definition television (HD-TV), which is designed to maintain visual clarity in large-area flat displays, is a key emerging technology, particularly in the Far East.

III-V technologies have two important roles in HD-TV. The first is in these LED backlights, which reproduce colors in a truer fashion than conventional cold-cathode fluorescent tubes. This is particularly the case with the red portion of the spectrum, and anybody who has seen an LED-backlit display will appreciate the improvement in that color’s reproduction. The trouble with HD-TV is that so much extra data is required that conventional storage options do not have sufficient capacity for recording or playback. That’s where the GaN-laser-inspired Blu-ray Disc format comes in, something that Sony mentions when promoting its new televisions. It doesn’t stop there – Sony is also planning to exploit the 50 GB-capacity Blu-ray format in its next games console, dubbed the PlayStation 3.

Opto device manufacturers aren’t the only ones to feel the force of convergence. In the digital age, people will no doubt want to view their high-resolution digital holiday snaps in HD-TV format, ideally using a fast wireless interface of the kind enabled by GaAs- or SiGe-based devices.

Convergence of another kind is happening in Monterey, CA, later this year. Running in tandem, the CS-MAX and CSICS conferences will aim to spur the commercial development of all the types of devices mentioned above. For more details see pp23–4.

Michael Hatcher

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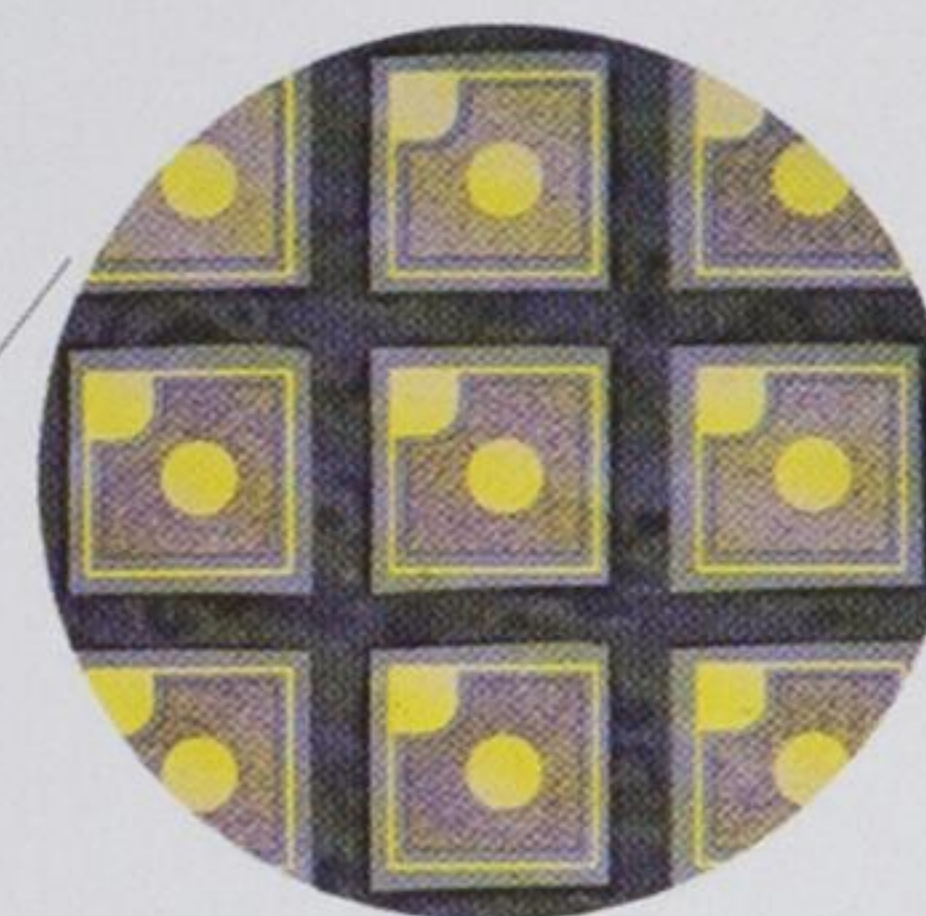
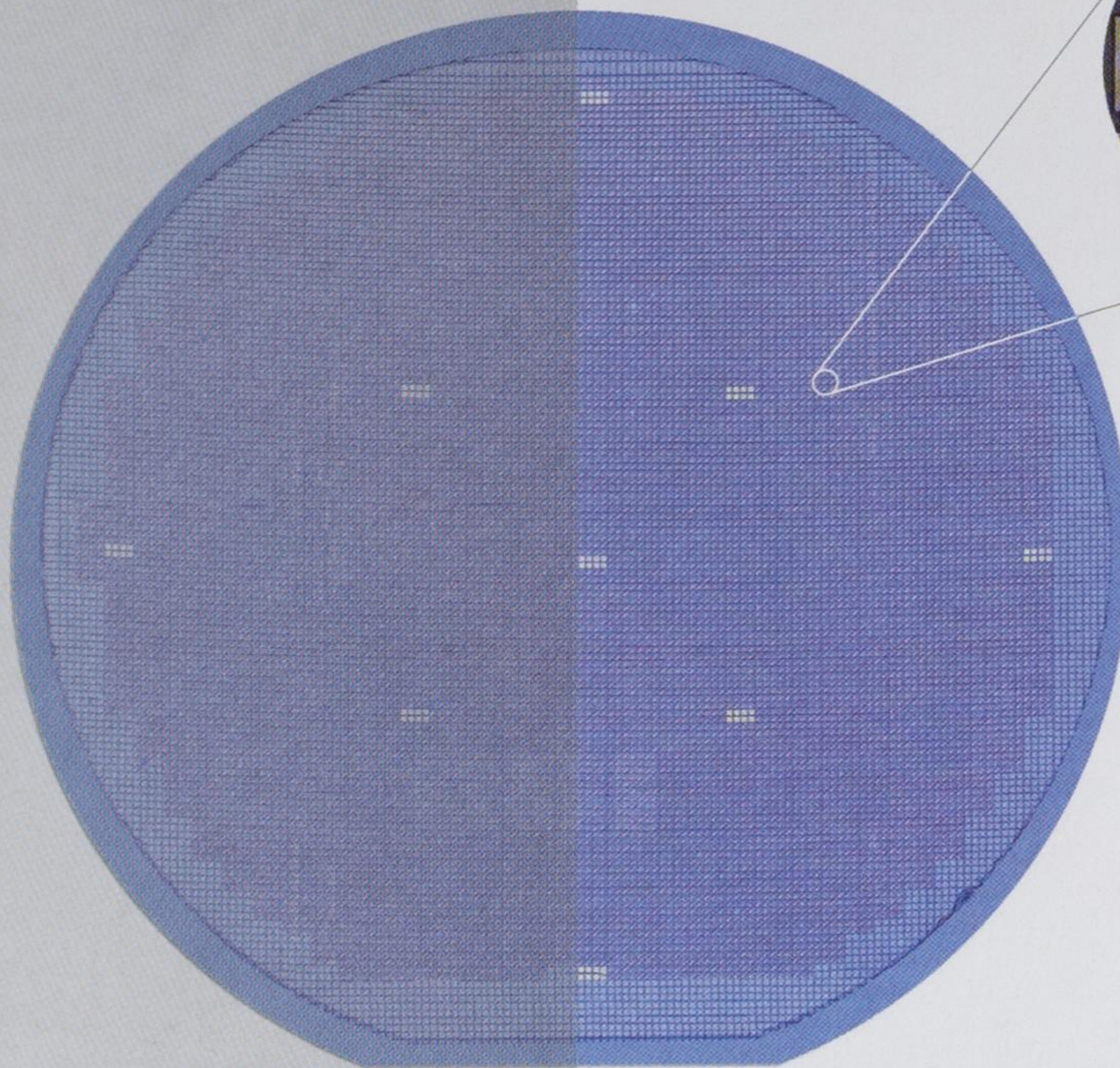
PERFORMANCE

A Bright Idea

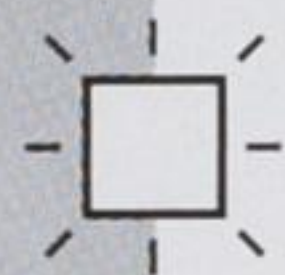
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Cree spells out \$300 m expansion plan

By Michael Hatcher

US-based LED, RF device and substrate manufacturer Cree will increase manufacturing capacity through the investment of \$300 million on plant and equipment and the creation of at least 300 jobs over five years.

The expansion, which will focus on manufacturing and R&D, is to be located in the Research Triangle area near to the company's Durham headquarters in North Carolina. Work will start this fall.

"This expansion will help position the company for our targeted future growth not only in LED chips, but also in our new XLamp and power product lines," said Cree's CEO, Chuck Swoboda, in a recent conference call.

The XLamp is Cree's most recent product introduction and marks the company's first foray into the supply of packaged LEDs. Before releasing the company's fiscal 2004 financial results, Swoboda revealed that the first in a family of high-powered packaged LED products was available in production quantities for the first time. Or, as he put it: "Cree has now officially entered the race to replace the lightbulb."

Norbert Hiller, VP of Cree Lighting, said: "We have been sampling selected customers over the past two quarters for potential use in applications such as channel letters, appliance lighting, track lighting and reading lamps. Feedback on the design and perfor-

mance has been very positive."

"We can now focus on ramping our production capability to service our customers while continuing to expand our product line to address the needs of several emerging applications, including automotive headlamps and backlighting for large-format LCD screens."

The company is also transferring LED growth to 3 inch wafers, a task that will take approximately a year to complete but that will double the number of production chips that can be manufactured on each wafer. Cree

"Cree has now officially entered the race to replace the lightbulb."

CHUCK SWOBODA, CREE CEO

plans capital equipment expenditure of up to \$120 million in the coming year.

In the conference call, Swoboda revealed more plans for future products, including the launch of a 30 mW packaged LED chip by the end of calendar 2004. Such a device would enable white light output of 100 lm/W, a figure of merit that is critical for more widespread LED lighting, said Swoboda. The Cree CEO described LED sales as "soaring" due to demand for use in cell phone handsets and

LED displays, and said that with the company running LED production "at full capacity" Cree needed to improve yield while adding more equipment and people to its fab.

Meanwhile, pilot production of the XT24 XThin device (the company's brightest LED chip at 24 mW) has begun, and the company has also started sampling the even brighter XT27. In a reference to the variety of lawsuits and manufacturing licenses recently issued in the GaN-based LED community, Swoboda said that Cree's legal team was on standby to enforce the company's intellectual property.

Sales of LED chips make up the vast majority of Cree's revenue, but Swoboda said that its power device division was also growing. However, with what was described as a "production bottleneck" in its wafer fabs (possibly due to the overwhelming demand for LEDs), manufacture of Schottky diodes will now transfer to the company's fab at Sunnyvale, CA. The transfer is expected to be completed around the middle of next year. Cree now manufactures power devices on 3 inch wafers but has long-term plans to convert to 4 inch production. Swoboda said that Cree was evaluating strategic partnerships with respect to its silicon LDMOS product line.

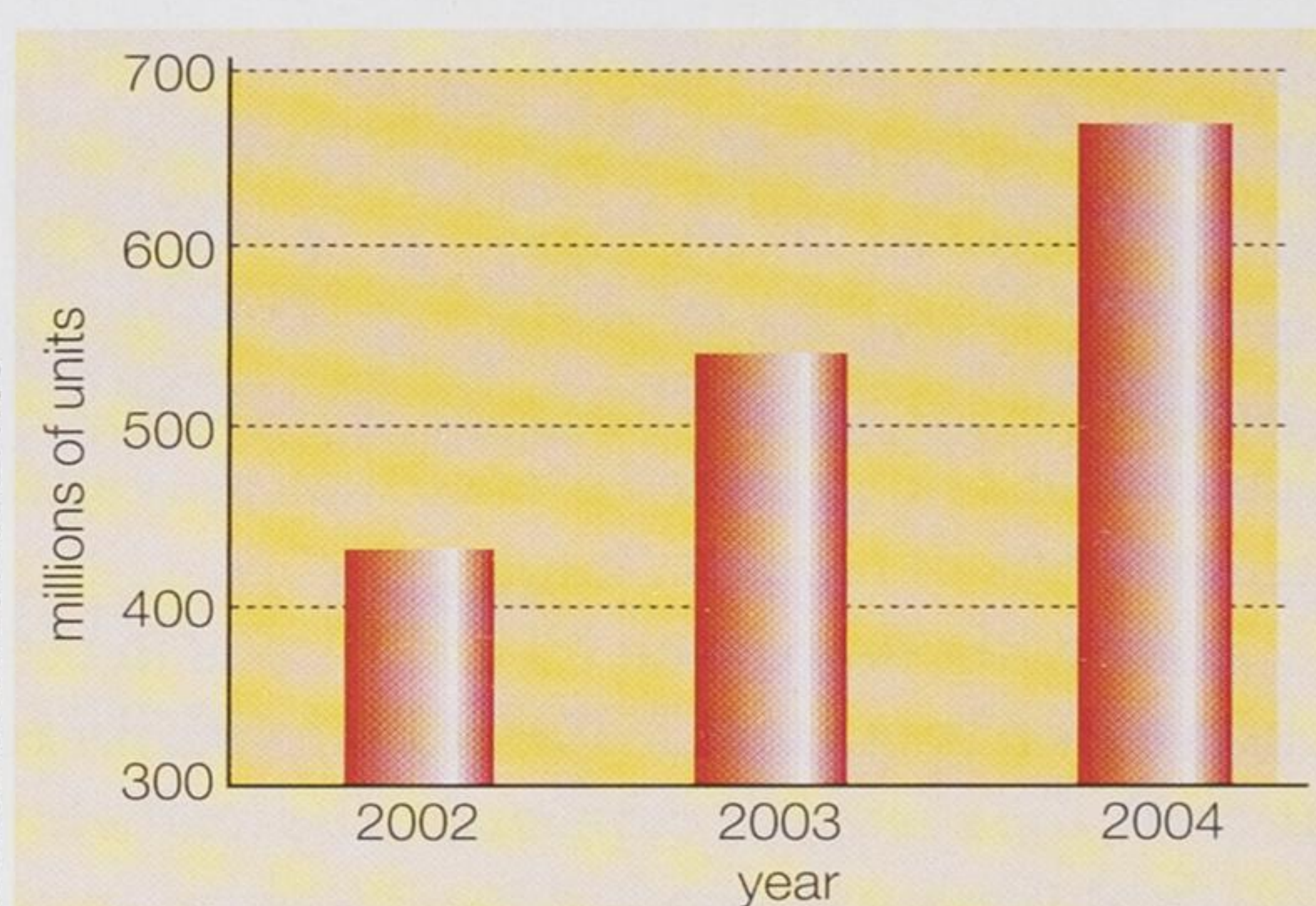
● Cree reported record revenue of almost \$307 million and a net income of \$58 million in its fiscal 2004 financial results. For more details, see Portfolio on p33.

Handset market looks set for another bumper year

Sales of cell phone handsets will reach a record 670 million units this year, says a new report from the market research company Strategy Analytics. If correct, the figure, which is equivalent to around 10% of the world's population buying a new phone, would represent a huge increase on the 540 million phones estimated to have been sold in 2003.

Handset sales are a key market indicator for the compound semiconductor industry because most cell phones use GaAs ICs in their power amplifier stages and an increasing number of LEDs to illuminate the keypad and screen. Even more LEDs are required on newer models that feature high-resolution cameras and video messaging.

The report says that 157 million phones were shipped in the second quarter of 2004, with the Korean company Samsung making strong



Still booming: with a "cell phone frenzy" in Brazil and Russia, the sale of handsets is predicted to go through the roof this year.

gains on the number-two supplier, Motorola.

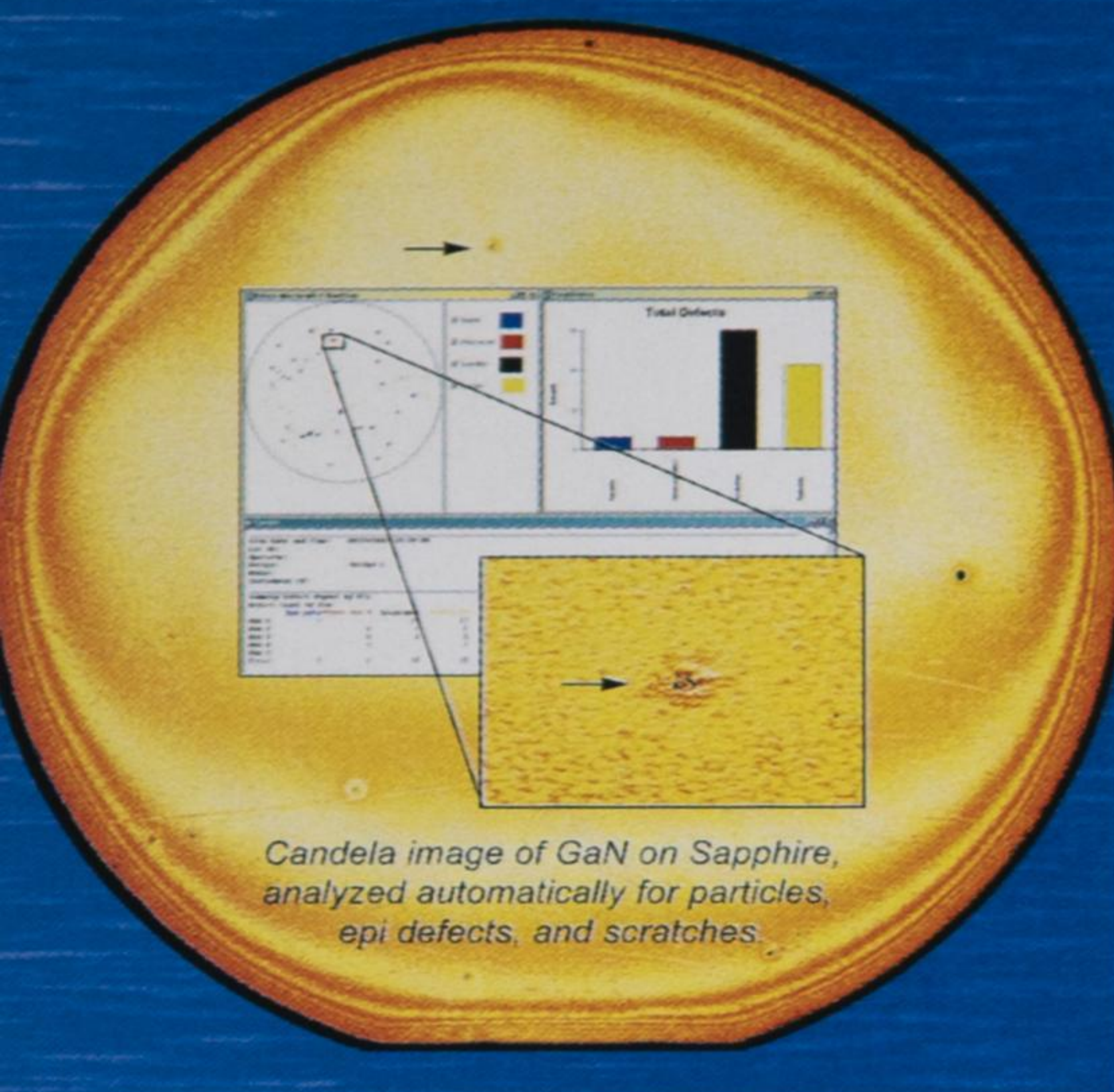
Strategy Analytics had initially forecast that 586 million handsets would be sold this year, but raised this figure by over 14% in the face

of strong economic drivers, fierce industry competition, and the roll-out of enhanced wireless services.

Neil Mawston, who authored the report, told *Compound Semiconductor* that another key driver was the widespread transition from monochrome to color phone displays.

"It is a global phenomenon. From the Asia-Pacific region to Europe to the Americas, demand has surged in low-, mid- and high-[end] segments," Mawston continued. "The low-end is driving volume in developing markets, while the mid- and high-end color is driving sales in developed regions."

Mawston added that consumers in Brazil and Russia were experiencing a "cell phone frenzy", although he also noted that in 2005 and 2006 the cell phone handset market is not expected to grow at the same pace.



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Rockwell Scientific's HBTs join the high-speed club

By Richard Stevenson

US-based Rockwell Scientific is the latest company to develop a 152 GHz InP-based transistor under DARPA's TFAST program. A collaboration headed by the company made the static frequency divider circuit using double heterojunction bipolar transistor (DHBT) technology.

Rockwell's work is part of a program funded by the Defense Advanced Research Project Agency (DARPA) called Technology for Frequency Agile Digitally Synthesized Transmitters (TFAST).

Bobby Brar, Rockwell Scientific's program manager for TFAST, told *Compound Semiconductor* that other program participants, namely Northrop Grumman Space Technology, HRL Labs, and a BAE Systems/Vitesse team, have made similar transistors operating in the 150–153 GHz range.

"Digital circuit performance has increased from 100 GHz to 150 GHz in 18 months, which is an unbelievable feat," said Brar. Rockwell's

DHBTs have smaller lateral and vertical dimensions than standard devices, allowing them to be operated at higher currents, he explained. Higher currents equate to lower charging times for device and load capacitances, leading to the higher operating speed.

The company claims that its DHBTs provide high electrical breakdown, low phase noise, and wide bandwidth for use in systems that include in-flight reprogrammable satellite communications links and millimeter-wave transmitters.

Brar explained that Rockwell intends to produce the DHBTs commercially in the future. The aim of the second phase of the TFAST program involves increasing the functionality in either digital or mixed-signal circuits through higher levels of integration.

"The near-term applications of TFAST are focused on the high-performance needs of military systems, but the potential for future commercial uses are great, especially in wireless and telecom applications," said Brar.

Radar and sensors aim to cut 'friendly fire'

A high-speed scanning radar system that incorporates GaAs devices has been successfully operated aboard US Navy warplanes.

Developed by US defense contractor Raytheon, the APG-79 Active Electronically Scanned Array (AESA) radar system promises to improve the situational awareness of aircrew. Because the technology scans far more quickly than older, mechanically operated radar, it enables the simultaneous tracking of multiple targets. According to Raytheon, AESA radar also allows multiple targets to be detected at a far greater distance than previous generations of radar technology.

Following more than 80 test flights in the past year on board the US Navy's Super Hornet aircraft, the system is expected to be ready for full deployment by September 2006.

Raytheon has also received substantial funding to develop three different ground sensors that should reduce the likelihood of troops being killed by "friendly fire", or "fratricide" as Raytheon calls it. All three sensors appear likely to incorporate compound semiconductor technology.

The medium-range electro-optical infrared



GaAs in action: the US Navy's Super Hornet has used AESA in more than 80 test flights.

sensor, an advanced image-processing system, will use near-infrared emitters for laser designation of military targets.

The second sensor under development is based on millimeter-wave communications, and its aim is to determine whether soldiers or vehicles in the battlefield are "friend or foe". The final ground sensor uses advanced radar to alert on-board protection systems of an impending attack, as well as to enable ground-to-air communication.

The three sensors will be developed with total funding of almost \$223 million.

1
GaAs
Gallium Arsenide

2
ZnSe
Zinc Selenide

3
InGaP
Indium Gallium
Phosphide

4
ZnO
Zinc Oxide

5
SiC
Silicon Carbide

6
InGaAlP
Indium Gallium
Aluminum Phosphide

7
InP
Indium Phosphide

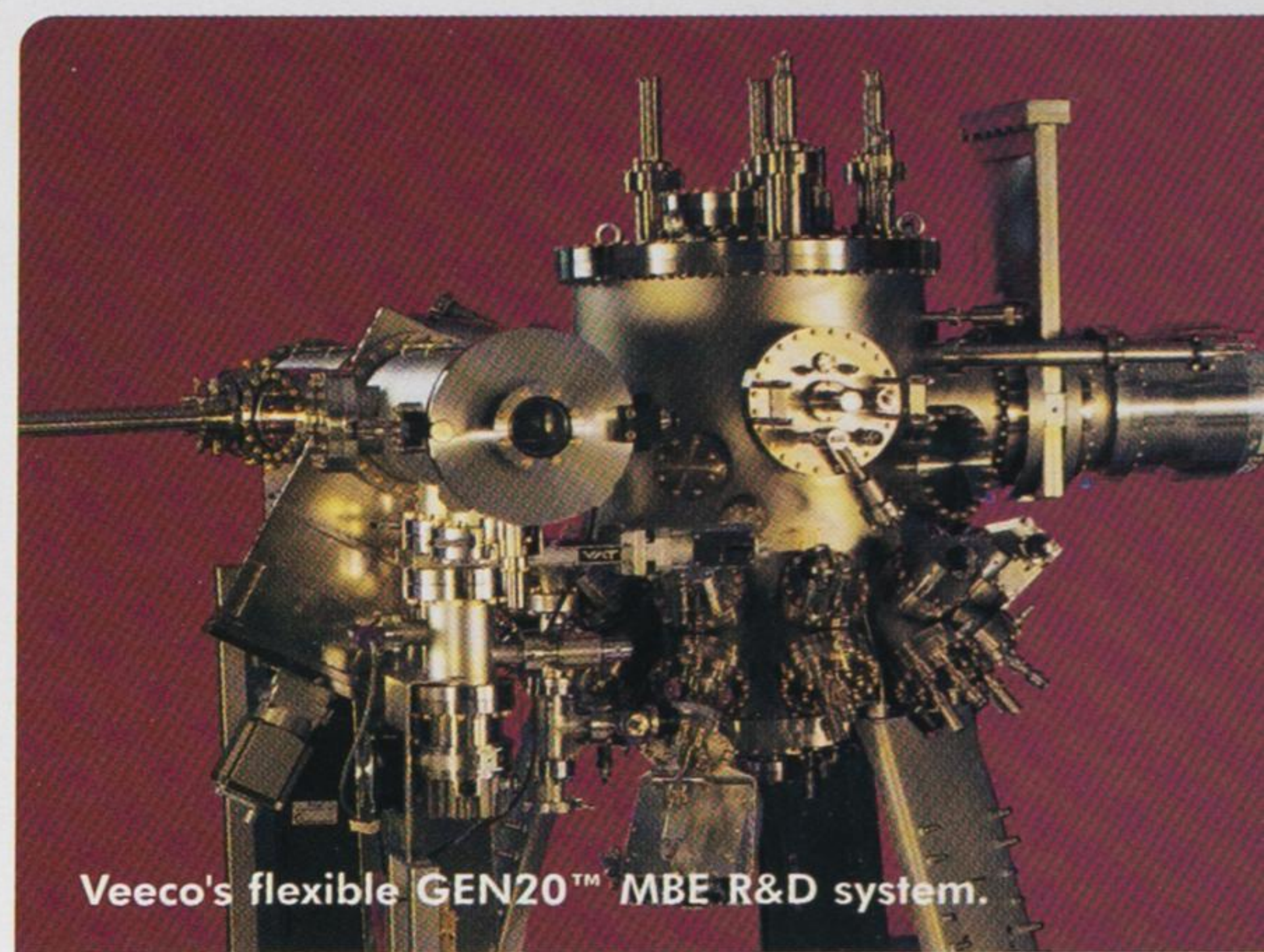
8
GaN
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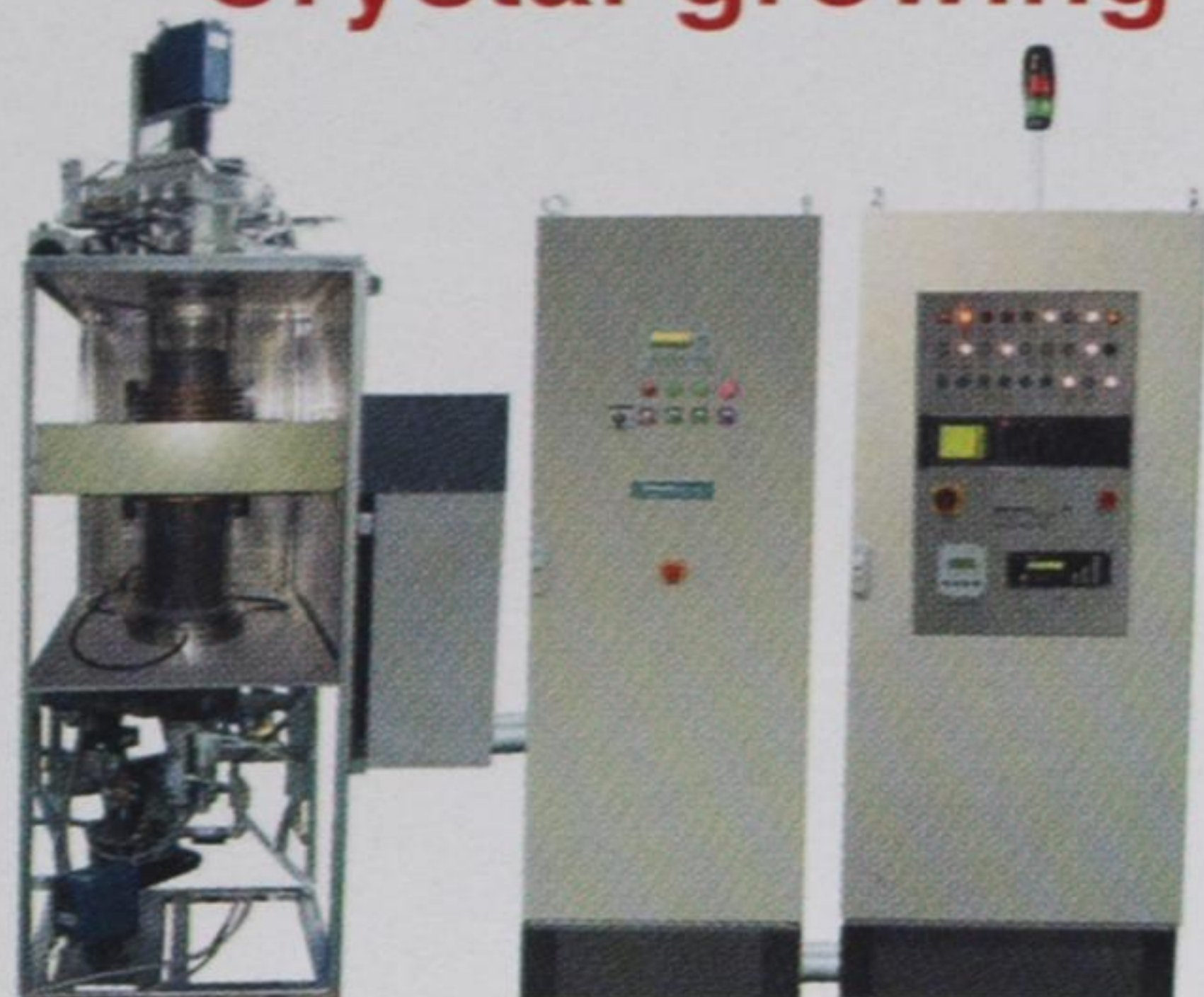
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GaAs & WIRELESS NEWS

GaAs IC market expected to reach \$3.9 bn in 2004

The GaAs IC market grew by almost 33% in 2003 to reach \$2.86 billion. That's the conclusion of a report from US-based analyst company The Information Network (TIN), based in New Tripoli, PA. The report says that growth this year will be even faster, with the total market predicted to reach \$3.9 billion.

Although the weakened US dollar has undoubtedly contributed to the increase, TIN president Robert Castellano estimates that the currency effect accounted for only around 10% of the growth.

Predictably, it is the evergreen cell phone handset market that is primarily driving growth, with Castellano confident that well over 600 million handsets will be shipped this year worldwide. Handset power amplifiers accounted for 53% of the total GaAs IC revenue in 2003, while wireless LAN applications contributed strongly with 22% of the market, says the TIN report.

Castellano expects growth to slow over the

next two years, despite being bolstered by the implementation of WiMax and 3G cellular technologies. He believes that the GaAs IC market will grow a further 25% in 2005 and then by around 16% the following year. If he's right, the 2006 figure of \$5.65 billion would represent a doubling of the 2003 market.

One unpredictable element of the GaAs IC market is price erosion, which has resulted partly from the emergence of cheaper suppliers in the Far East. Castellano estimates that the average selling price of GaAs ICs fell by 13% in 2003, and that prices will continue to drop by 10–15% each year.

He added that foundry revenues came in at \$105 million in 2003, representing less than 4% of the overall GaAs IC market. RF Micro Devices remains the number-one GaAs IC vendor, ahead of Skyworks.

TIN expects sales of SiGe ICs to reach \$2.15 billion in 2006 as SiGe devices take market share from GaAs in handset receivers.

Power device vendors face tough future

A "very difficult period" lies ahead for manufacturers of RF power amplifiers (PAs) and RF power semiconductor devices used in cellular systems, according to a downbeat report from US-based market analyst ABI Research.

ABI's report focuses on the PAs and power devices used specifically in cellular base stations. While the cell phone handset market for PAs dwarfs that of the infrastructure market, ABI warned that the base station sector faces an "inevitable slow-down".

Despite the substantial roll-out of third-generation networks such as W-CDMA, ABI believes that total spending on cellular systems will fall as the large-scale deployment of GSM networks peters out.

"Due to an interplay between consumer usage patterns, system efficiencies and falling component costs, the net spending on RF

power amplifiers will actually decline as the new networks are rolled out," said ABI.

And the component suppliers, rather than the base station builders, will bear the brunt of this slow-down, according to ABI analyst Lance Wilson. "For independent manufacturers and suppliers of RF power amplifiers, this is not good news," he said.

Wilson added that manufacturers of RF devices will face an even tighter squeeze as price erosion takes its toll. "Their only way out is to diversify into making other types of semiconductors that base stations also need," he concluded.

Wilson acknowledged that some PA suppliers had anticipated the slow-down and had moved towards vertical integration to supply more of the base station components and complete systems.



One billion and counting: RF Micro Devices, the US-based RFIC manufacturer, claims it has set an industry record as the first wireless semiconductor firm to ship one billion power amplifiers for mobile phones. RFMD was confirmed as the market leader in GaAs ICs in two recent surveys.

Consortium proposes 540 Mb/s Wi-Fi standard

Six leading companies involved in the wireless LAN sector have proposed a new standard that could operate at up to 540 Mb/s. The WWiSE consortium, which includes the chip manufacturers Texas Instruments (TI) and ST Microelectronics (STM), has submitted its idea to the IEEE's Task Group N. The group is overseeing the development of next-generation wireless connectivity that can sustain data throughput of over 100 Mb/s.

The broadband standard that eventually emerges will be denoted 802.11n, and will supersede the 802.11a, b and g standards that are used at the moment. These existing standards have a maximum theoretical link speed of 54 Mb/s, but in practice the throughput of such connections is far below this data rate.

According to the consortium, WWiSE

stands for "worldwide spectrum efficiency". The six companies involved say that their proposal was developed with global deployment and backwards compatibility in mind.

The proposal is centered around the use of the current 20 MHz Wi-Fi channel width. The 540 Mb/s links will be generated by using either a 2×2 configuration of 135 Mb/s connections at 20 MHz, or a 4×4 structure that uses a 40 MHz channel width.

The wireless LAN, or Wi-Fi, sector has emerged in the past few years as a substantial market for manufacturers of GaAs and SiGe ICs because these devices are required in the power amplifier stages of wireless links.

As well as chip makers TI and STM, the WWiSE group includes Airgo Networks, Bermai, Broadcom and Conexant Systems.

Anadigics gets in trim with laser patent

US-based RFIC manufacturer Anadigics has been awarded 14 new US patents, including patent 6,664,500 that describes laser trimming or severing of the resistive links fabricated on a GaAs substrate.

The technique can cleanly process a thin-film resistor fabricated on an undoped GaAs substrate without damaging adjacent circuits. It can also trim thin-film transistors, enabling, for example, bias current adjustments to a power amplifier to tune its quiescent current.

Laser trimming has already been successfully applied to resistors on silicon substrates, but Anadigics believes no-one has transferred the technique to GaAs.

Anadigics' method recommends using a laser with emission at 1047 nm, although satis-

factory results may be obtained with wavelengths between 900 nm and 1500 nm.

Other patents awarded to Anadigics include:

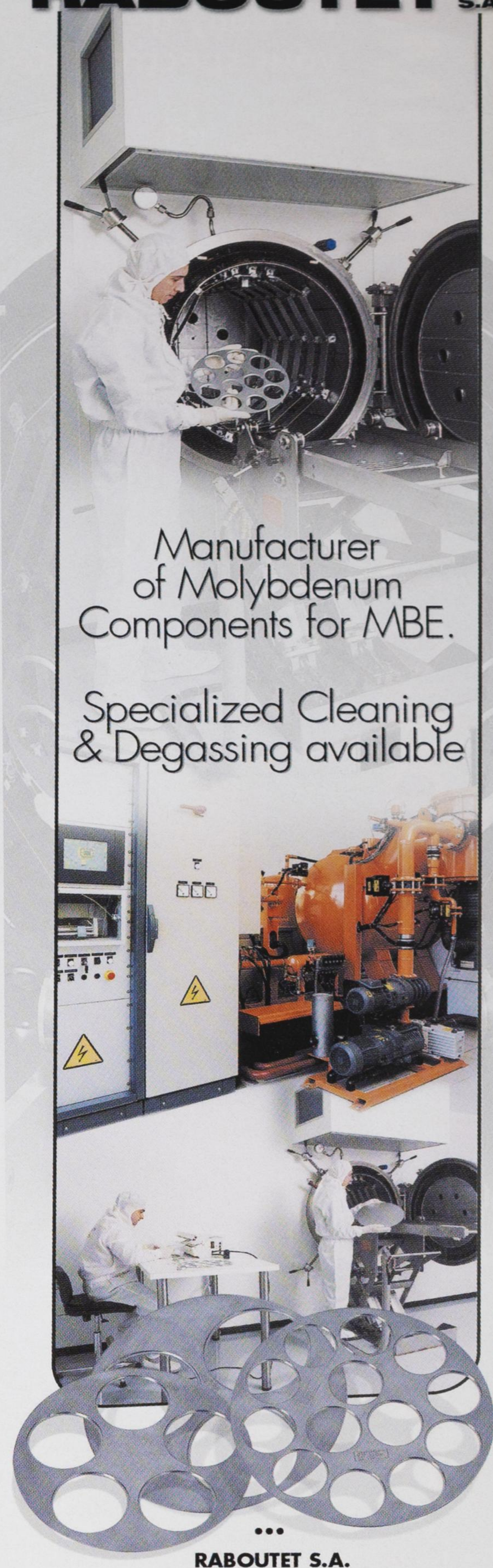
- 6,759,922, which describes an RF power amplifier coupler that is considerably shorter than a quarter wavelength coupler, and which achieves directivity requirements for both the GSM and DCS/PCS bands;
- 6,645,790, granted for a method that reduces the time required to bring new RF and microwave devices to market by enabling designers to selectively couple and uncouple device blocks late in the design process; and
- 6,559,722, granted for a new bias circuit that improves cellular handset battery life by operating near Class B mode while the driver signal level is low.

In brief

● **Gatex Technology**, the Taiwan-based RFIC design house, is to start volume production of chips for power amplifier (PA) modules used in W-CDMA cell phone handsets. According to a report at *Digitimes.com*, the company, which already makes several PA products for wireless LAN applications, says that the third-generation PA modules will enter volume production in either late 2004 or early 2005.

● **WJ Communications** has launched a raft of PAs for wireless-infrastructure applications. The eight new devices are based on InGaP HBT technology.

● **Fairchild Semiconductor**, which makes GaAs HBT and PHEMT MMICs, has released the RMPA1959, a high-performance linear PA module for CDMA and CDMA2000-1X personal communications system applications.



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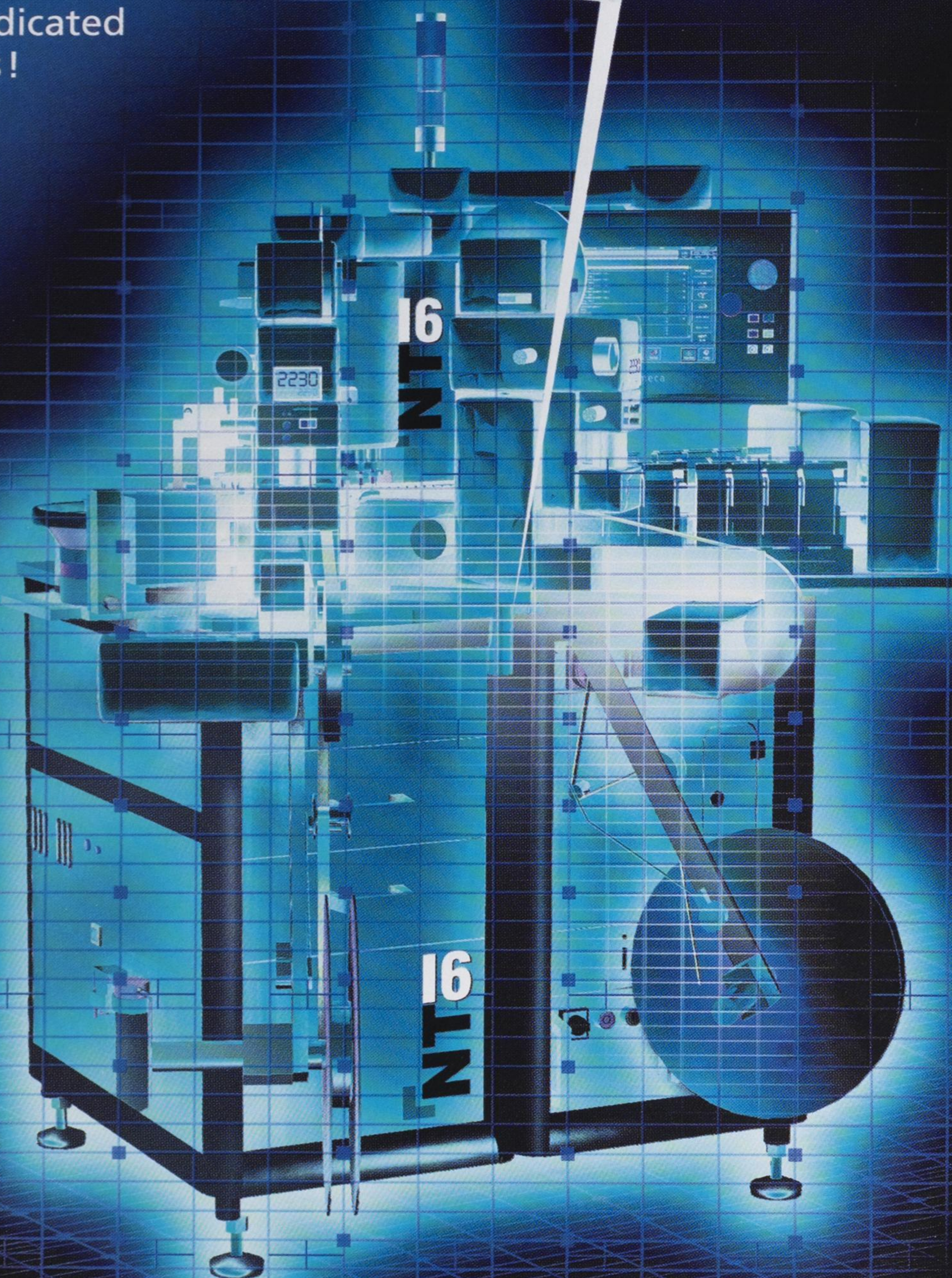
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Solid-state lighting teams receive \$20 m from DoE

The US Department of Energy (DoE) has selected 11 research projects to fund under its solid-state lighting initiative. Just under half of the overall figure of \$20 million is earmarked for work directly relating to compound semiconductor materials, while the remainder will be spent on organic alternatives.

Of the six projects related to compound semiconductors, the one to receive the most funding (\$4.2 million) will focus on the development of advanced phosphors used to convert blue LED emission into white light.

Boston-based Cabot Superior Micro-Powders, which is developing the phosphors, expects to double the external quantum efficiency of such light sources to around 60%. Devices that can emit over 80 lm/W may result.

Another DoE project will look at using hydride vapor phase epitaxy to make GaN-based LEDs (*Compound Semiconductor* August 2004 p23). Boston University researchers will receive \$1.2 million for this effort.

Meanwhile, two projects at Sandia National Laboratories will receive \$1.55 million in total to develop microcavity photonic crystal LEDs and improve InGaN epitaxy for green LEDs via precise temperature measurement through infrared pyrometry. It is hoped that the latter project will dramatically improve the wafer yield of LEDs made in commercial reactors, leading to inexpensive white-light LEDs.

The University of California, San Diego, will receive \$1.2 million to improve the internal quantum efficiency of nitride LEDs.

Nichia cuts InGaN deal with Optotech

Nichia says that it has entered into a collaboration with the Taiwan-based LED manufacturer Optotech.

According to a statement on Nichia's website, the two firms will focus on InGaN materials that are used in blue LEDs.

Japan-based Nichia said that with global LED demand expanding it "has a responsibility to answer the calls for its LEDs", and that the Optotech deal was part of its plans to "secure" the LED supply.

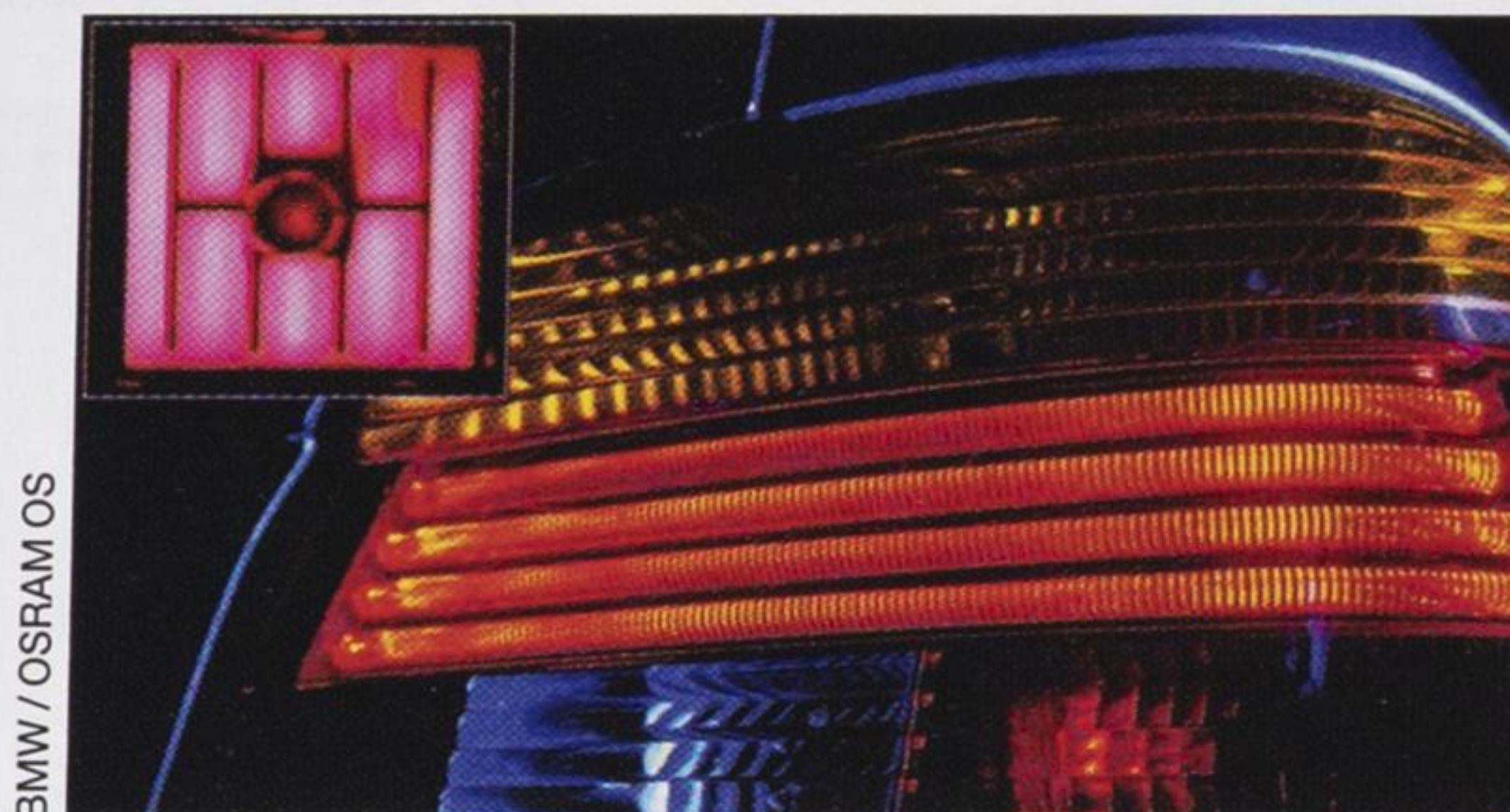
Having originally announced its intention to form alliances with Taiwanese manufacturers in early June, Nichia maintains that this process is ongoing.

Optotech, which makes other products including thermopiles, optical sensors and driver ICs, announced plans in March to build a factory in Ningbo, China.

No stopping for red LED brake lights

Osram Opto Semiconductors of Germany has developed a red-emitting AlGaInP-based LED with an efficiency of 108 lm/W. The emitter, part of the company's TOPLED range, delivers 2 lm at 20 mA and is a refinement of the company's first-generation device (*Compound Semiconductor* December 2003 p20). The second-generation TOPLED employs fewer microprisms, with all the surfaces modified to minimize loss.

Osram's next step is to extend the technology to all AlGaInP colors, and then offer small



BMW employs LED-based rear lights. Inset shows Osram's latest red-emitting TOPLED.

chips that have comparable efficiency to mid-size and large-area chips.

The company is targeting applications that require high-brightness LEDs, such as car tail-

lights and rear combination lamps.

Another LED manufacturer, US-based Lumileds, claims that its Luxeon LEDs have sufficient power to light all rear-vehicle applications, including fog lamps. "Luxeon does to the filament bulb what the bulb did to the gas lamp," said Leonard Livschitz, Lumileds' director of automotive business development.

● Arima Optoelectronics, a Taiwanese LED chip maker, is expecting to receive increased orders for its AlGaInP-based LED chips. The growth of orders is thanks to international car manufacturers launching new models that have LED brake lights. Arima is working in partnership with Japan-based Stanley Electric, a brake light provider for Honda Motors.

In brief

● A government-supported project has been launched in Japan to develop medical equipment based on LEDs. The Ministry of Education, Culture, Science and Technology has allocated ¥500 million (about \$4.6 million) for the 2004 financial year to establish the Yamaguchi-Ube Medical Innovation Centre. Similar amounts are expected to be allocated in each of the subsequent four years.

● **Kopin's** CyberLite LED product line looks to have an uncertain future. The company's CEO, John Fan, explained: "We are evaluating different business models,

including pairing our technology with a lower cost structure. We expect to complete our evaluation by the end of the year."

Reports suggest that manufacturing LEDs at the Taunton, MA, facility is "unviable".

● Taiwanese chip maker **Harvatek** saw sales of its SMD (surface-mount device) LEDs decrease by 20–30 million units in July, according to *Digitimes.com*. In July Harvatek shipped 170 million SMD LEDs, with 130 million used in handsets. It predicts that shipments will rise from August to October, then fall in November. Taiwan-based LED manufacturer **Epistar**

expects third-quarter shipments to remain flat or even fall, according to the same source. Epistar previously predicted that it would ship 130 million GaN-based LED chips in the third quarter, although this figure will be revised: second-quarter shipments were 80 million units.

● A collaboration between **Agilent Technologies** and **Lumileds** will develop a series of mid-power LEDs. The devices, which target automotive, mobile phone and lighting applications, will complement Lumileds' high-power Luxeon LEDs and Agilent's low-power devices.

Sony and Samsung use LED-backlight technology in televisions and monitors

For the first time, high-brightness LEDs have made inroads into the key consumer electronics market of televisions. The Japanese consumer electronics giant Sony has launched two ranges of LED-backlit televisions, while its Korea-based rival Samsung is offering 17 inch and 21 inch LCD monitors featuring LED-backlights.

Sony has launched what it believes is the world's first LED-backlit liquid-crystal display (LCD) television. Dubbed "Trilumines", the LED backlighting improves the color rendering of the displayed image.

Cold cathode fluorescent lamps, the conventional backlights used in flat-screen televisions, typically do not have a particularly strong emission in the red part of the visible spectrum, meaning that red colors tend not to reproduce well on screen. With LED backlighting, the red colors are displayed much more strongly.

The LEDs used in Sony's Qualia televisions are high-power Luxeon LEDs manufactured by US-based Lumileds Lighting. Lumileds claims that the Luxeon-lit televisions deliver a color gamut that exceeds the requirements of the US National Television

System Committee. This "color space" represents a 35–40% improvement compared with conventional technologies, and translates into finer and more exact color definition for the viewer.

Lumileds explains that other advantages of using Luxeon LEDs include a reduction in waste material thanks to the extended life of the backlight system. Since the backlights emit no ultraviolet radiation or forward heat, they also provide designers with a greater degree of flexibility.

Sony is reported to have launched two televisions in its high-end Qualia range that feature the technology: a 40 inch and a 46 inch version. A further six televisions in the company's Wega range, from 26 inch to 50 inch models, are also to be introduced.

According to a *Reuters* report, Sony believes that there will be an unprecedented peak in demand for flat-screen televisions at the end of this year. Available in Japan initially, the models are expected to be released to overseas markets by the beginning of 2005.

Not to be outdone by its rival, the Korean electronics manufacturer Samsung also released a variety of display products at the

recent Asia Display 2004 show held in Daegu, Korea. Samsung, which claims to be the world's largest provider of TFT-LCD display panels, exhibited 17 inch and 21 inch LED backlights for LCD monitors at the show, as well as a one-piece touch-screen panel for mobile LCDs and a 46 inch portrait LCD panel.

The company claims that its 21 inch LED backlight is only half the thickness of comparably sized monitors, and that its 17 inch version delivers a brightness of twice that found in competitive technologies.

Samsung also unveiled a 46 inch LCD panel in portrait configuration, which it hopes will penetrate various other commercial applications such as billboards, picture frames, menus, fashion shows and interior decoration. Although conventional portrait products tend to display only graphics, the company has gone one step further and has developed software for its new product for both business-to-business and business-to-consumer applications.

Earlier this year, NEC-Mitsubishi unveiled prototype LED-backlit monitors measuring 23 and 21.3 inches that incorporate Luxeon LED technology.

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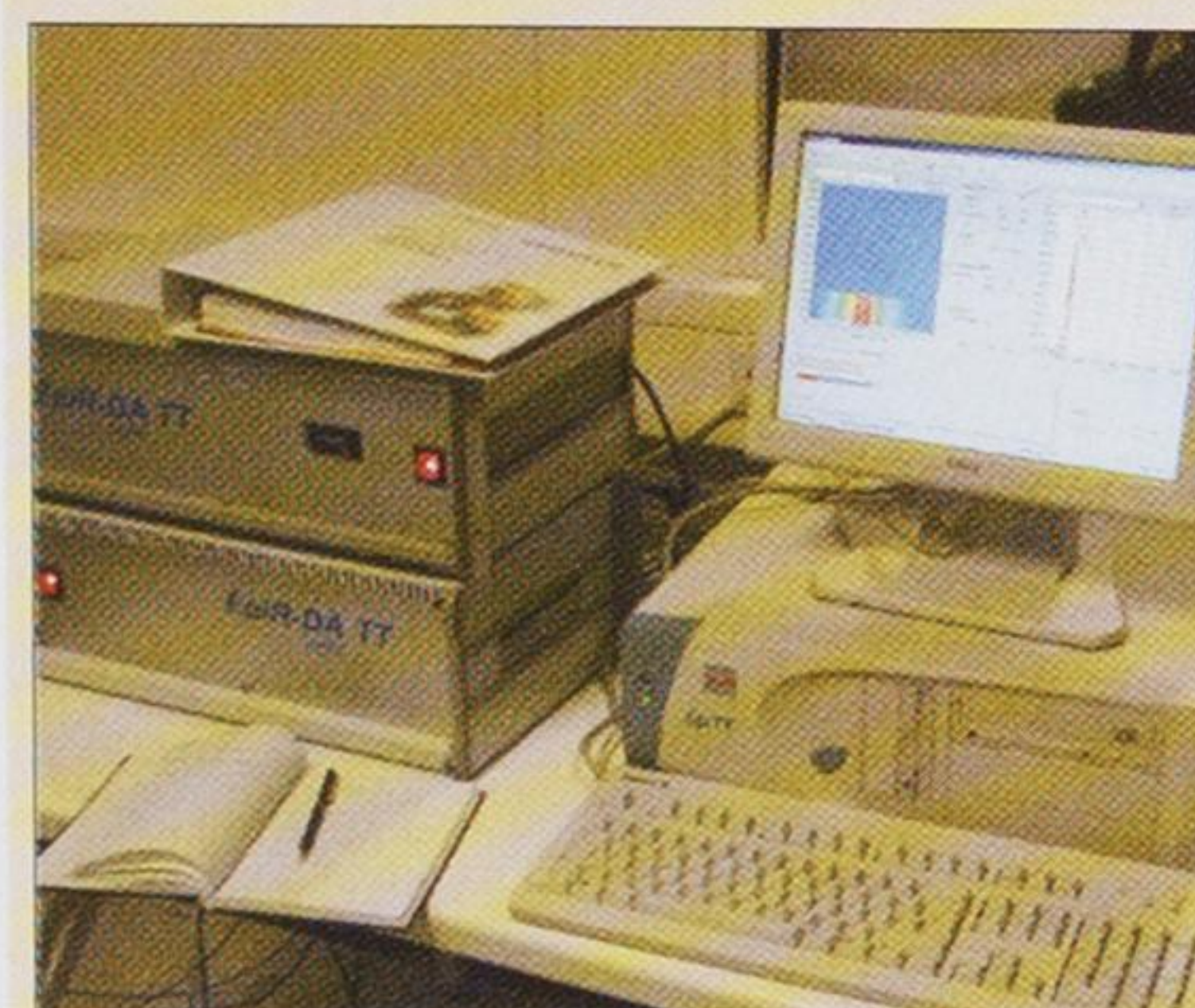
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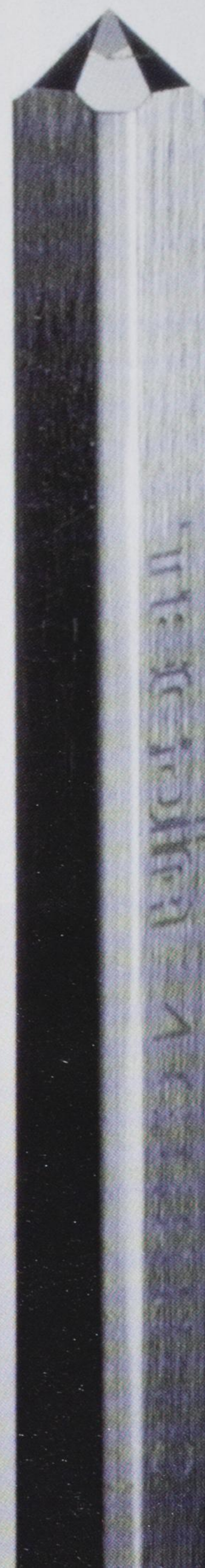
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Games console to use Blu-ray format

Japanese electronics powerhouses Sony and JVC are to accelerate the development of Blu-ray Disc data-storage technology.

Sony is believed to have plans to use the format, which relies on GaN-based diode lasers, as a key component in its forthcoming games console, PlayStation 3. According to reports in the Japanese press, Sony revealed its decision to use the format at a press conference held by the Blu-ray Disc founders.

Sony has been investing cash in the development of Blu-ray technology and has an agreement with Nichia, the leading GaN laser manufacturer, under which the two companies share intellectual property relating to the manufacture of the 405 nm devices.

Sony is expected to reveal more details about the use of the 50 GB dual-layer discs in the games console next March.

At the press conference, the Blu-ray Disc founders approved the playback-only, or BD-ROM, version of the technology. "Blu-ray



Sony's prototype Blu-ray recorder. The firm is said to be planning to use the new storage format in its PlayStation 3 games console.

Disc is on schedule for companies to introduce BD-ROM players, drives and pre-recorded software to consumers beginning in late 2005," said Maureen Weber, the general manager of Hewlett-Packard's optical data storage business.

Meanwhile, JVC says that it has developed a manufacturing method that enables Blu-ray Discs to be produced at low cost. A report in

the Japanese newspaper *Nihon Keizai Shimbun* suggests that master discs can be manufactured using current DVD production equipment. This means that the capital investment required to shift to the new format should cost less than 10% of the conventional cost of changing technologies.

JVC plans to make the master discs using a laser that emits in the far ultraviolet, says the report. So far, more complex approaches – for example, electron beam equipment – have been used to make the master discs.

At the other end of the supply chain, Japanese materials suppliers have formed an R&D association to develop large GaN and ZnO crystals for use as substrates upon which the blue diode emitters can be manufactured.

Mitsubishi and five other companies plan to have equipment in place to fabricate 2 inch substrates from the crystals within five years. The market for these substrates is expected to reach ¥40 billion (\$366 million) in 2010.

Princeton Lightwave nets \$1 m laser fund

High-power diode-laser maker Princeton Lightwave Inc (PLI) is to develop highly-scalable eye-safe solid-state lasers for the US military. Exploiting the company's expertise in InP-based ultra-low photon defect diode pumping, PLI will receive more than \$1 million in funding from the US Air Force contract over two years.

It is hoped that this will culminate in the development of multikilowatt lasers under the program run by the Department of Defense's High Energy Laser Joint Technology Office.

The award is the latest example of technology that was initially developed for optical communications being exploited for defense applications.

Under the program, PLI plans to build on its capabilities in InP-based high-power single-mode and multimode laser diodes. PLI lasers are based on separate confinement quantum-well structures that allow for control of the injection current components and minimization of optical losses.

Central to the program is the development of InP-based 2D diode-pumped laser arrays with high output powers. These laser arrays will be optimized for pumping an erbium-doped YAG crystal gain medium at wave-

lengths close to the solid-state laser's emission wavelength. PLI says that this design will greatly reduce undesirable heating of the gain medium and allow the laser systems to scale up to multikilowatt output, while maintaining high beam quality.

"The transition to InP-based long-wavelength pump lasers is a natural progression for the next generation of eye-safe solid-state and fiber lasers," said Dimitri Garbuzov, PLI's chief scientist. "In addition to alleviating active media overheating, the use of InP-based pump sources avoids a critical problem inherent to GaAs diode lasers associated with the degradation of the diode laser mirror facets."

In brief

- US defense contractor **Lockheed Martin** has won \$15 million to develop a prototype "laser radio" network for the Defense Advanced Research Project Agency (DARPA) and the Air Force Laboratory. The network will combine the speed of laser-based communications with the reliability of radio-frequency links. The Optical and Radio Frequency Combined Link Experiment (ORCLE) will create a network that can adapt to changing weather conditions. In good visibility the optical

link will enable high-speed communication, while the RF link will provide a back-up when visibility is reduced.

- UK-based optoelectronics manufacturer **Intense Photonics** has received £5 million (\$9.2 million) in its latest funding round. The InP chip maker plans to use the money, which came from five investors, to expand the business. This will include adding capital equipment for chip fabrication. Module packaging in particular will benefit from the investment.

- Laser chip manufacturer **BinOptics** of Ithaca, NY, says that its etched-facet devices (*Compound Semiconductor* July p14) have passed reliability tests with flying colors. In the year-long tests, the Fabry–Perot lasers showed stable behavior after more than 12,000 hours of continuous operation. The lasers were tested at 90 °C under an operating current of 50 mA. The results of the tests suggest that the devices would have a lifetime of more than 135 years at room temperature operation.

New Avanex CEO targets number-two ranking

California-based fiber-optic components maker Avanex has appointed a new CEO. Jo Major, formerly general manager of the components business group at JDS Uniphase (JDSU), replaces Walter Alessandrini.

Alessandrini, who was brought out of retirement by Avanex in November 2002 to resume his prior roles of president and CEO, reshaped the company by acquiring the fiber-optic component wings of Alcatel, Corning and Vitesse in 2003. Alessandrini will now serve as the chairman of Avanex's board of directors.

Major aims to make up ground on his former employer, JDSU, and turn a profit at Avanex. He may have a tough job on his hands — although the acquisitions made last year

have had a positive impact on Avanex's revenue, the company is still making a hefty loss.

In the recently ended fiscal year 2004, Avanex notched up an operating loss of \$121.3 million on sales of \$106.9 million. Performance at the gross margin level is also still in the red. "I am committed to helping the company accelerate its plan to profitability [and] become the clear number-two player in the industry," said Major.

It seems that he will have much work to do. Recent analysis by market research company Communications Industry Researchers ranks JDSU as the market leader with 19.3% of the fiber-optic components business. Avanex is eighth with a market share of 5.1%.

Fiber-optic growth is sustainable, says KMI

KMI Research of the US predicts strong and sustainable growth in the fiber-optic communications industry over the next five years.

The market research company says in a report that the optical networking market will enjoy double-digit growth from 2004 through 2006. The market is expected to grow at a compound annual rate of 12% and reach \$15.9 billion in 2009, up from \$7.6 billion in 2003, says KMI.

According to the report, it is not just the short-haul sector that is driving growth. "The long-distance segment will show a healthy near-term bounce upward for some products, such as DWDM, because systems installed a few years back are filling up," it is believed.

KMI added that although demand for bandwidth is growing more slowly than in previ-

ous years, it is still sufficient to force the deployment of new equipment. KMI's general manager, Richard Mack, said: "With carrier capital spending getting stronger, and with the introduction of increasingly versatile transmission equipment, the market is returning to annual growth rates of 10–20%. More importantly, we believe that these growth rates are sustainable."

Another US-based market research firm, ElectroniCast, forecasts a rapid increase in the global consumption of multi-fiber transmit link components, particularly VCSELs. According to ElectroniCast, the market, which addresses short optical links from 1 m up to around 2 km, will grow most rapidly between now and the end of 2005. It is expected to reach over \$400 million by 2008.

In brief

- **Microsemi Corporation** of Irvine, CA, has released a co-planar waveguide photodiode for high-bandwidth single-mode-fiber optical networking applications. The InGaAs/InP PIN photodiodes are ideal for high bandwidth 1310 and 1550 nm optical networks, claims Microsemi.
- Photonic IC developer **ASIP** of Somerset, NJ, has developed an enhanced version of its uncooled 1310 nm electro-

absorption modulated laser, which has a higher operating temperature of 95°C.

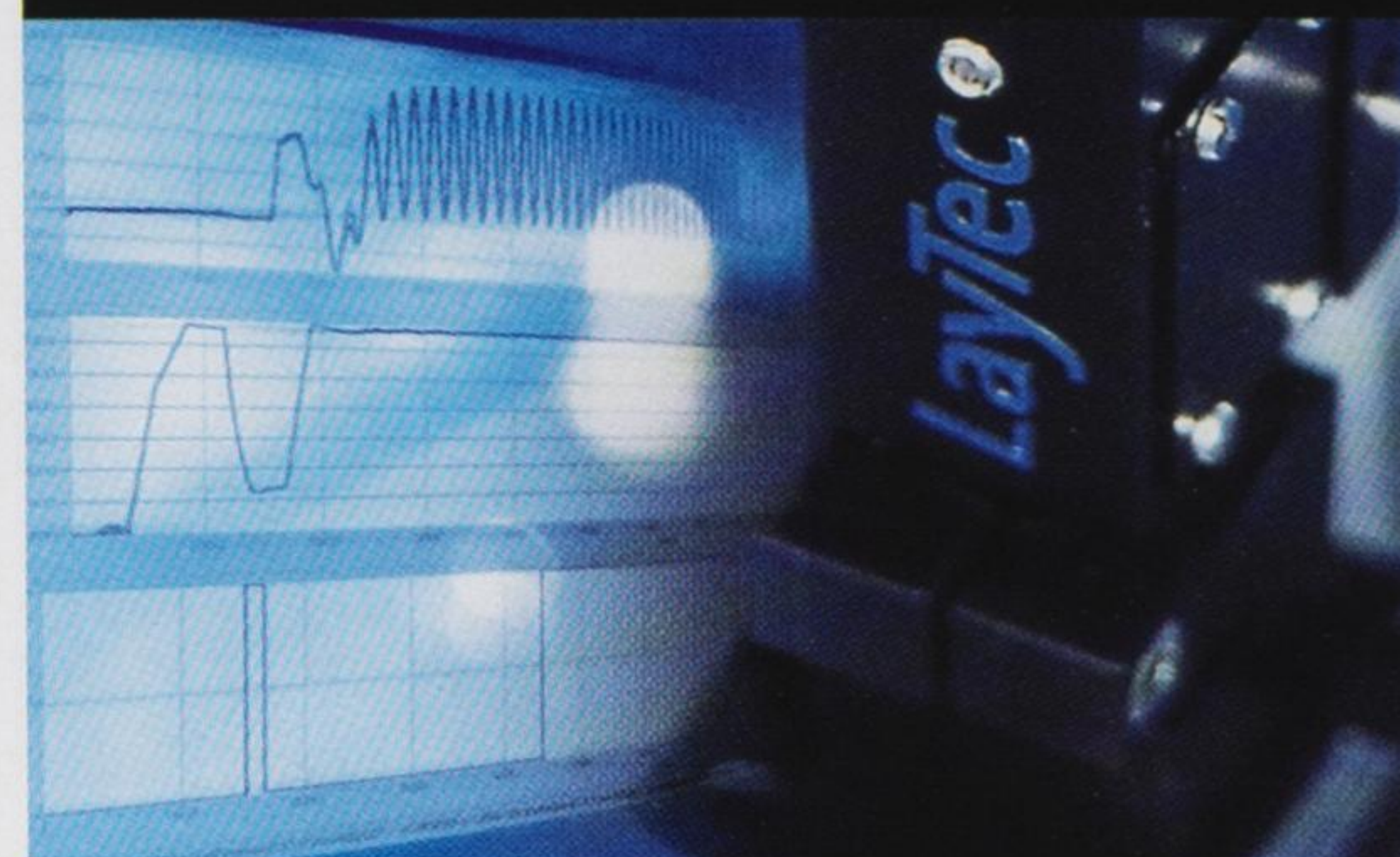
- **T-Networks**, based in Allentown, PA, has made its entire laser-integrated modulator (LIM) product line available in CWDM versions. These products will operate at the standard CWDM wavelengths from 1470nm to 1610nm, with the same specifications as the current C-band product line. The LIM platform incorporates InP lasers, modulators and optical amplifiers.

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No Surprises!

Asia sales boost Aixtron's quarterly takings to \$41 m

Booming sales of MOCVD equipment in Asia have driven quarter-on-quarter revenue up by 35% at Aixtron.

In the quarter that ended June 30, the company, based in Aachen, Germany, recorded €34.2 million (\$41.2 million) in sales, an increase of 53% on the same period last year. The figures translated into a €0.5 million net income, whereas this time last year Aixtron posted an €8.3 million loss.

Orders also rose substantially, up 23% sequentially to €36.9 million, representing the fifth consecutive quarterly increase.

The reason for the boom is clear: there is a rising demand from LED manufacturers, in particular those based in Asia.

In the latest quarter, 82% of Aixtron's

revenue was generated in Asia, while 15% came from the US and just 3% from Europe. This balance looks set to continue, with Arima Optoelectronics, Epistar and United Epitaxy Company among the customers that have placed recent orders.

Aixtron CEO Paul Hyland said: "In the second quarter we saw market optimism in the compound semiconductor manufacturing industry continue."

Hyland added that the company expects full-year revenue to be in the €130–140 million range, with a net income of €2–5 million if acquisition costs relating to the Genus merger are ignored.

In the first half of the year, Aixtron's sales reached almost €60 million.

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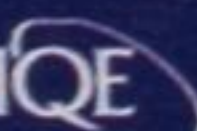
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Veeco reports 40% increase in revenue

Veeco Instruments has recorded sales of \$102.9 million for the quarter ending 30 June – a sequential increase of \$8.4 million and up 40% on the equivalent quarter in 2003. Net profit for the second quarter was \$1.6 million.

Sales for the US-based equipment manufacturer's second quarter were dominated by process equipment, which netted \$60.6 million. Metrology contributed \$42.3 million, and compound semiconductor products accounted for \$25 million.

Veeco's orders for the second quarter were \$124.7 million: \$82.7 million for process equipment, and \$42.0 million for metrology.

"Orders were up 7% sequentially due to strength in the compound semiconductor/

wireless market (up 31% sequentially) and the semiconductor market (up 121% sequentially)," explained Edward Braun, Veeco's CEO. "This included \$42.4 million for Veeco's TurboDisc MOCVD products, which are required for high-brightness LED manufacturing, and a quarterly record \$13.7 million in orders for automated atomic force microscopes."

● Veeco has received a multiple-system order for its GEN2000 MBE system from a leading wireless device manufacturer. The 7 × 6 inch wafer systems will be used to manufacture compound semiconductor devices for power amplifiers and RFICs used in wireless handsets and wireless LANs.

In brief

● Sypris Test & Measurement, a subsidiary of Sypris Solutions, has added RF and microwave testing capabilities to its range of product- and component-testing services.

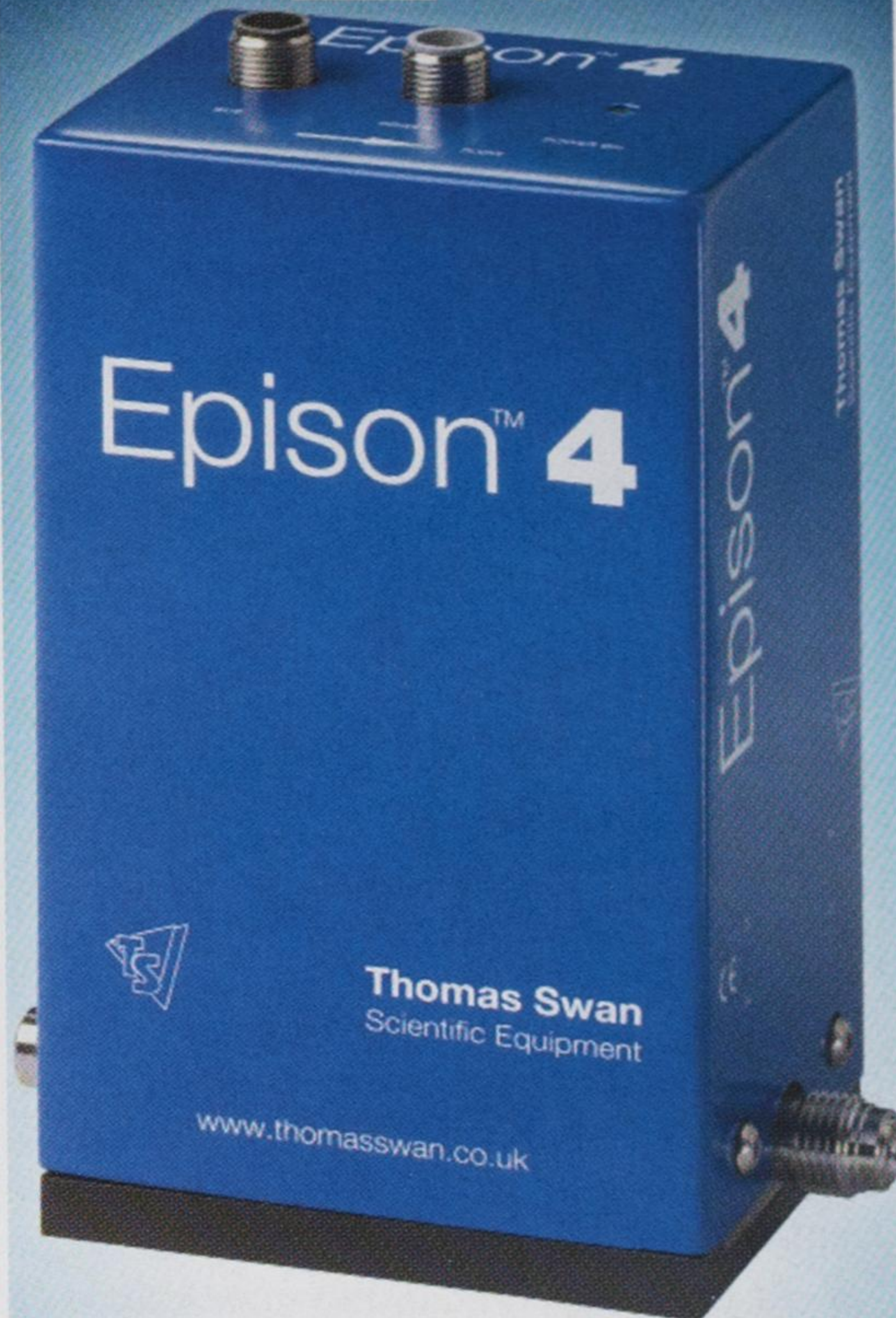
Sypris will offer RF test services that include component qualification, parts management across the supply chain, life testing, and burn-in/environmental testing to meet military requirements.

RF tests will include power at 1dB compression point, input power, output power, saturated output power, gain at 1dB

compression point, linear gain, maximum stable gain, and maximum available gain.

● The EV Group (EVG) has received an order from an undisclosed US high-brightness LED manufacturer for an automated and fully integrated temporary bonding cluster. The EVG system enables the processing of wafers well below 100 µm thick, a key to making high-intensity LEDs for use in mobile appliances, and other compound semiconductors, such as power devices and high-frequency devices.

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Lumileds places \$10 m order for Veeco MOCVDs

Veeco Instruments has received a \$10 million order to supply its GaNzilla MOCVD production systems to LED manufacturer Lumileds Lighting of San Jose, CA.

The initial order was received during Veeco's second quarter, and is part of a multi-year purchase order for additional systems.

Lumileds, which is one of the world's leading manufacturers of high-power LEDs, recently made a similarly large order for MOCVD equipment from Veeco's Germany-based rival, Aixtron.

Michael Holt, the CEO of Lumileds, said:

"Our experience with Veeco's GaNzilla reactors has been excellent, and led to this large equipment order."

According to Edward Braun, the chairman and CEO of Veeco: "The rapid emergence of high-power high-brightness LEDs will be helped by the joint efforts between our companies. Veeco is committed to maintaining a strong presence in this fast-growing market."

Strategies Unlimited, a market research firm, reports that the GaN LED market was worth \$2.7 billion in 2003 and is forecast to reach more than \$5 billion by 2008.

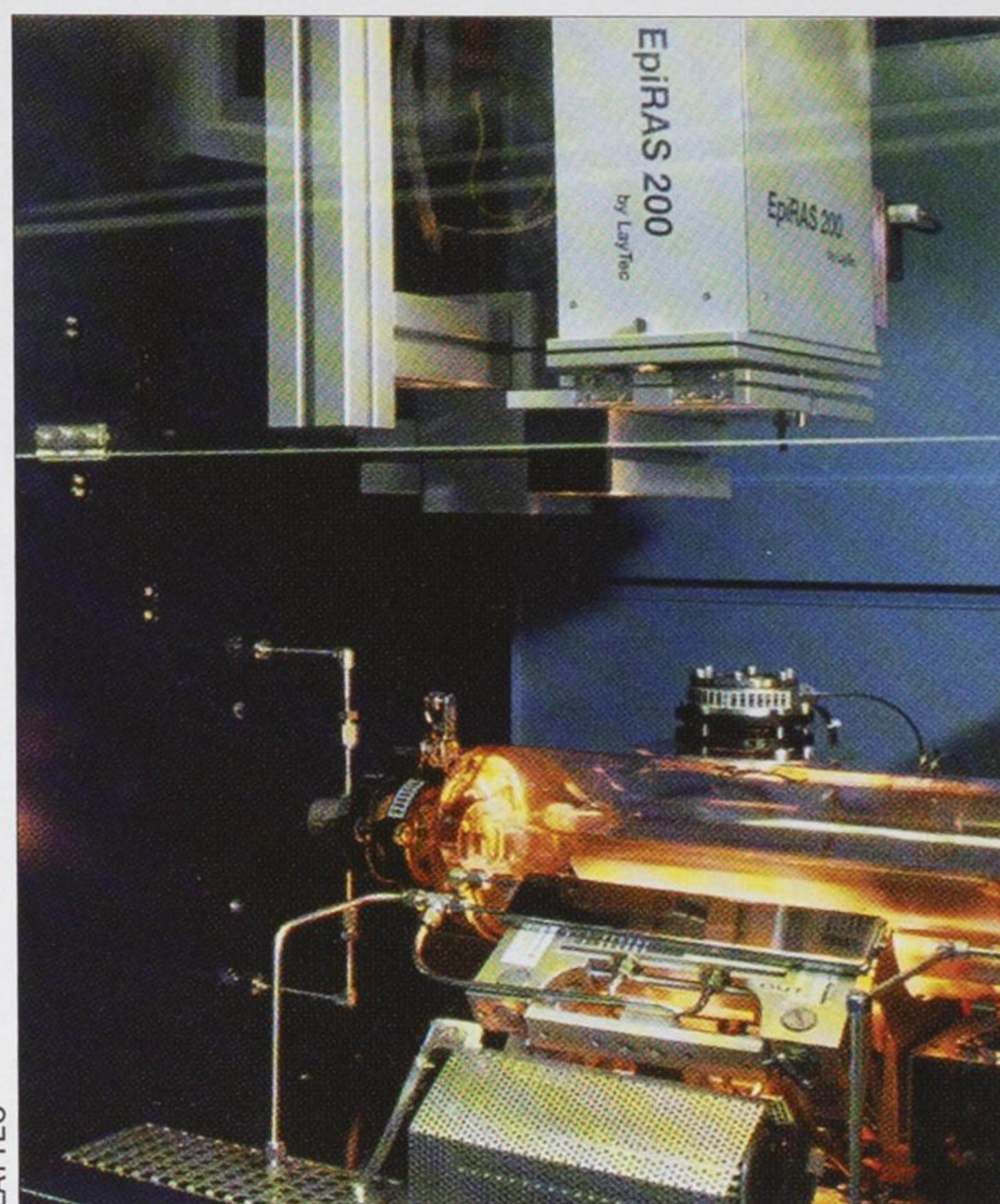
Sony purchases Aixtron reactor

Sony has purchased and successfully started up one of Aixtron's AIX 2600G3 systems. The MOCVD reactor can grow on multiple-wafer configurations ranging from 3 inch to 6 inch diameter and is equipped to process various compound semiconductor devices.

The system includes a LayTec EpiRAS 2000TT sensor that measures doping, composition, thickness and true temperature *in situ* during the epitaxial growth.

A project leader at Sony said: "We have proved that the AIX 2600G3 system is a highly versatile tool equally well suited for R&D purposes as for high-volume production with respect to the large process window, high reproducibility and uniformity of epitaxial growth."

"Furthermore, the EpiRAS allows us to control the epitaxial process, which is essential for the development of next generation's devices and their transfer to mass production."



A Laytec EpiRAS sensor monitors doping and composition during MOCVD growth.

IQE dismisses staff to reduce losses

UK-based epiwafer vendor IQE has reported revenue of £8 million (\$14.5 million) for the half-year ended June 30, 2004. Sales during the period were up £0.1 million on the previous half-year, but down £0.8 million from the equivalent period in 2003.

The operating loss for the recent half-year was £5.6 million, while the loss at the gross margin level was £1.9 million, or 24%. This

compares with 20% and 16% for the two previous half-years, sequentially.

The company's cash position weakened from £21.7 million at the start of the year to £15.5 million by June 30. IQE has recently reduced its head count by 40 in an attempt to cut costs.

"Further progress has been made in the first half of 2004 in reducing the group's cash break-even revenue point to \$26.5 million, and our plan remains to be exiting 2004 in an on-going break-even situation," said Drew Nelson, IQE's CEO.

ADVANCED SILICON

RF applications beckon as

Strained-silicon and strained-silicon-on-insulator devices look certain to have a massive impact on the digital device sector in years to come, while another opportunity lies in traditional GaAs applications, particularly RF switches. **Michael Hatcher** examines recent developments in advanced-silicon technology.

Conventional scaling of silicon transistors is facing some fundamental challenges. Gate dielectrics have already been reduced to a thickness where the effects of tunneling currents are becoming significant, while device voltages cannot be scaled down as quickly as transistor dimensions.

With no alternative gate-dielectric materials ready to replace silicon dioxide, silicon chip manufacturers are increasingly turning away from scaling and towards the use of strained materials to boost transistor speed and maintain the march of Moore's Law.

As such, strained-silicon technology in its various forms is incorporated on the International Technology Roadmap for Semiconductors (ITRS). The ITRS emerging materials team defines three types of strained silicon: bulk strained silicon; strained silicon on insulator (s-SOI); and strained silicon on SiGe on insulator (SGOI).

The central fact driving the development of the technology is this: strained layers of silicon improve carrier mobility compared with standard relaxed silicon. This means that transistors can operate at a higher speed (see box).

Biaxial strain

Bulk strained silicon has already found its way into high-end digital devices made by the likes of Intel, Texas Instruments and IBM. Having begun shipping SOI-based microprocessors in 2000, IBM is pushing a major research effort in the strained-silicon field. In US patent 6,649,492, awarded in November 2003, IBM describes a UHV-CVD method that can be used to manufacture strained-silicon devices. IBM distinguished engineer Gary Bronner told *Compound Semiconductor* that the company's research wing has demonstrated significant improvements in electron mobility by using biaxial strain.

"The advantages of increased electron and

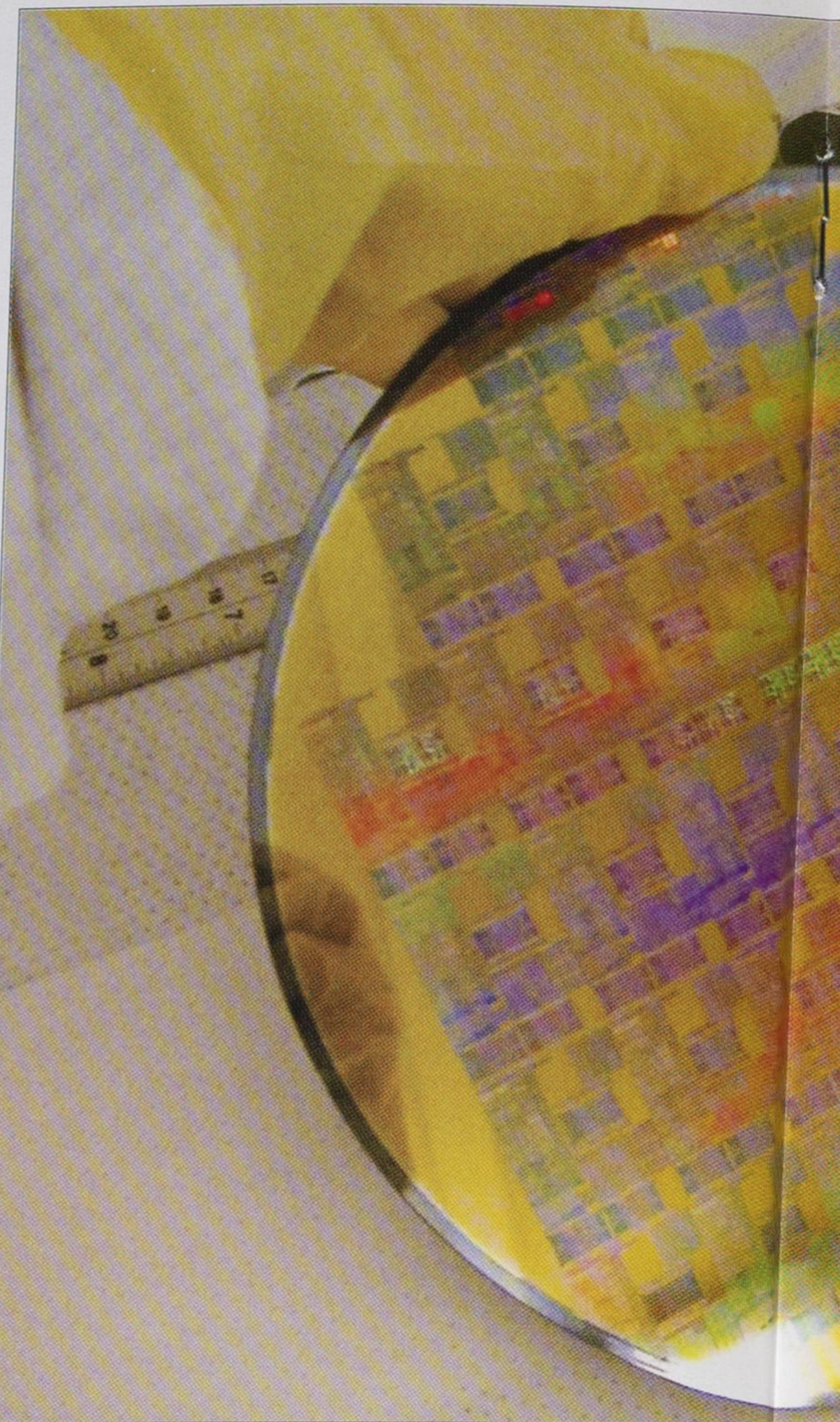
hole mobility through the use of strain are quite compelling," said Bronner. "Rather than wait for the technology that is required to make the s-SOI substrates mature, IBM has found other means to introduce strain in the channels of the SOI transistors during conventional processing."

According to Bronner, the basic idea is to deposit strained films and then transfer the stress from these deposited films onto the SOI substrate. IBM started doing this with its 90 nm SOI products that were launched in the first quarter of this year. "In our current 90 nm technology we believe we are seeing more than a 10% performance advantage from the use of strain," Bronner said.

Intel first revealed that it was using strained silicon in its 90 nm logic process back in 2002. At the International Electron Devices Meeting in December the following year, the world's biggest chip maker further expanded on the technology it had developed, which features 45 nm gate-length CMOS transistors.

Intel uses a selectively deposited SiGe source-drain structure to induce channel strain in PMOS devices (see figure 1). According to the company, this improves drive current by 25% relative to standard devices. Intel Senior Fellow Mark Bohr adds that incorporating a high-stress cap layer of Si_3N_4 material creates strain in NMOS devices, improving drive current by 10%. And the effect on cost is minimal – Bohr estimates that the double optimization only adds 2% to the process cost. Intel initially ramped up the strained-silicon process at its D1C fab in Oregon this year.

Despite these initial steps, the major impact of s-SOI technology is not expected to take off until at least 2007–2008. Said IBM's Bronner: "s-SOI is being actively explored for the 45 nm generation. It needs to meet aggressive goals in terms of starting wafer cost and defect density to ultimately make it into



AMBERWAVE

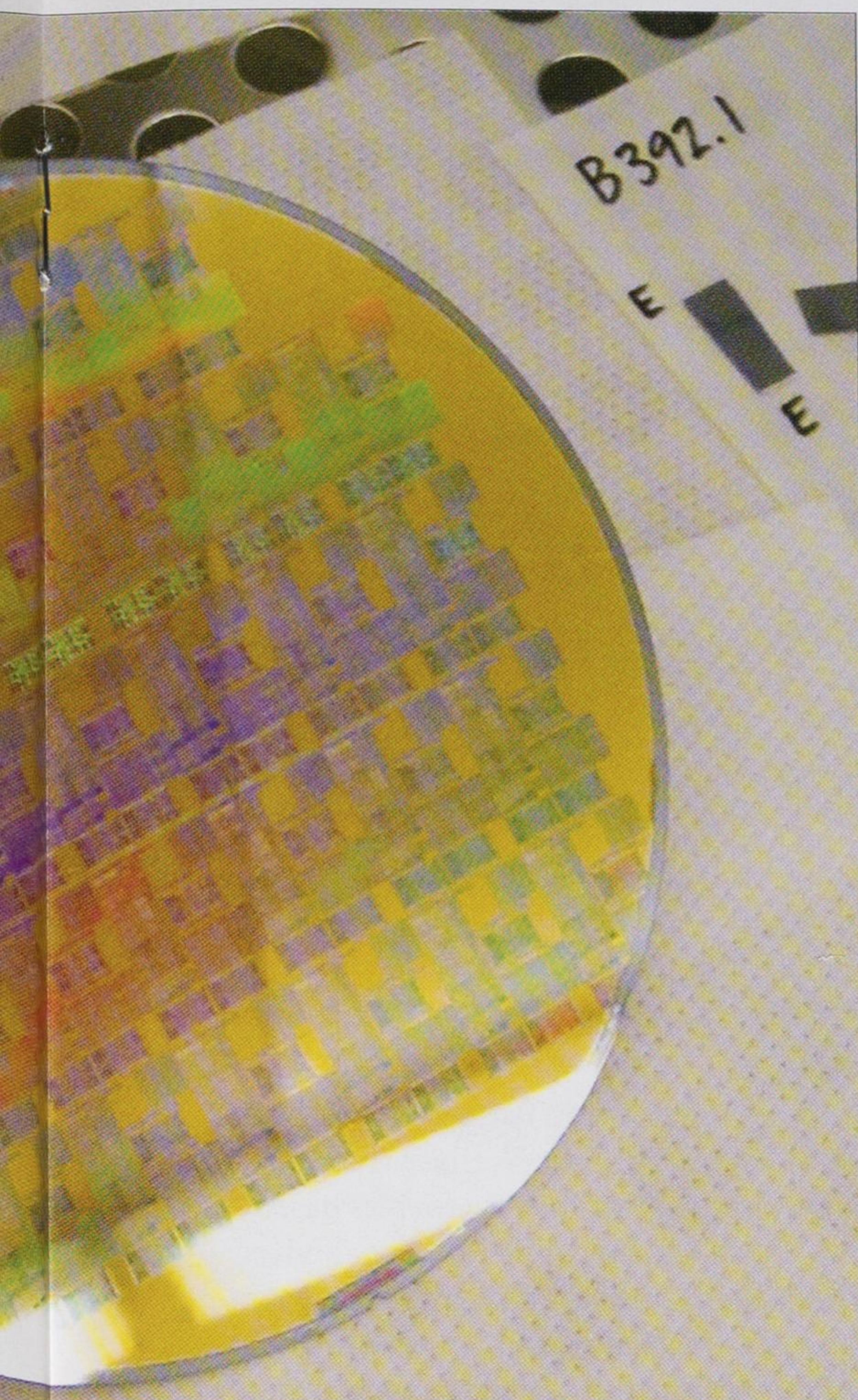
A finished 200 mm strained-silicon wafer with 20% germanium fabricated using Amberwave's intellectual property. This co

manufacturing. It also needs to show compelling advantages over other techniques for introducing strain into the silicon transistors."

So the use of s-SOI technology is not a foregone conclusion, according to Bronner. "The use of strain to boost transistor performance in silicon is inevitable. Whether s-SOI is used to introduce this strain or other techniques are adopted is still undecided."

Until recently, one of the major problems with s-SOI technology was the sheer number of defects and dislocations in s-SOI substrates. According to Soitec, the French company at the forefront of advanced silicon substrate development, the number of defects has now been reduced by a factor of 100 to 1000 compared with the previous industry standard.

strained silicon shapes up



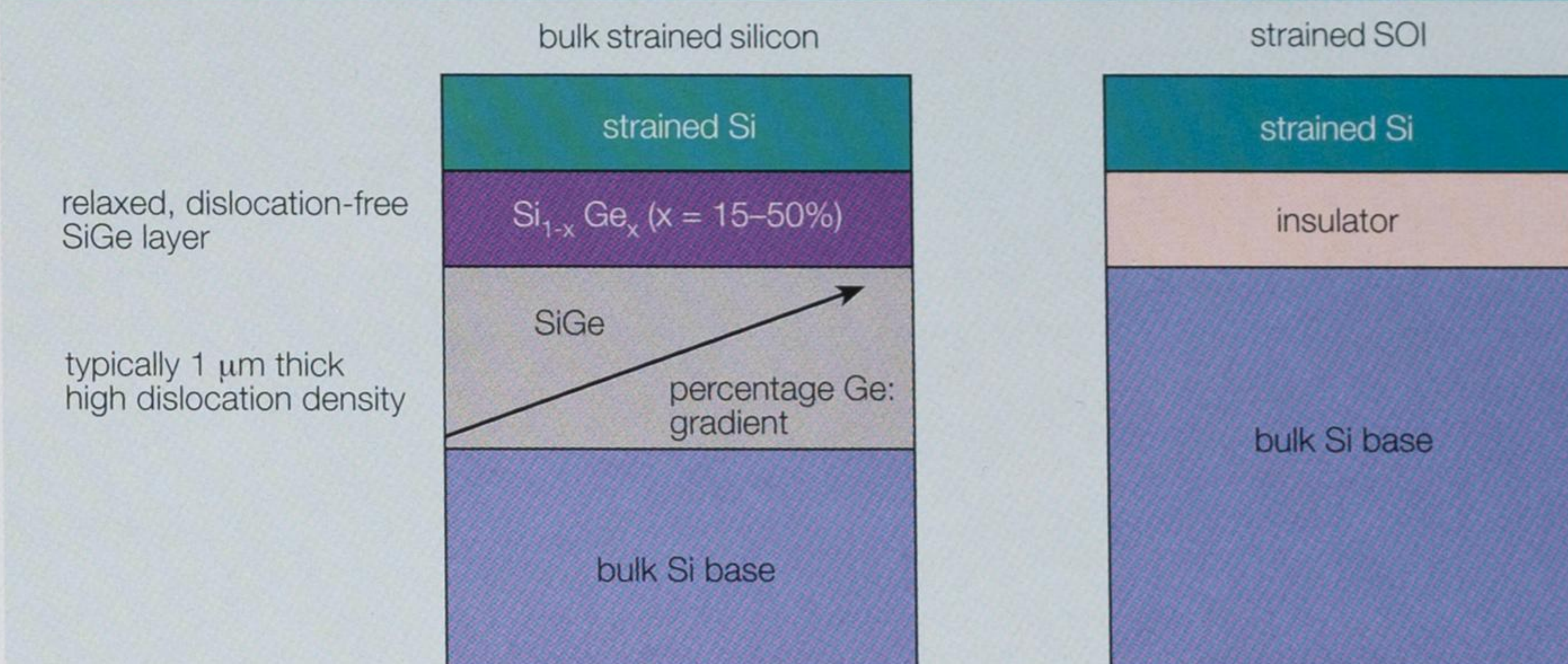
% germanium in the SiGe layer below the strained layer, ty. This composition improves electron mobility by 90%.

Soitec says that, following a recent development project with ASM International of the Netherlands, it can now make s-SOI substrates of a quality similar to that of standard SOI and bulk silicon. Soitec has been sampling 200 mm s-SOI wafers for more than a year already, and plans to be the first company to offer 300 mm materials. It is in the process of upgrading its production line for sampling and pilot manufacturing.

Soitec sees s-SOI as a possible technology for the 45 nm silicon chip generation that is scheduled for implementation in 2007–2008, but ultimately it will depend on the demand from device manufacturers.

Soitec is not the only company looking to advance strained-silicon substrate technol-

Creating the strain



Layers of strained silicon, which have a carrier mobility that is higher than conventional silicon, incorporate germanium to generate the required tensile strain in the crystal lattice. Although crystalline germanium and silicon have the same lattice structure, the larger germanium atoms are spaced 4.2% further apart than silicon atoms. Alloys of SiGe have a lattice constant somewhere between that of the two pure crystals, whose exact value depends on the proportion of the two elements incorporated in the alloy.

Grown on top of a SiGe template, the atoms in a thin

layer of pure silicon will attempt to align with the atoms below it and therefore be spaced further apart than normal – thus creating a “strained” layer as the silicon is stretched like a rubber membrane. However, fabricating a high-quality SiGe template presents its own difficulties, and switching from a pure silicon substrate to the alloy inevitably causes threading dislocations and other defects in the final structure.

According to Soitec, the way around this is to epitaxially grow a stack of layers on top of the silicon, beginning with a buffer layer where the proportion of

germanium is graded from zero at the interface to up to 50% at the top. Another SiGe template layer is grown on top, with a lattice constant matched to the buffer below. This creates a fully relaxed template, with no strain, upon which a strained-silicon layer may be deposited optimally (above left).

In strained-silicon-on-insulator (s-SOI) technology, the advantages of strained silicon are combined with the benefits of ultra-thin SOI layers, where a layer of insulation allows SOI-based chips to function at a much higher speed and lower power (above right).

ogy. Silicon Genesis (SiGen) of the US recently developed its own wafer-level strained substrate. SiGen says that the key advantage of its substrates is that they feature uniaxial strain, where the strain is directed in a single axis across the wafer, rather than biaxial strain, which operates in both axes across the wafer surface.

According to SiGen, uniaxial strain is more effective than biaxial strain when it comes to enhancing the performance of PMOS transistors, particularly when a high effective electric field of around 1 MV/cm is applied.

“Biaxial strain has been plagued with process integration issues such as high defect levels and germanium interdiffusion, but more importantly it is much less efficient at boosting PMOS transistor performance,” said Scott Thompson, a former Intel Fellow and previously director of the company’s strained-silicon program.

Until recently, says SiGen, uniaxial strain could only be induced locally, for example in the transistors made by Intel. The company’s key breakthrough has been to achieve global uniaxial strain across a complete wafer, which

ADVANCED SILICON

should boost transistor performance further.

"Production costs are expected to be significantly lower than with biaxial technologies because [our process] avoids the costly steps of growing and relaxing thick SiGe layers," said François Henley, SiGen's CEO, of the technology, which could be implemented in both bulk silicon and s-SOI.

Suited to RF

Although logic devices are the obvious focus for the likes of Intel and IBM, and they undoubtedly offer the bigger market potential, RF applications are also within the reach of s-SOI. Soitec has collaborated with ST Microelectronics and Renesas on this front. ST is actively developing RF devices based on standard SOI technology, and has demonstrated that SOI-CMOS coupled with a high-resistivity substrate is suitable for fully integrated microwave applications up to 5 GHz.

Strained-silicon specialist AmberWave Systems is a pioneer in the field, and has sampled its technology to around 15 device manufacturers. Chief technology officer Mayank Bulsara says that now the fundamental doubts about the technology have been overcome, the main issue that needs to be addressed is that of yield—a sure sign that the technology is moving towards commercial deployment.

AmberWave recently bagged \$21 million in Series D financing and will use this to complete the commercialization of its bulk strained-silicon technology, although much of this cash will be spent on R&D. The company has also been busy assessing the potential of strained-silicon for RF applications. In a paper presented at the International SiGe Technology and Devices Meeting in May this year, Amberwave's researchers concluded that strained silicon has "excellent" suitability for analog and RF switching, and "good" prospects for RF low-noise amplifiers. And although there are question marks over its suitability for RF power amplifiers (mainly

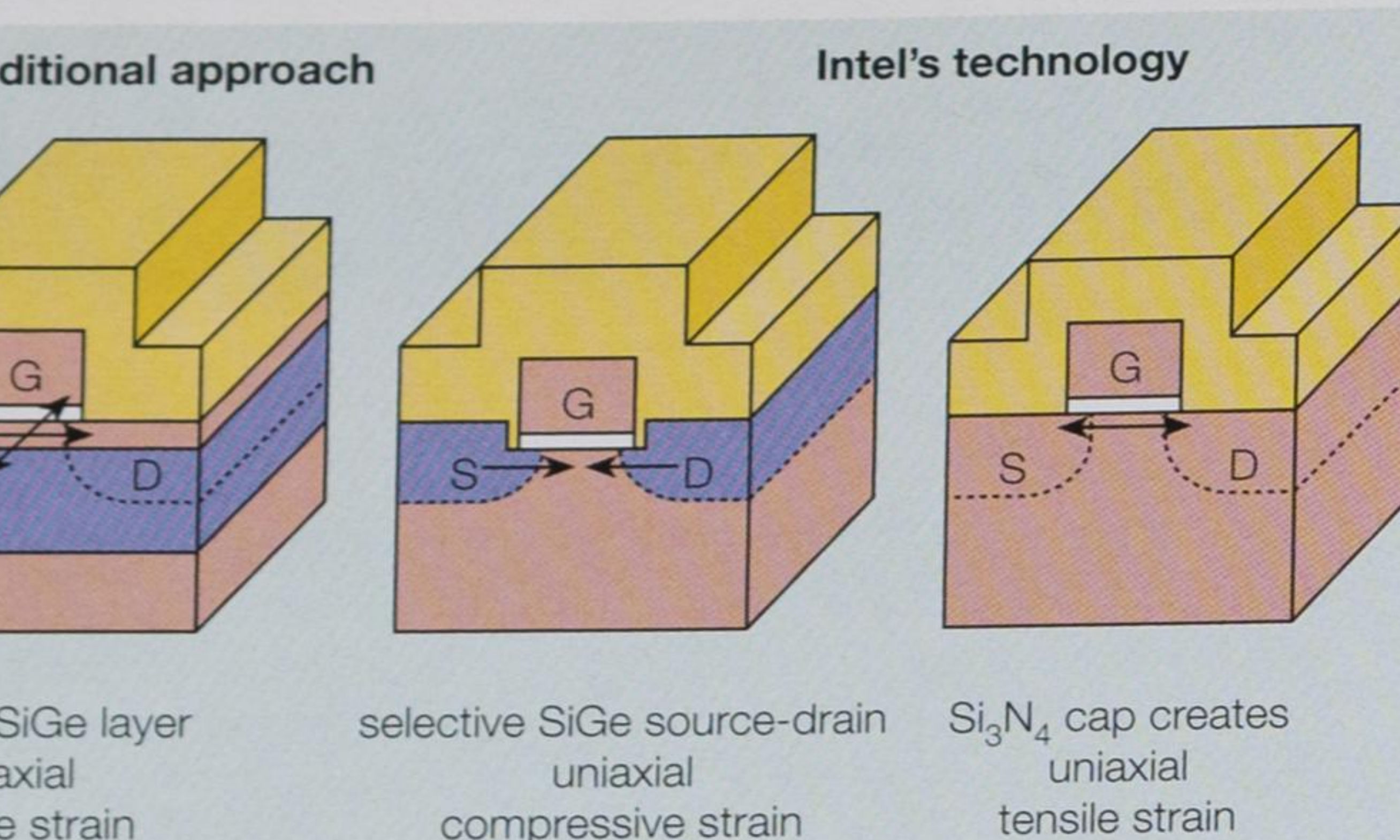


Fig. 1. Intel's 90 nm transistor technology features uniaxial compressive strain for PMOS, and uniaxial tensile strain for NMOS.

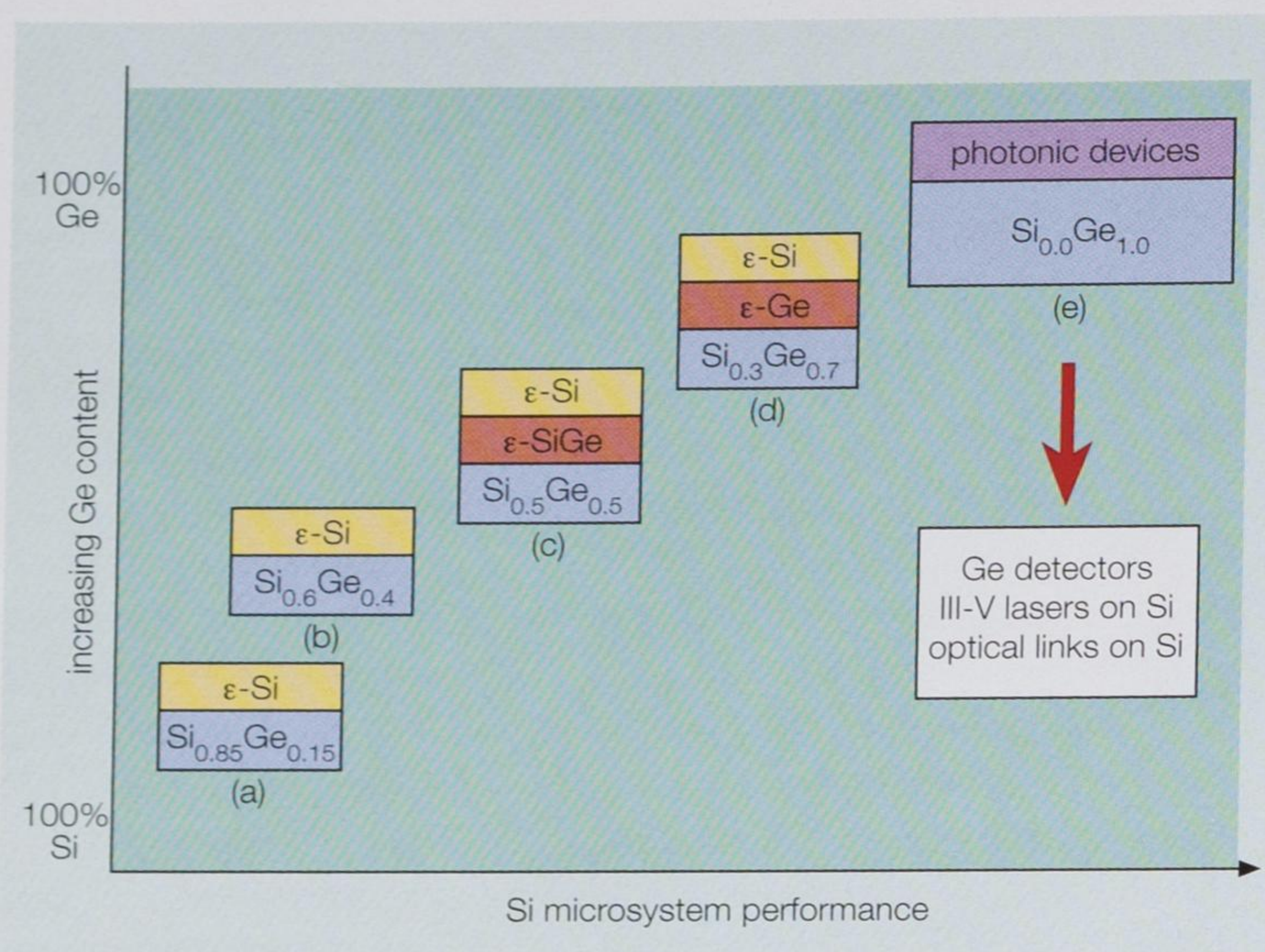


Fig. 2. The functionality of advanced-silicon devices will change as the proportion of germanium used in the SiGe alloy increases. Stages (a) to (d) will demonstrate the following enhancements: (a) 80–100% improvement in electron mobility; (b) 120% improvement in hole mobility; (c) 500% improvement in hole mobility; (d) 700% improvement in hole mobility. At 100% germanium content (e), integration of III-V devices and optical interconnects is expected for use in future generations of chip-level architecture.

“Using strain to boost transistor performance in silicon is inevitable. Whether s-SOI is used to introduce this strain or other techniques are adopted is still undecided.”

GARY BRONNER, IBM

because of the adverse effect of self-heating), it seems clear to AmberWave that RF and analog functions suit the technology.

In the first demonstration of the RF and analog properties of a standard digital MOSFET process, AmberWave, Texas Instruments and International Sematech collabor-

ated to make a direct comparison between strained bulk silicon and the standard material.

With a germanium composition of 20%, strained-silicon devices demonstrated an electron mobility enhancement of 90% at an effective field of 1 MV/cm. With a gate length of 0.15 μm they also showed an improved cut-off frequency (f_t) of 44 GHz compared with the 34 GHz of standard material. “Strained-silicon CMOS has tremendous potential for RF and analog circuit applications,” concluded the team.

Other recent developments in RF applications include a strained-silicon HFET operating in the microwave region. Researchers at DaimlerChrysler in Germany and Paris-Sud University in France have found that by replacing the thick relaxed buffers (that are traditionally used to study SiGe for microwave applications) with much thinner substrates, the RF and low-frequency noise characteristics can be “greatly improved”.

Photonic future

AmberWave's Bulsara can see yet another role for devices based on variants of SiGe, where high carrier mobility, light emission and detection, and light-routing capability are integrated on a single chip. “The SiGe alloy system is the key to integrating high-mobility transistors with optoelectronic interconnect technology economically,” Bulsara said. In his opinion, now that strained-silicon transistors are being commercialized, the future will bring germanium-based photodetectors integrated with silicon. This technology was recently advanced by researchers at IBM (*Compound Semiconductor* August 2004 p26).

Bulsara even envisages a time when lasers can be manufactured on a silicon platform, making use of SiGe graded layer technology. “All photonic technologies on silicon using SiGe graded layers are an extension of the mobility-enhanced transistor technology that is being commercialized today,” he said. ●

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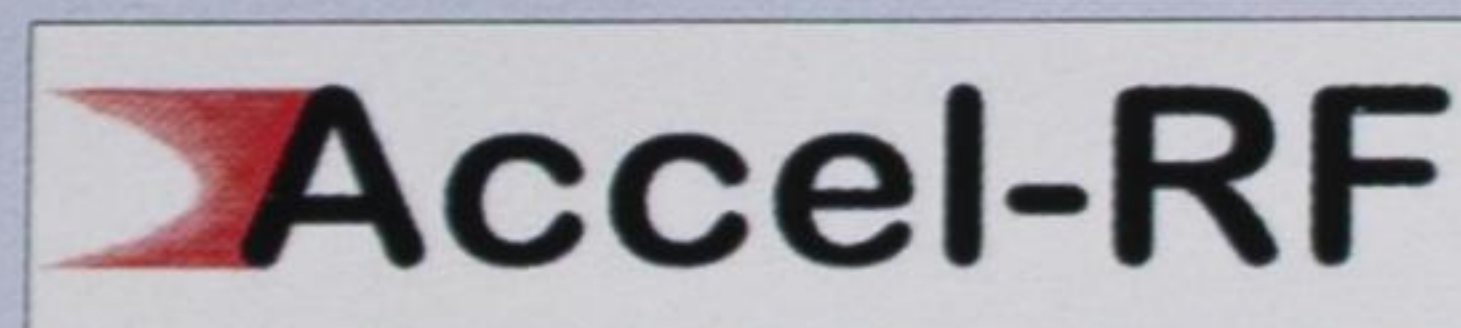
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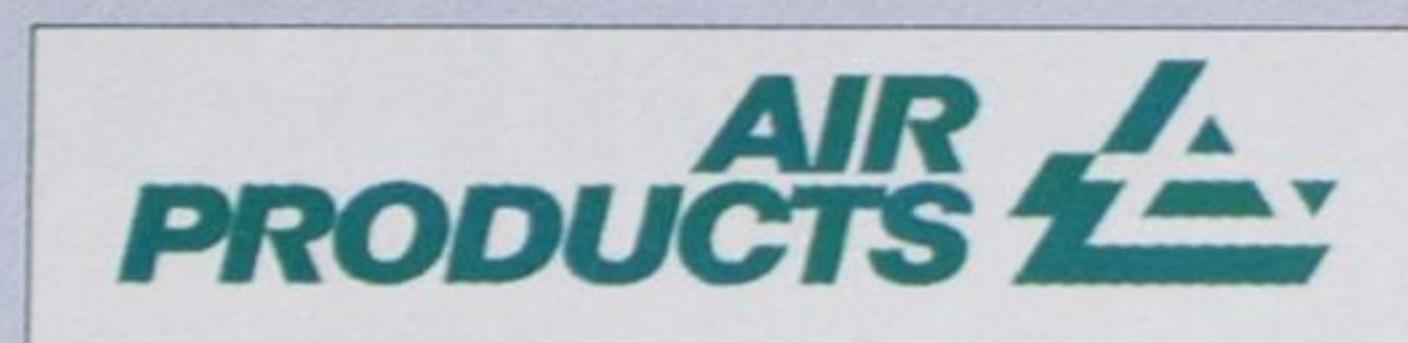
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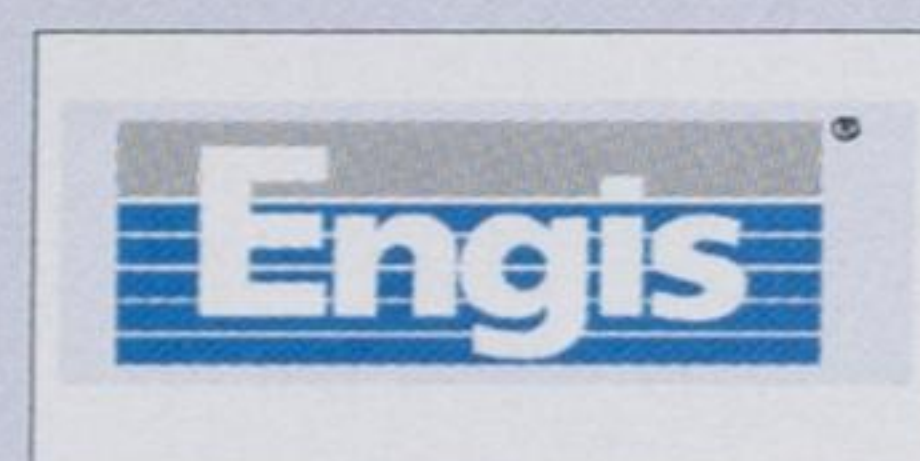
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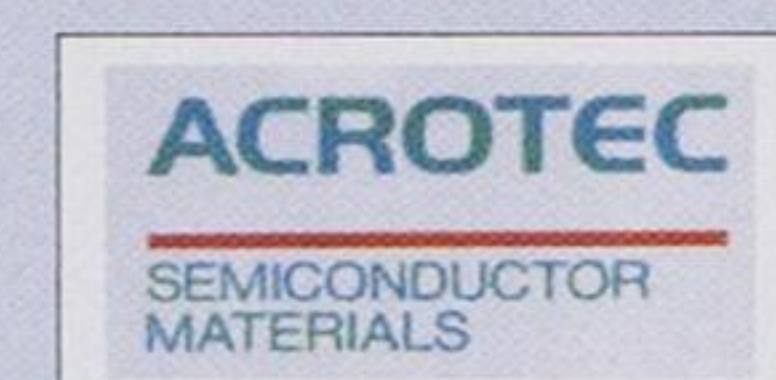
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Monterey provides idyllic venue for combined events

The inaugural Compound Semiconductor Week will bring together two technical conferences and a technology exhibition to cater for every level of the compound semiconductor supply chain. **Michael Hatcher** looks forward to the various events that will take place in Monterey in October.

This October two of the key events in the compound semiconductor calendar are being brought together in Monterey, CA, to form Compound Semiconductor Week.

Co-locating the Compound Semiconductor Manufacturing Expo (CS-MAX) and the IEEE Compound Semiconductor IC Symposium (CSICS) will ensure that, for the first time, the entire compound semiconductor supply chain is addressed in a single location. While the CSICS technical program focuses on device design, CS-MAX covers high-volume device manufacturing.

Both conferences will feature presentations from some of the key companies in the industry, including the market-leading GaAs manufacturers RF Micro Devices, Skyworks Solutions and TriQuint. The week-long series of events will run from Sunday 24 to Friday 29 October.

CSICS kicks off

The IEEE symposium will begin on Sunday in traditional fashion, and will feature short courses on power amplifiers and high-speed data converters, and a primer course for those new to the compound semiconductor business.

First up on Monday is the CSICS plenary session, which will feature two presentations that touch on the future of wireless infrastructure. Bill Vassilakis from Powerwave Technologies will kick off the discussion with an overview of the evolution of wireless base station technologies. Later, a more detailed look at the recent progress made in GaN HEMTs for this market will be presented by Tashihide Kikkawa from Fujitsu Laboratories. CSICS technical sessions run through Wednesday with topics ranging from optical-system building blocks to advanced-silicon transceiver ICs.

While the main focus of CSICS will be the design of RF devices, issues relating to optoelectronics and LED manufacturing will also be catered for during the week. Presentations



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from Sony, Bookham Technology and Osram Opto Semiconductors will feature prominently in the CS-MAX schedule.

CS-MAX opens on Tuesday afternoon, and its plenary session will take place on Wednesday morning. This year's plenary features six talks that will cover the full spectrum of compound semiconductor manufacturing.

Plenary session

The first three talks will focus on RF devices, starting with an overview of today's market and future prospects from Asif Anwar of the market research firm Strategy Analytics. Sam Lee, the CEO of GaAs foundry Global Communication Semiconductors, will then look at the manufacturing demands of wireless LAN communications; and Dave Reamer from Veeco's Compound Semiconductor division will round off the first half of the session with a look at the convergence of silicon and compound semiconductor manufacturing.

The second part of the CS-MAX plenary will concentrate on optoelectronic devices, beginning with a round-up of the latest trends in the HB-LED and semiconductor laser markets from Bob Steele of Strategies Unlimited. What promises to be one of the highlights of the week follows: Michiro Chiba's presentation on Sony's laser diode manufacturing operation. Chiba's talk will include a detailed discussion about all aspects of the Japanese company's laser diode production, including an insight into its plans for GaN-based blue/violet lasers as the demand for Blu-ray Disc optical-storage technology heats up. Following Chiba and rounding off the CS-MAX plenary will be Zeljko Spika, the head of InGaN production at Osram Opto Semiconductors, who will discuss the company's new HB-LED manufacturing facility.

Later on Wednesday the opto devices session will include an invited talk from Bookham Technology on the production of

Compound Semiconductor Week planner

	Sun 24	Mon 25	Tues 26	Wed 27	Thur 28	Fri 29
am	CSICS short courses	CSICS plenary session	CSICS technical sessions	CS-MAX plenary session Exhibition luncheon	CS-MAX technical sessions	Golf
pm	CSICS short courses CSICS opening reception	CSICS technical sessions CSICS panel sessions CSICS party	CS-MAX and CSICS technical sessions Joint panel session on foundries Exhibition opening reception	CS-MAX and CSICS technical sessions CSICS panel sessions	CS-MAX technical sessions CS-MAX cocktail party	

high-power laser diodes for industrial applications, while the LED session running in parallel will reflect the recent ramp-up of production in Asia with a presentation from Lumei Technology on LED manufacturing in China. A more technical focus follows, with a talk by Taiwan's Highlink Technology on enhancing the brightness of ITO GaN LEDs.

RF devices

Another highlight of CS-MAX will undoubtedly be Thursday's sessions on RF devices, which feature an invited talk from Tom Rogers, the director of MBE operations at RF Micro Devices, on the volume manufacturing of HBT epiwafers. Now that GaAs is being increasingly challenged by SiGe in the RF

One of the many highlights of the week promises to be Michiro Chiba's presentation on Sony's laser diode manufacturing operation.

sector, the second talk in this session promises to stir up plenty of debate: Jose Harrison from SiGe Semiconductors may ruffle a few feathers with his presentation on "debunking the myths surrounding process technology and cellular PAs".

Later, Neil Morris, chief technology officer at WJ Communications, will discuss the company's recent move into power devices for wireless infrastructure following its recent acquisition of EiC's GaAs fab. The emphasis will then switch to wide-bandgap devices, which are generally regarded as next-generation devices for base station power amplifiers. Edwin Piner will discuss Nitronex Corporation's plans to produce GaN HFET power transistors.

And that's just for starters. The remainder of the CS-MAX program will feature sessions that focus on many important high-volume manufacturing issues, including materials and substrates, epiwafer characterization techniques, epitaxy and back-end processing.

What with a discussion of the latest technical advances in device design at CSICS, plus the opportunity to find out about the latest products and services at the combined technology exhibition on Tuesday and Wednesday, the week promises to have something for everyone involved in the compound semiconductor industry.

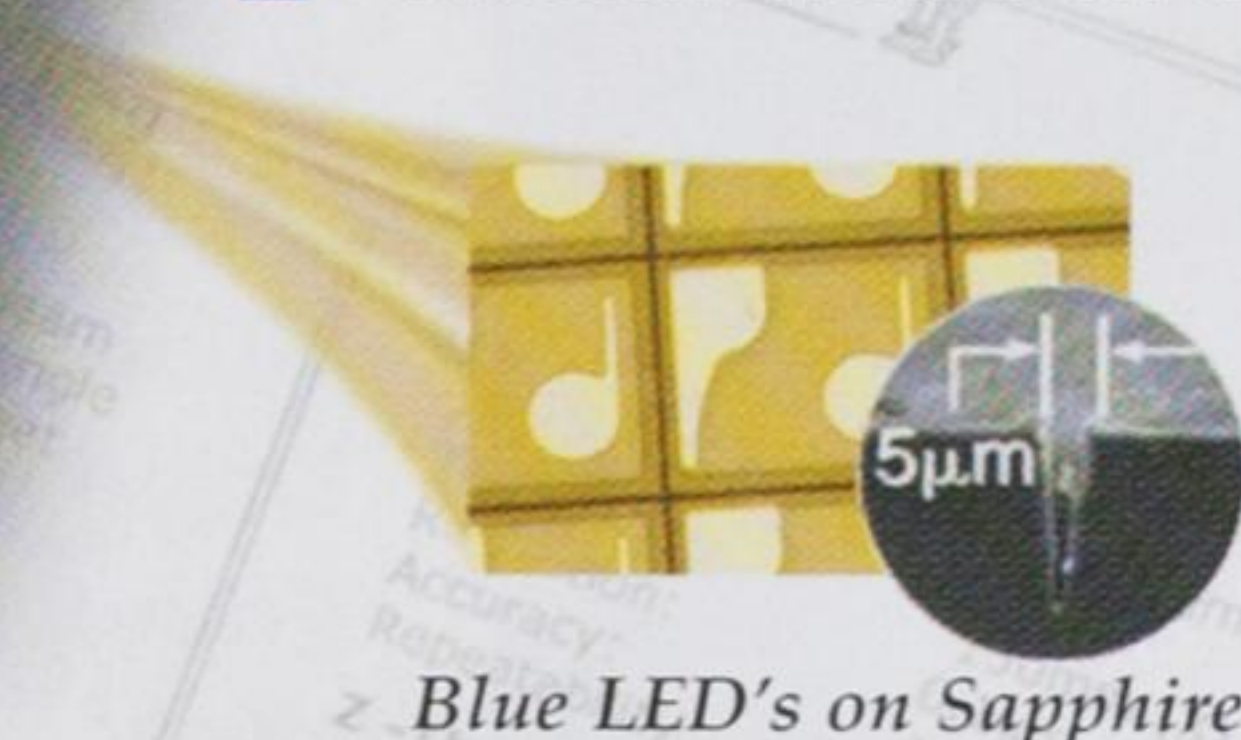
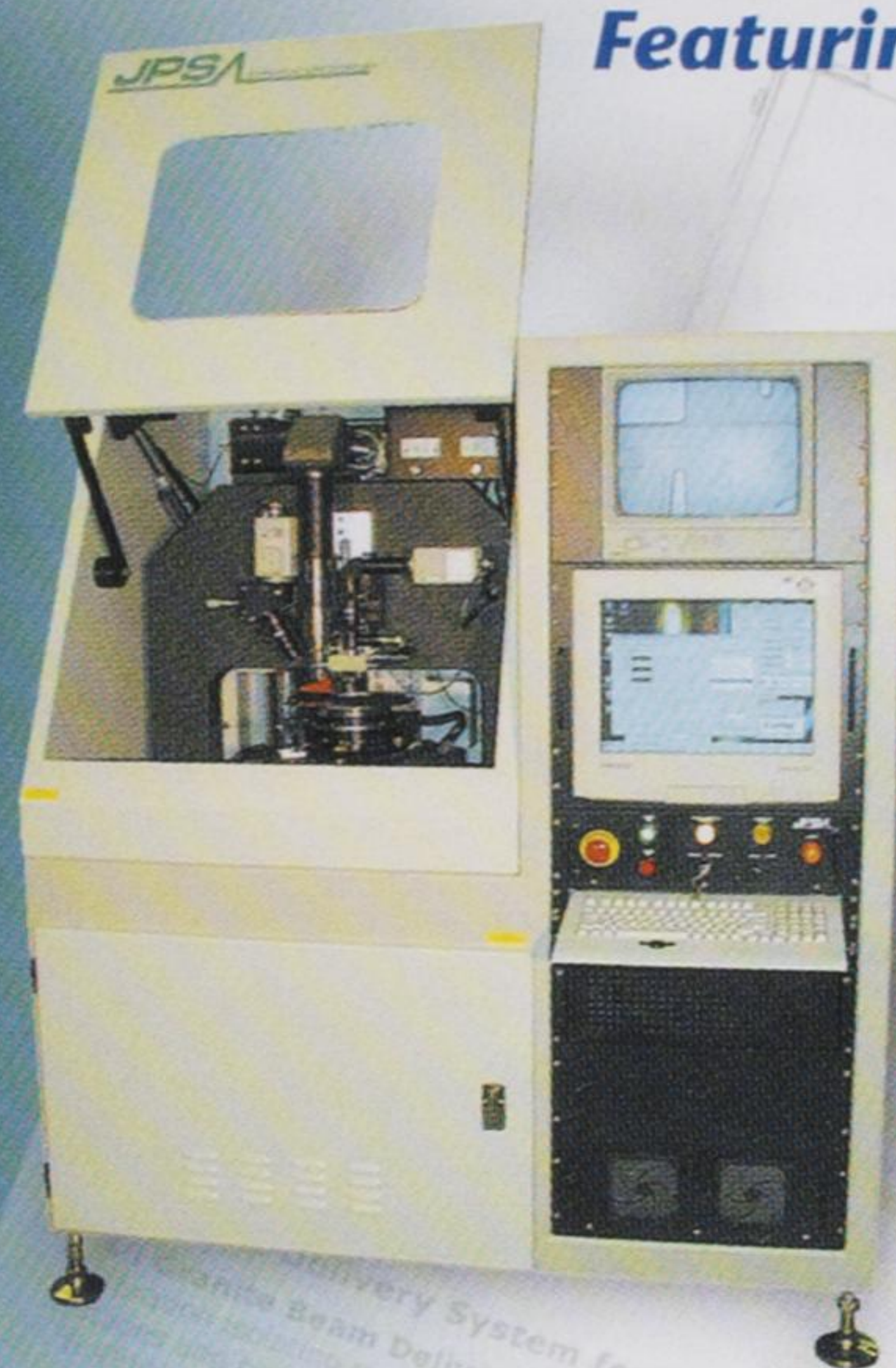
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Using antimonide-based lasers for the mid-IR gap

Tim Whitaker rounds up the latest developments in antimonide-based laser diodes, which can operate at room temperature and continuous-wave mode at wavelengths of up to 2.8 μm .

Powerful and easy-to-use lasers operating in the mid-infrared (IR) range are important for a variety of industrial and military applications, including IR countermeasures, light detection and ranging, remote trace-gas sensing, and secure free-space communications. Meeting these criteria are the antimonide lasers: type-I structures (see box) have demonstrated room-temperature (RT) continuous-wave (CW) operation up to 2.8 μm , while type-II “W” lasers (so-called because of the shape of their conduction band) operate at longer wavelengths, but require cooling below RT or optical pumping.

Quantum cascade lasers (QCLs) have demonstrated RT CW operation at even longer wavelengths (greater than 6 μm), but a void remains in the mid-IR region that several research groups are hoping to fill.

Room-temperature type-I lasers

One leader in antimonide-based high-power laser-diode development is the optoelectronics group at Sarnoff Corporation (Princeton, NJ). Teaming up with mid-IR research groups such as the State University of New York (SUNY) at Stony Brook for type-I band structure devices, and the Naval Research Laboratory (NRL) in Washington for type-II W quantum-well (QW) structures, Sarnoff has achieved record performance marks for high-power mid-IR diode lasers (figure 1).

Initially the team achieved RT laser-diode emission at wavelengths exceeding 2 μm using designs containing InGaAsSb active regions and grown on GaSb substrates. However, output power was limited to 10 mW. Increasing the operating wavelength to 2.7 μm was achieved through using InGaAsSb/AlGaAsSb multi-QW structures with an indium content of up to 40% in the wells.

More recently, a collaboration between Sarnoff, SUNY and Princeton Lightwave (a Sarnoff spin-out) has implemented a new design for AlGaAsSb/InGaAsSb/GaSb type-I MQW lasers, demonstrating RT CW

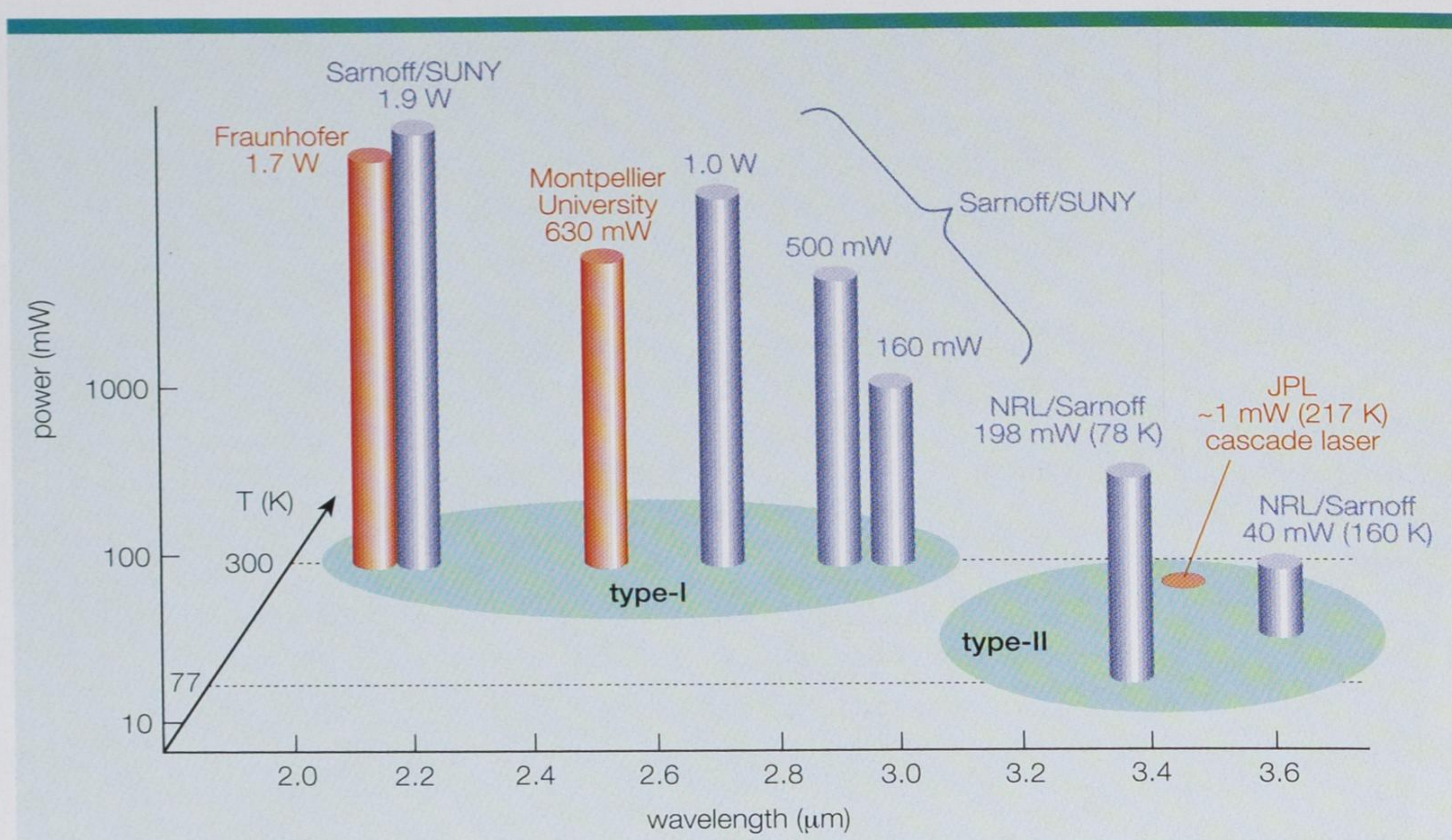


Fig. 1. Type-II antimonide lasers, operating at room temperature, can operate up to about 3 μm . Type-II lasers emit at even longer wavelengths, but at lower operating temperatures.

operation at 2.5 μm with a power of 1 W. In these MBE-grown structures, compressive strain in the In-rich InGaAsSb QWs was reduced through the addition of As.

Using these new designs, Sarnoff and SUNY have reported 2.7 and 2.8 μm lasers operating at RT with output powers of 500 and 160 mW, respectively (Kim *et al.* 2003). However, increasing emission to 2.82 μm resulted in a fall in output power to only 50 mW. The decrease in power with wavelength – and also with operating temperature – is caused by the reduction of hole confinement within the structure and the degradation of material, rather than by Auger recombination as was previously thought (the latter is a non-radiative process involving either two electrons and a hole, or one electron and two holes).

The Sarnoff/SUNY team has also demonstrated a 19-emitter laser array exhibiting RT CW operation at 2.3 μm with an output power of 10 W. The 1 cm-wide laser bar contained 19 emitters with 100 μm apertures and 1 mm-

long cavities. Peak wall-plug efficiency was 9%, with the differential gain of such GaSb-based QW lasers double that of comparable InP-based devices.

George Kim, technical manager in optoelectronics fabrication at Sarnoff, has revealed that the company is now focusing its efforts on high-power RT CW operation above 3 μm to fill the gap between type-I lasers (which operate at up to 2.8 μm) and QCLs, which now operate down to 4.3 μm (see last paragraph).

One option is to use InGaAs(N)Sb QWs. Incorporating N into various III-V structures decreases the bandgap by more than 100 meV per atomic percentage. As well as increasing the laser wavelength, the incorporation of N reduces compressive strain in the QW and suppresses Auger recombination. Kim and co-workers estimate that adding 1% N to In_{0.5}Ga_{0.5}As_{0.19}Sb_{0.81} QWs (used in 2.7 μm lasers) could increase the laser wavelength to 3.5 μm , while adding 2% N could result in emission above 4 μm .

The company is positioning itself as a

small-production-scale provider of IR laser diodes operating above 1.8 μm . “This will support the needs of researchers or manufacturers in developing mid-IR laser-based systems,” said Kim.

Type-II W lasers

Diode lasers, even if requiring a heat sink to be able to operate at 250 K, and offering output powers of a few milliwatts, could still fulfill several applications. For example, the detection sensitivity of methane at 3.3 μm is 1.7 ppb, an improvement of more than two orders of magnitude on 600 ppb for the more accessible wavelength of 1.65 μm . Also, high-power mid-IR lasers emitting in the transparent-window regions of the atmosphere have direct applications in secure communications, target designation and laser radar.

Single-stage and interband cascade type-II W devices continue to show the best performance of any semiconductor lasers in the 3–4 μm region, but a number of issues remain to be resolved.

Optically pumped type-II W antimonide lasers operating well above RT in pulsed mode have achieved good CW performance – for example, CW operation at 290 K at 3 μm and 210 K at 5.9 μm . At 77 K, such devices have produced output powers of more than 0.5 W/facet, and power-conversion efficiencies of 12% per facet.

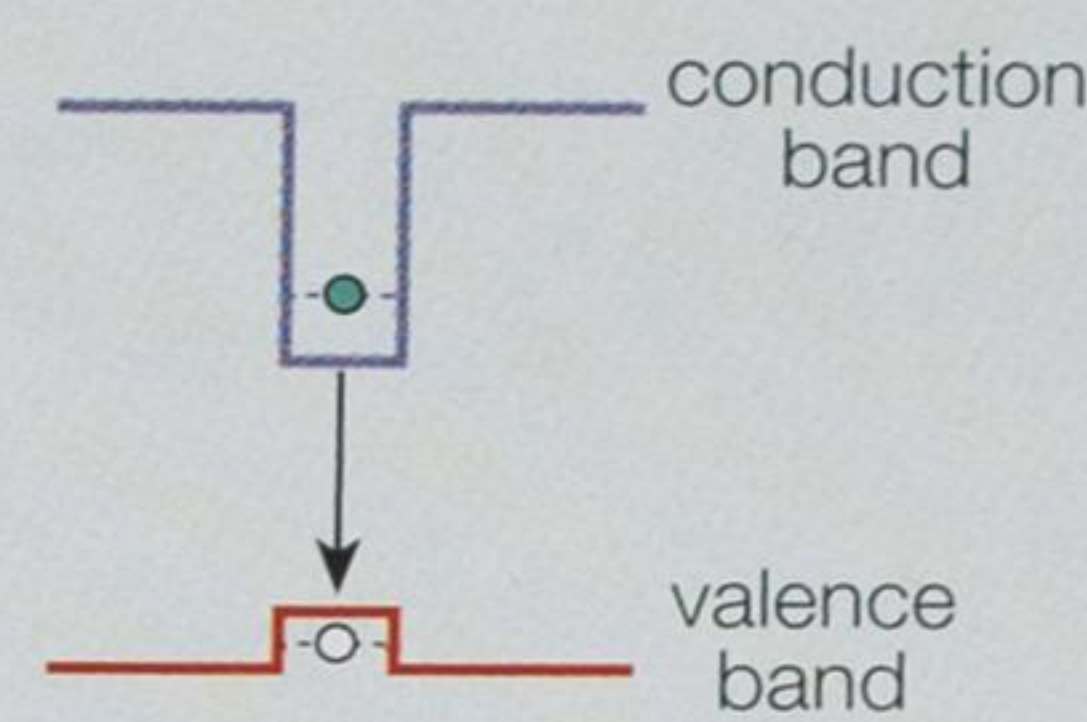
However, manufacturing electrically pumped W lasers is a complex task; carriers must be transported through the cladding and SCH layers before being injected into the active region in an efficient manner. One issue specific to the type-II structure is the result of electrons and holes in different layers of the structure – a typical W laser might have electrons in its InAs wells, with holes in the central InGaSb layer. Carriers must recombine across the InAs/InGaSb interface to produce a mid-IR photon, so the quality of that interface is critical. This issue is one reason for the almost exclusive use of MBE in the growth of antimonide-based IR lasers.

Satisfactory performance in the 3–4 μm region has been achieved from electrically pumped W lasers; in 2000, NRL, Sarnoff and Sensors Unlimited reported 3.25 μm broadened waveguide diode lasers operating in CW mode at up to 195 K. At 78 K, the threshold current density was 63 A/cm², and 140 mW of CW output power was generated.

NRL's Igor Vurgaftman said: “W lasers now operate in CW mode up to around 200 K with a wavelength of about 3.5 μm . At 78 K

Type-I , type-II and quantum cascade lasers

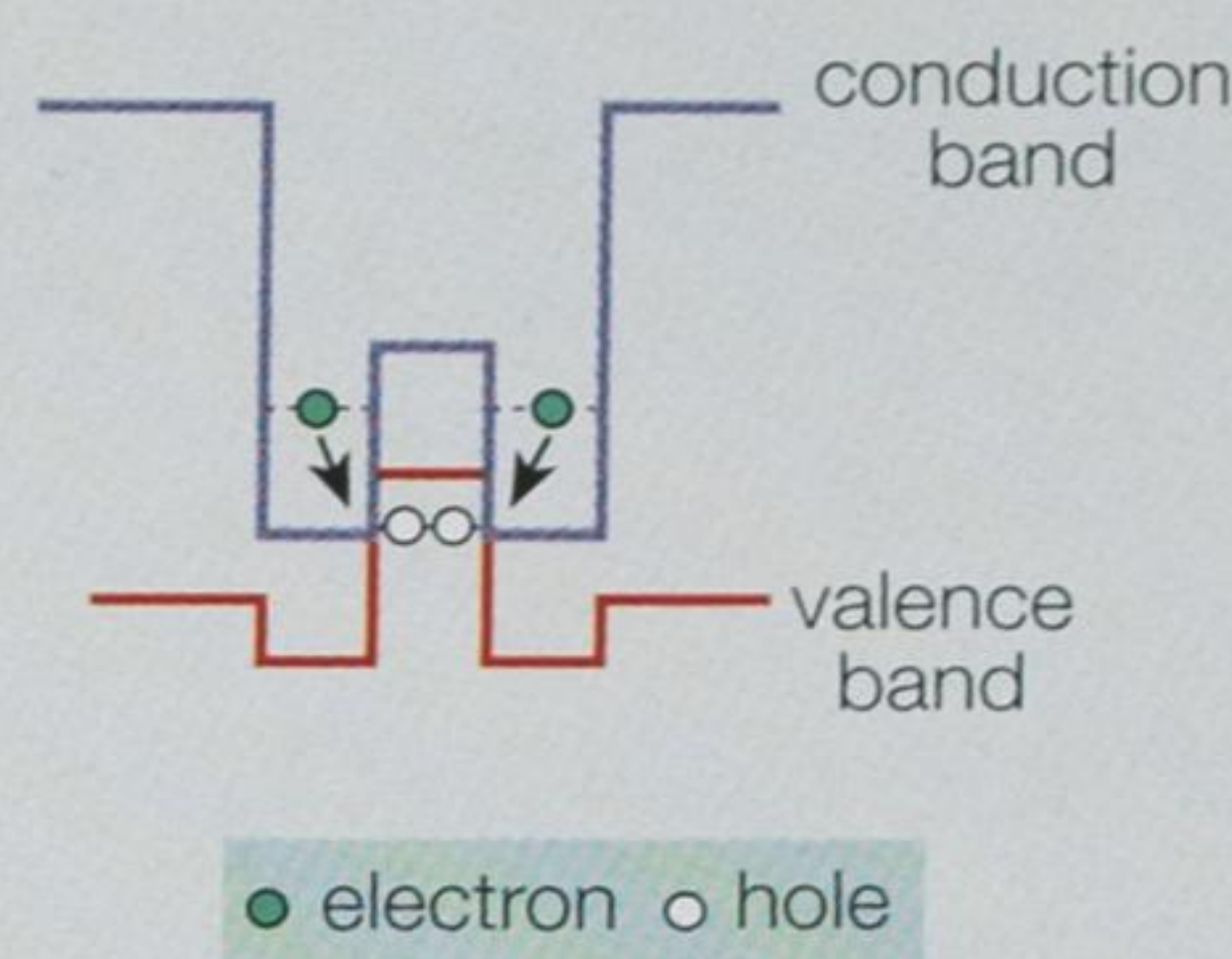
type-I interband QW laser



Conventional interband diode lasers have a type-I QW structure with electrons and holes localized in the same layer. These devices operate up to around 3 μm , but at longer wavelengths their performance decreases rapidly.

In type-II interband lasers, also termed “W”

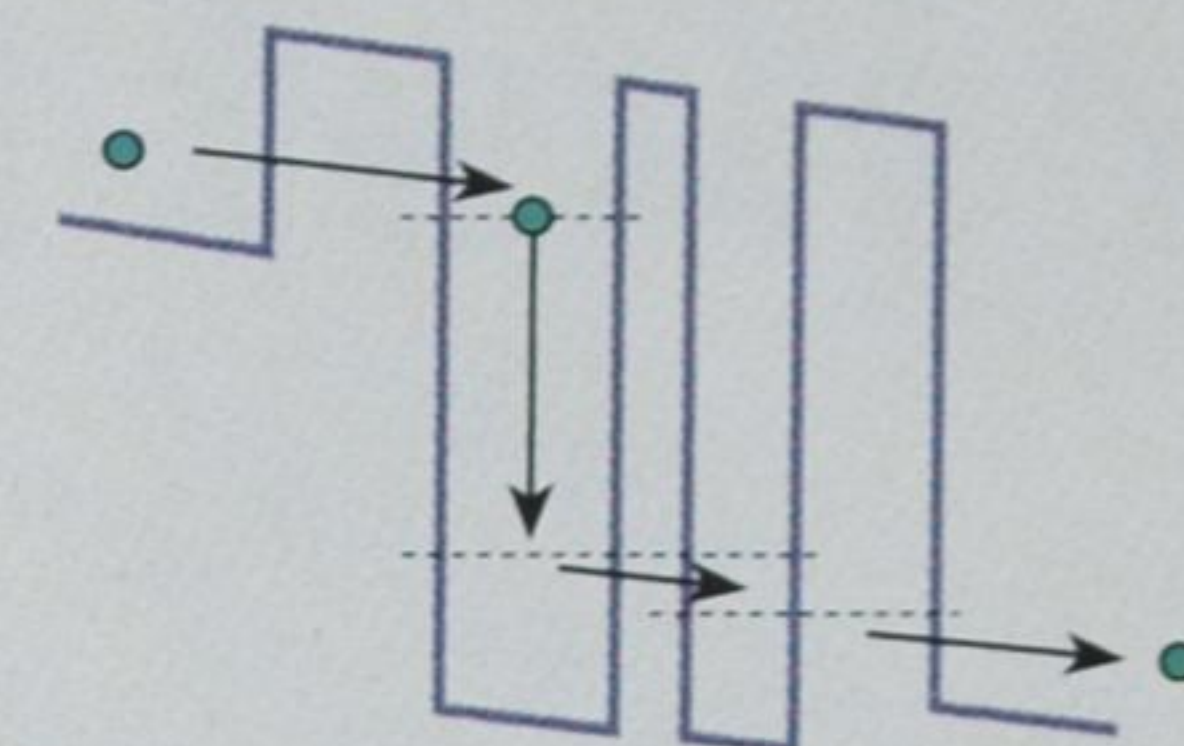
type-II interband “W” laser



lasers, electrons and holes are in adjacent layers. Photons are emitted with an energy significantly lower than the bandgap energy of the constituent layers, helping to suppress loss from Auger recombination.

For intersubband QCLs, the lasing transition takes place between two

intersubband quantum cascade laser



quantized states (sub-bands) of the conduction band. The transitions occur inside several series of coupled QWs with cascaded energy levels, connected by injector regions to supply electrons. It is also possible to fabricate type-II interband cascade lasers.

the devices have an output power of around 200 mW, together with a threshold current density of 67 A/cm² and a maximum slope efficiency of 106 mW/A. The device structure, grown by MBE on an n-type GaSb substrate, contains a five-period W active region in the sequence InAs (well), Ga_{0.75}In_{0.25}Sb, InAs (well), Al_{0.15}Ga_{0.85}As_{0.05}Sb_{0.95}.”

One such device was used for preliminary experiments to detect methane, which has a strong absorption band around 3.315 μm . With the laser operating at a heat-sink temperature of 110 K, the system could detect methane at a partial pressure of 7×10^{-7} atm in a nitrogen atmosphere (Bewley *et al.* 2004).

Cascade lasers

An alternative approach, using type-II interband cascade structures, has enabled CW operation at up to 214 K in the 3–5 μm range, according to Maxion Technologies and the US Army Research Laboratory. At 80 K, the devices operated in CW mode at 3.4 μm with 23% power-conversion efficiency and a differential external quantum efficiency of 532%.

Rui Yang at the Jet Propulsion Laboratory says that his group has operated mid-IR interband cascade lasers at temperatures up to 217 K in CW mode. In pulsed mode, the lasers operated up to 325 K at 3.2–3.36 μm , and up to 300 K at 4.1 μm .

While the maximum CW operating temperature of type-II antimonide lasers creeps

slowly upwards in the 3–4 μm region, QCLs have been able to demonstrate CW RT operation at ever-shorter wavelengths.

Northwestern University researchers have demonstrated RT CW operation from an InP-based intersubband QCL at 6 μm , with an output power of 132 mW at 293 K and 21 mW at 308 K (Yu *et al.* 2003). Manijeh Razeghi, from Northwestern, says that a paper describing 4.7 μm operation has been accepted, while RT CW operation has already been demonstrated at 4.3 μm .

Further reading

W W Bewley *et al.* 2004 *Proc SPIE* 5365-29.
J G Kim *et al.* 2003 *Appl. Phys. Lett.* **83**(10) 1926.
J Yu *et al.* 2003 *Appl. Phys. Lett.* **83**(13) 2503.

To find out more information about Sarnoff's commercial mid-IR laser products, contact David Zish at dzish@sarnoff.com.

The commercialization of quantum cascade lasers, devices that operate at around 4–150 μm , is discussed on p28

QUANTUM CASCADE LASERS

QCLs: mass-market devices or just interesting physics?

High-power quantum cascade lasers (QCLs) operating at wavelengths not easily accessible by other laser sources could address substantial markets such as gas sensing. However, growing QCLs today amounts to little more than a cottage industry. **Richard Stevenson** investigates.

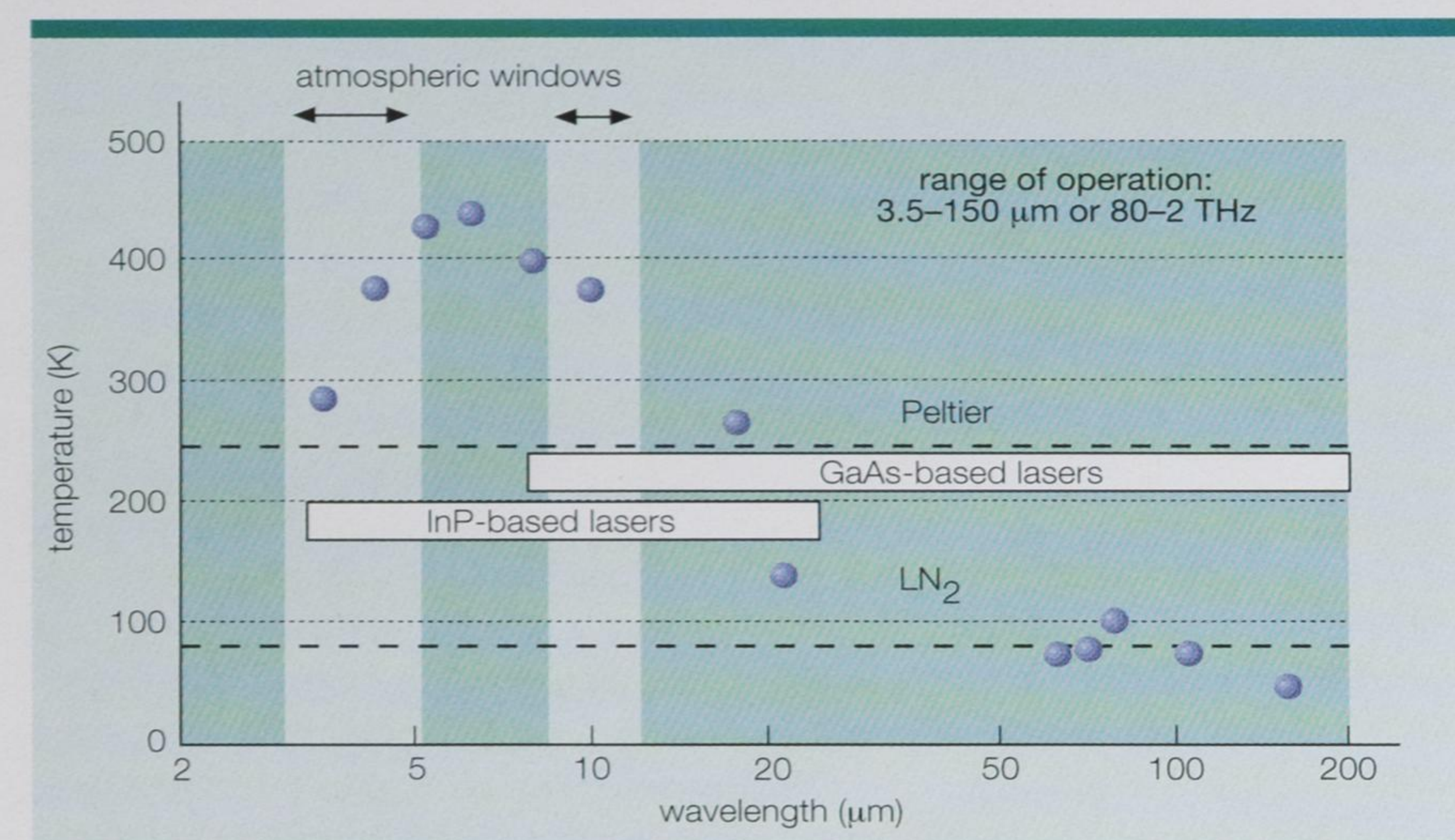


Fig. 1. The operating temperature of state-of-the-art QCLs from various research groups, which generally decreases with increasing wavelength.



Fig. 2. Fraunhofer Institut Physikalische Messtechnik's QCL system detects various gases including NH_3 , CO_2 and NO .

Ten years have passed since the invention of the quantum cascade laser (QCL) by researchers at Bell Labs – a device that operates through the cascading of electrons between different states in the conduction band (see box). Advances during this decade include using different material systems to increase the range of lasing wavelengths (figure 1), improved output powers, and higher temperatures of operation. Today's QCLs can operate in continuous wave (CW) mode at room temperature, delivering output powers of about 1 W. But despite all this progress, there is only one company, Switzerland-based Alpes Lasers, that is fabricating QCLs commercially.

An industry exploiting QCLs would not be limited by potential applications. For example, QCLs are the only solid-state lasers that can access the mid-infrared region of the spectrum where toxic gases and vapors have their tell-tale absorption features. This gas-sensing market is worth \$7 billion worldwide, and opportunities for QCLs also exist in a variety of other lucrative markets: detection of explo-

sives, oil and gas exploration, medical diagnostics, and perhaps even countermeasure systems to protect aircraft from missile attack.

One company hoping to exploit the opportunities provided by QCLs is UK-based laser-applications business Cascade Technologies, a spin-off from the University of Strathclyde. The company was founded in January 2003, but was busy raising funds until April 2004, and aims to produce a highly sensitive gas sensor by April 2005. Cascade has developed prototypes emitting at around $10.25\text{ }\mu\text{m}$ which have been used for the analysis of car fumes, detecting levels of carbon dioxide and of ethylene, an unburnt hydrocarbon.

"Cascade's first product is a packaged laser system which enables QCLs to be operated in a user-friendly way," said Richard Cooper, the company's director of operations. Its advantages include "ease of use, that it is simple to set up and install, and its small size". Cascade's new system will be demonstrated at the 5th Workshop on Quantum Cascade Lasers, which will take place in Freiberg, Germany, on September 23–24.

Sensing the opportunity

The gas sensor is sensitive to the parts-per-trillion level, can operate at room temperature with up to 1 million measurements per second, is portable, and requires no consumables, claims Cooper. "The initial price of the gas sensor will be comparable to high-end gas chromatography mass spectrometry [GCMS], but it offers superior performance and requires only limited training to use," he said. GCMS is the present industry choice and achieves sensitivities in the part-per-billion range, but it takes around 40 minutes to produce a reading, according to Cooper.

Cascade is not the only company seeking to exploit QCLs for gas sensing. Physical Sciences, based in Andover, MA, has developed two separate systems using 5 ns pulses, one for detecting carbon monoxide and the other for detecting nitrogen dioxide. With a sensitivity of 10 parts per billion, these products are suitable for atmospheric monitoring, pollution emission monitoring, and the analysis of exhaled human breath.

Cooper explains that systems from com-

petitors tend to use significantly shorter pulses and vary the laser frequency by superimposing a slow voltage ramp onto the pulse train. One pulse corresponds to one data point, so several seconds are required to build up a picture. “Meanwhile, the gas has moved on,” pointed out Cooper. He believes Cascade’s other advantage is that its system has fewer complex, expensive elements.

Cascade plans to exploit a discovery by its technical director, Erwan Normand, that will make positive use of a QCL feature that was previously seen as a disadvantage. The technique uses a 300 ns pulse that contains a spread of wavelengths caused by changes in laser temperature. The resulting pulse covers a spectral window broad enough to fingerprint several molecules at once, and gives a “full picture in less than a millionth of a second”.

Since the global gas-sensing market is so valuable, Cascade needs to take only a small cut to be successful. Cooper explains that other potential uses for its systems include the oil and gas industry, for both process and environmental monitoring, and in the longer term medical diagnostics, such as determining diseases from breath analysis. The point-of-care medical diagnostic industry alone is valued at \$22 billion.

The source of QCL chips for Cascade, along with the US-based Jet Propulsion Lab, the Fraunhofer Institute in Germany, and many others, is Alpes Lasers, a spin-off from the University of Neuchâtel, which currently employs about 10 people. It was founded in 1998 by Matthias Beck, Antoine Muller and Jérôme Faist, co-inventor of the device. Alpes is growing slowly but steadily, and senior R&D engineer Yargo Bonetti believes it is the only company in the world offering commercially grown QCLs.

A solitary manufacturer

Bonetti feels that the QCL market is big enough to support two companies of Alpes’s size, but demand is insufficient for a large enterprise to enter the business. “Laser demand is not sufficient to produce thousands or tens of thousands of lasers per week,” Bonetti explained. He notes that four or five competitors have emerged in the last year only to withdraw, presumably because the venture offers little reward for the efforts involved. US-based Applied Optoelectronics, for example, was manufacturing QCLs until about 12 months ago.

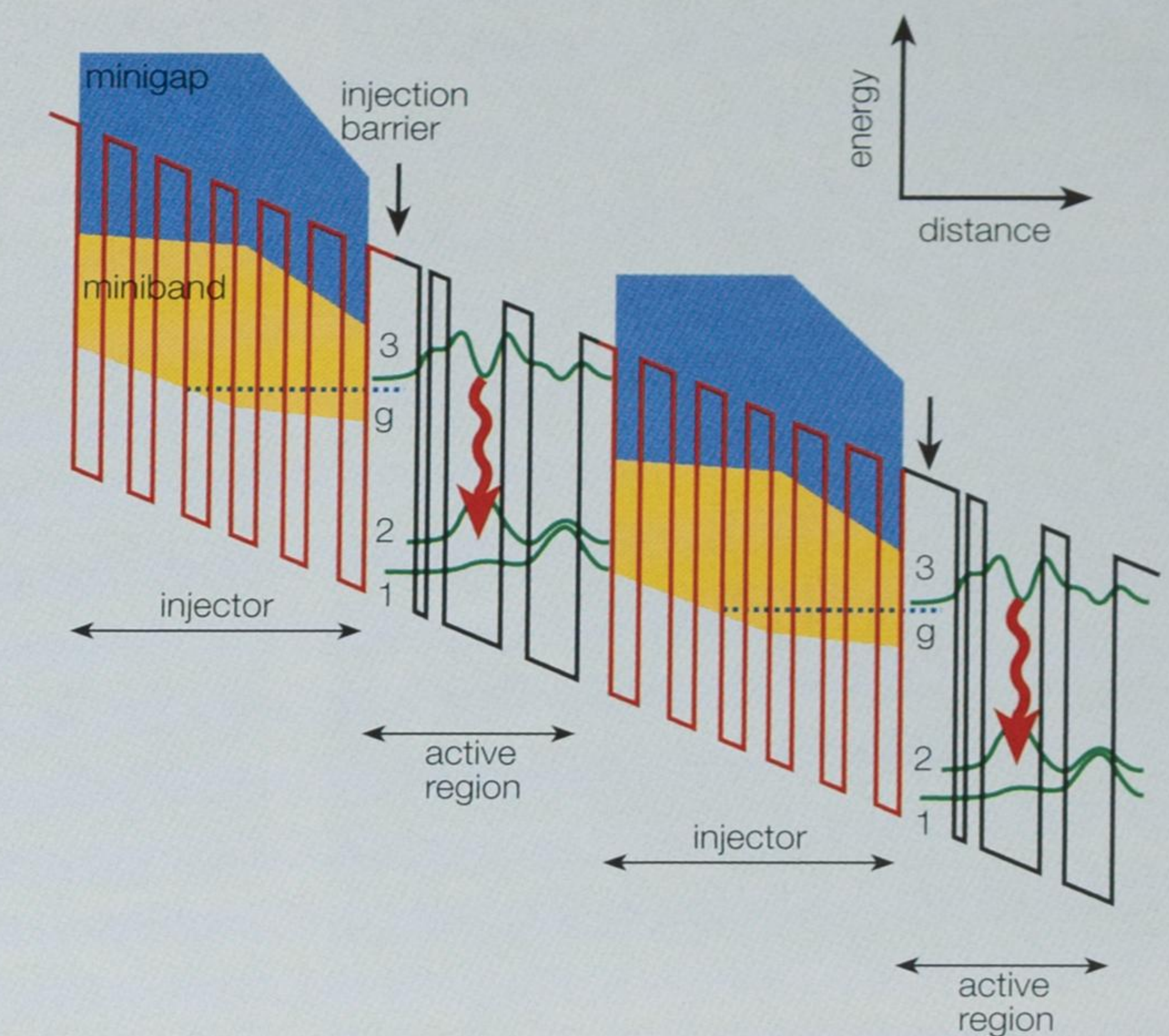
Alpes conducts its MBE growth of QCLs at the University of Neuchâtel. Currently

Operating principles of a QCL

The diagram shows a section from the conduction band of a typical QCL. The valence band has been omitted because QCLs are unipolar devices, exclusively n-doped, with holes playing no part in the device.

The formation of typically 25–75 alternating injector and active regions is achieved through the precise control of several hundred layers of material, each only a few nanometers thick. The active region contains three quantum wells with three discrete energy levels; the injector consists of layers too thin to confine electrons, and instead a miniband and a minigap are formed.

QCLs are essentially electronic waterfalls, with one electron capable of generating tens of photons. Electrons, present in the miniband owing to high n-type doping, are driven (left to right) towards the active region by an applied electric field. Once trapped in the quantum well of the active region, relaxation from the third to the second energy state releases a photon – and its wavelength is solely



determined by the difference in energy between these two states.

The device design optimizes light output, with the position of the minigap suppressing electrons exiting the active region by tunneling into the lower injector region without radiating.

Through lattice vibrations the electron then rapidly relaxes into the first state, before entering the next injector region. Again the electron, under the influence of the electric field, traverses the injector region, and emits a photon in the

active region. It is this cascading process that enables just one electron to generate many photons.

Although electron relaxation determines the lasing wavelength, the laser cavity supports up to 20 closely spaced wavelengths. A Bragg grating can be used to select a single wavelength, which is essential for many applications. The QCL can then be tuned over a wide range of wavelengths by changes in temperature which alter the cavity’s effective length through changes in refractive indices.

developing CW sources, Alpes offers either pulsed singlemode QCLs in the regions of 5.3–6 μm and 10–10.5 μm , or pulsed multi-mode QCLs, operating either at 5.0–6.2 μm or at 8.5–10.5 μm . Peak power outputs are 100–500 mW. The company also offers a “starter kit”, including the electronics required to drive the device and a temperature controller. Prices for off-of-the-shelf QCLs are €10,000–20,000 (\$12,000–24,000), but tailor-made devices sell for around €50,000.

QCL lifetimes are long and difficult to evaluate. Tests at elevated temperatures suggest it takes 10–50 years (or longer) for a QCL’s output power to fall by 20%. Bonetti reveals that some early devices failed after only one

or two years because of soldering or bonding issues, although these problems are now largely resolved.

Production times for QCLs at Alpes vary considerably, from just three weeks for established structures to about nine months for custom designs at new wavelengths. Bonetti believes the high level of skill needed to fabricate QCLs discourages potential competitors. “All the processes involved in producing these lasers are quite well-known, and are also published. However, to know how to basically make these lasers does not solve the problem of [actually] making them. There’s a lot of know-how that’s not documented.” Bonetti acknowledges that the small quantities of

QUANTUM CASCADE LASERS

lasers made today hinder yield improvements.

This view is not shared by Carlo Sirtori, another co-inventor of the QCL, who holds joint roles as a consultant at Thales's research and technologies division in Orsay, France, and as a professor at Université Paris 7 Denis-Diderot. He believes QCL growth is comparable to that of vertical-cavity surface-emitting lasers (VCSELs), a well-established technology. Although QCLs have more interfaces than VCSELs, abrupt interfaces are not critical, and QCLs' unipolar nature circumvents complications associated with dopants altering the material growth rate. Sirtori believes MBE holds the upper hand over MOCVD for QCL growth, thanks to its greater control of very thin layers, but he added: "If you care less about wavelength, and more about time, then MOCVD has an advantage."

Sirtori says that Thales is trying to implement antimonide materials on InP substrates, to produce high-power QCLs emitting at around 4 μm for applications such as detecting trace gases and optical free-space communication – in the 3–5 μm region the atmosphere is relatively transparent. To

achieve these short wavelengths requires a relatively large separation of the electron energy levels in the quantum well of the active region. Material systems such as AlAsSb barriers and InGaAs wells, lattice-matched to InP, are suitable – the large difference between their bandgaps allows formation of deep quantum wells providing emission at around 4 μm .

Of great interest for the future, in Sirtori's opinion, are QCLs operating in the terahertz region of the spectrum. "There is a gap in the region between 100 μm to below the terahertz [1.0 THz = 300 μm], with no [commercial] semiconductor lasers or transistors operating at these frequencies. The transistor dies at about 500 GHz. That is why this device [the terahertz laser] is important." As figure 1 shows (page 28), there have been only a handful of reports of lasing above 100 μm , and all with devices operating at around liquid-nitrogen temperature.

Converging dimensions

"The size of a quantum well in the terahertz laser, the unit of our structure, is about 50 nm," Sirtori continued. "Silicon technology today

has a 100 nm gate size, but the industry is studying transistors with a gate length of 50 nm. You can clearly see the merging of electronics and optoelectronics – the size of a gate is comparable to the quantum well where the photon is generated. My feeling is that the two worlds are getting together."

Returning to one of today's issues, the problem of having only one commercial QCL manufacturer, Sirtori commented: "If I would want to produce a system, all my investment towards this new idea would rely on a single small company. I would be really worried."

The factors affecting the growth of an industry for QCL devices are intriguing – the potential markets for QCLs are massive, but initial market penetration will require a reliable supply of devices. Clearly, competition between even only a handful of QCL manufacturers would drive performance up and prices down. However, current demand for QCLs is sufficient for probably only one other small operation, and the decision by Applied Optoelectronics to cease QCL production can only be detrimental to the development of the emerging sector.

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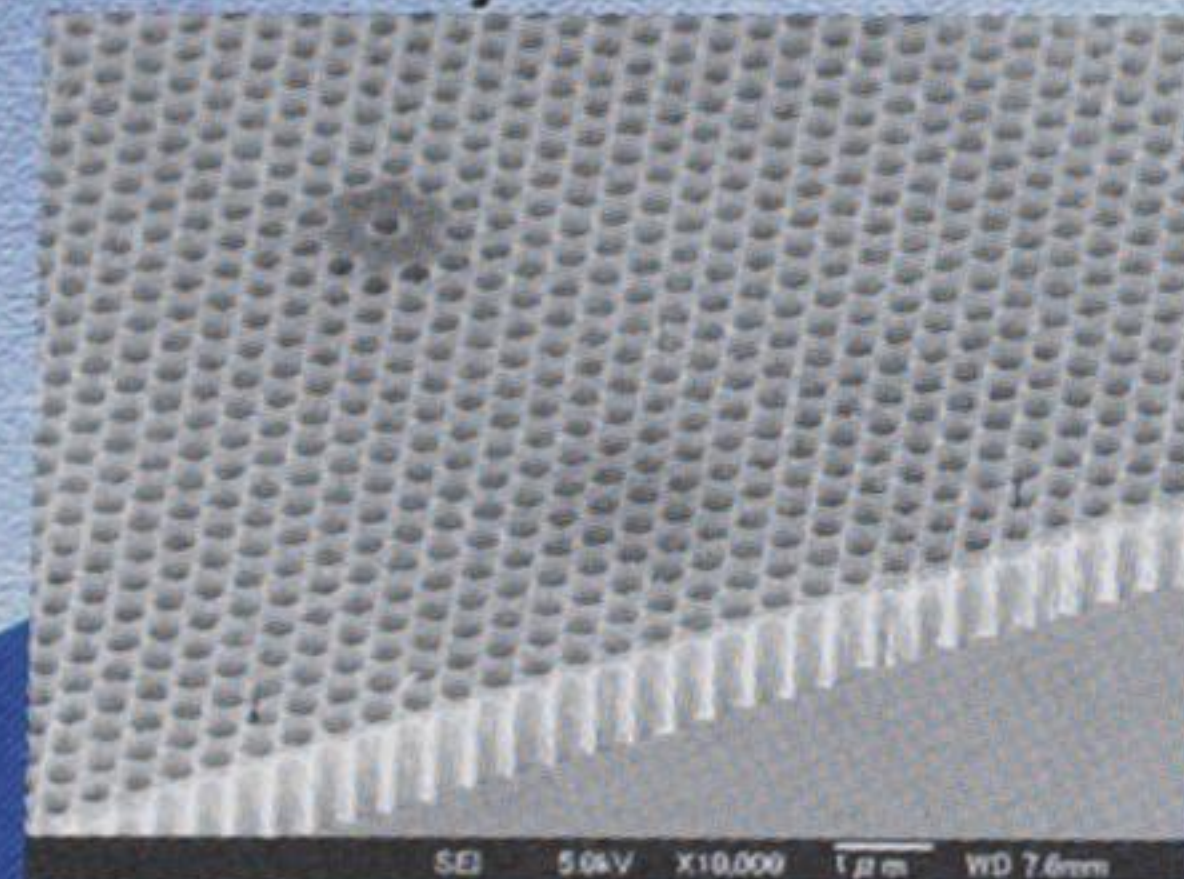


Photo Courtesy of Baba Research Lab, Yokohama National University



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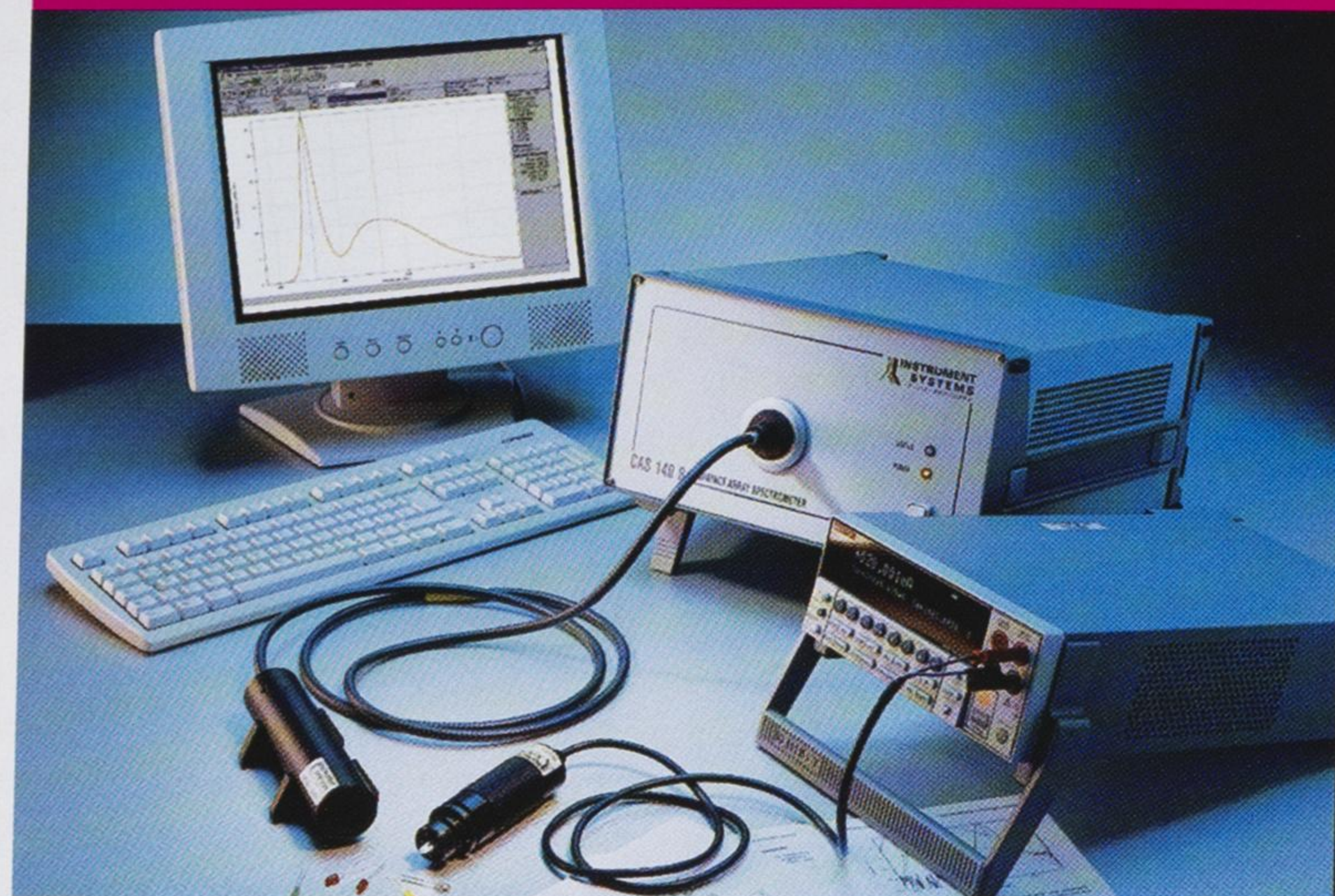
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Intrinsic's profile grows with Bandgap acquisition

Intrinsic Semiconductor, a Virginia-based company that focuses on GaN and SiC materials, is to acquire SiC wafer supplier Bandgap Technologies. Bandgap, of Columbia, SC, is a defense contractor.

The acquisition will provide Intrinsic with a greater variety of SiC wafers and will bring expertise in 4H/6H products. It will also add production capacity for SiC bulk crystal growth and the opportunity to increase crystal diameters.

Following the part-cash, part-stock deal, Bandgap president Yuri Khlebnikov will become director of bulk crystal growth, while Intrinsic's Cengiz Balkas remains CEO and president of the combined operation.

The merging companies were expected to be "fully integrated" by the end of August. Balkas told *Compound Semiconductor*: "Integration will happen very quickly. Much of the crystal growth will be relocated to our



Intrinsic will relocate much of Bandgap's crystal growth operation to its Virginia HQ.

Virginia facility, but some back-end operations will continue in Columbia."

"We will also look at ways to expand the business in Columbia," Balkas added. Intrinsic recently introduced a range of GaN-based HEMT epiwafers.

Riber and CNRS open nitride laboratory

France-based MBE equipment supplier Riber has set up a process technology center to develop nitride-based devices. The laboratory has been created in collaboration with French research body the Centre National de la Recherche Scientifique (CNRS), and is based in Valbonne, near Nice.

According to Riber, the center is dedicated to "the development and integration of new growth and characterization processes including (silicon-compatible) GaN-based HEMTs, HFETs, LEDs and laser diodes".

The laboratory features a Compact 21 GaN MBE system that will grow specific test struc-

tures. Riber is encouraging prospective users to visit the center to evaluate equipment or investigate device properties. The company had previously joined forces with CNRS to create a similar laboratory dedicated to phosphide work.

- CNRS has ordered a single-wafer Veeco MBE system. The GEN II kit will be integrated with an existing MBE system at the French laboratory, and will be used to grow high-mobility GaAs-based electronic devices.

"We selected the GEN II for its proven ability to grow devices with record-setting high mobility," said Ulf Gennser of CNRS.

SiGen's SOI wafers offer uniaxial strain

Silicon Genesis (SiGen), a US-based silicon-on-insulator (SOI) process technology provider, has developed wafer-level strained substrates that feature uniaxial strain.

SiGen says that its technology, coined "next-generation strain", avoids the mobility degradation and high defect levels associated with today's SiGe-based and strained SOI technologies that create a biaxial strain.

"This material can be directly integrated on silicon as an 'epi-like' strained bulk wafer, or on an insulator as strained-SOI," said François Henley, SiGen's CEO.

Scott Thompson, former Intel Fellow and director of Intel's 90 nm strained silicon program, added: "The availability of a global uniaxially strained substrate [will] substantially improve total transistor performance and has scaling advantages over local strain at the 45 nm node and beyond."

- See this month's feature on strained silicon (pp18-20) for more details.

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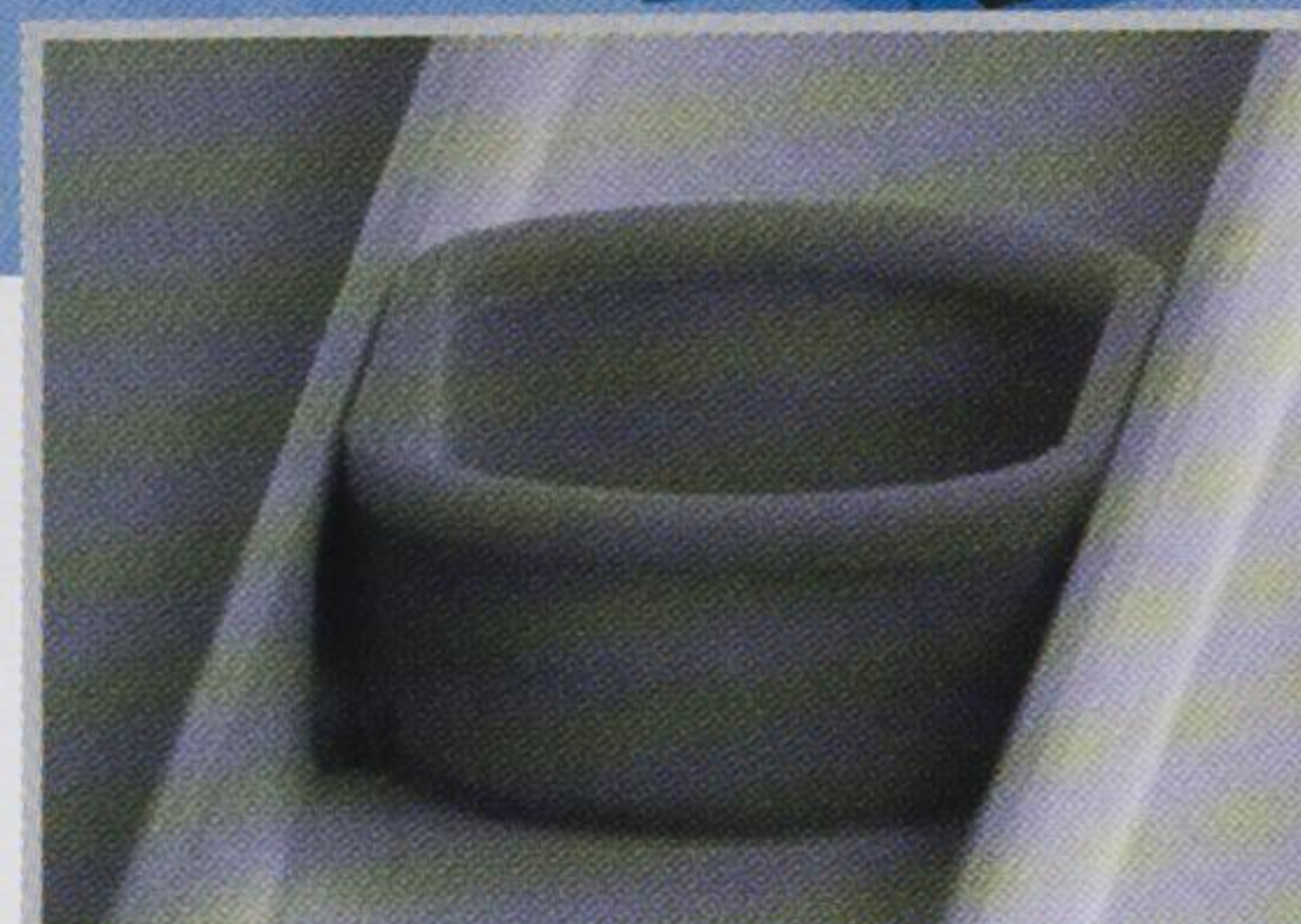
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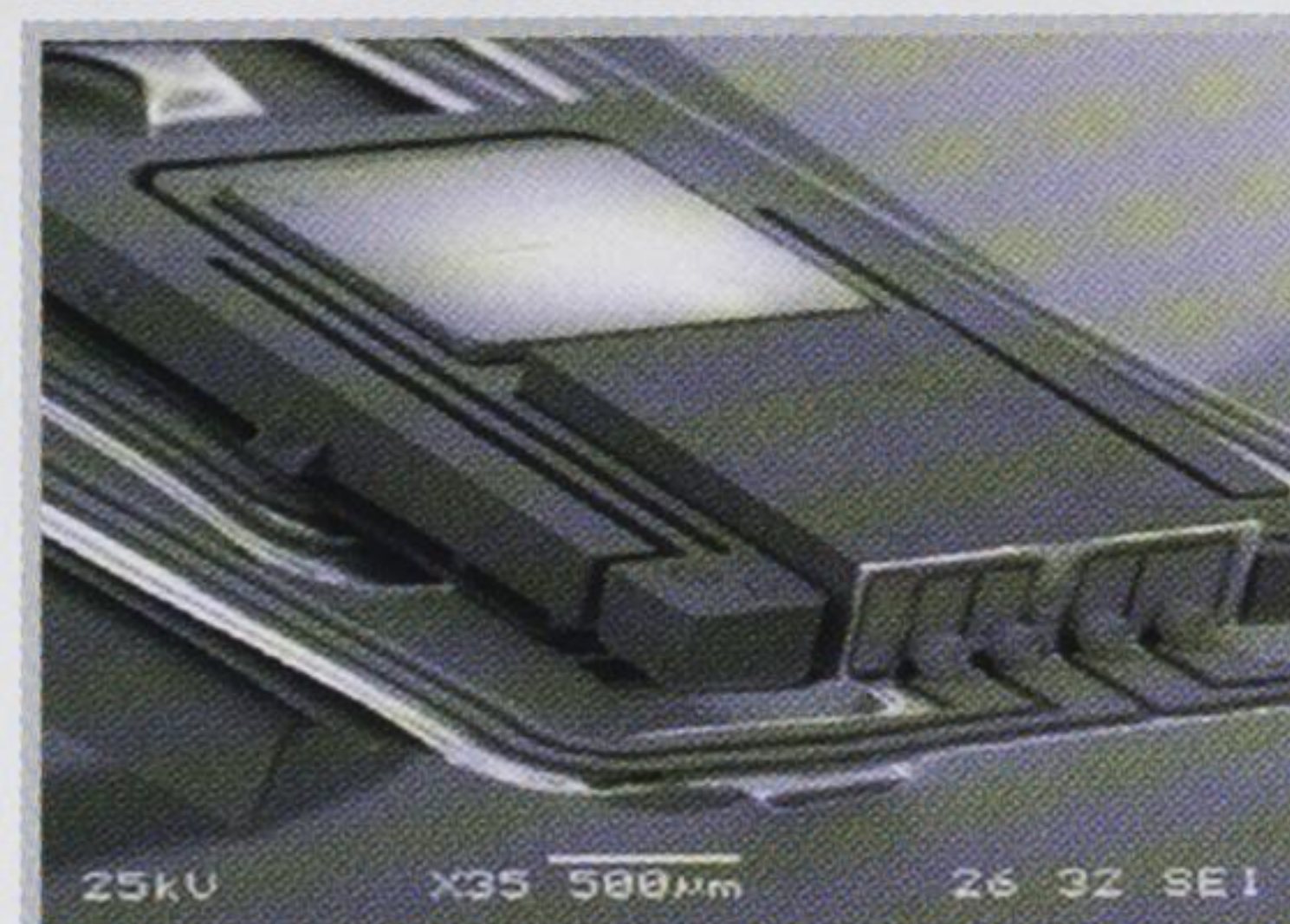
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Cree shines bright as RFIC makers reap profits from handset frenzy

Cree is the star turn of the III-V manufacturers, and with no sign of the cell phone handset market waning, RFIC manufacturers are also raking in profits after last year's widespread losses. Meanwhile, JDS Uniphase raises hopes of a return to form with strong bookings. **Michael Hatcher** reports.



For the first time in at least three years, there was good news all round for compound semiconductor companies in the recent raft of quarterly and full-fiscal-year financial reports. Of the three key sectors, RFIC manufacturers and LED makers alike are benefiting from the still-strong cell phone handset end market, while in fiber-optic components there are signs of a long-awaited upturn.

Phones with extra functionality are increasing the demand for GaAs-based power amplifiers, while features such as high-resolution cameras and video messaging require yet more LEDs. And with Strategy Analytics revising its 2004 forecast for handset sales from 586 million to 670 million, RFIC suppliers are set to make hay while the sun continues to shine.

Mixed messages surround any potential upturn in the infrastructure market. While the world's leading base-station builder, Ericsson, says that it believes this sector has finally turned the corner, a report from analyst company ABI Research concluded that this would not translate into positive news for suppliers of RF power chips and modules. ABI reckons that an inevitable slow-down in the deployment of GSM base stations will outweigh the roll-out of third-generation infrastructure, and that

tough times lie ahead, especially for chip makers.

The pick of the bunch in terms of pure profit are Skyworks Solutions, which posted a net income of \$13 m in its June quarter, and RF Micro Devices. The latter, which also predicts a boom in handset sales at the end of the year, made a net profit of only \$3 m under US GAAP accounting rules. However, in its pro forma accounts, which exclude some one-off charges, RFMD registered a net income of \$12.7 m.

Another major GaAs IC manufacturer, TriQuint, reported its third consecutive profitable quarter – just. In terms of share price, the top three GaAs manufacturers have performed similarly over the past year; all are slightly down on their price this time last year, as investors ponder the prolonged success of what has become a very competitive market. Price erosion, which has been forced upon handset component suppliers as the market leaders Nokia and Motorola cut prices to compete with Korea's Samsung and LG, will make it increasingly difficult for the RFIC manufacturers to improve their profit margins – perhaps it is this that is holding back the stock prices.

CIBC World Markets analyst Earl Lum rates Skyworks as the most attractive proposition in this

June/July quarter performance for publicly listed III-V device suppliers

Company	Symbol	Quarterly revenue (\$m, year change %)	Net income/loss (\$m)	Share price (\$) on Aug 26 (52-week range)	Price/earnings ratio
RFICs					
Agilent	A	1890.0 (+25%)	+100	21.96 (19.51 – 38.70)	36.02
Anadigics	ANAD	22.7 (+26%)	-11.7	3.90 (3.45 – 9.11)	n/a
Celeritek	CLTK	8.0 (+21%)	-0.97	3.45 (3.13 – 9.10)	n/a
Fairchild	FCS	414.0 (+19%)	+17	12.86 (12.05 – 28.50)	52.38
Freescale	FSL	1461.0 (+31%)	+43	14.50 (14.01 – 14.76)	n/a
RF Micro Devices	RFMD	166.0 (+26%)	+3	5.22 (4.66 – 12.51)	24.86
Sirenza	SMDI	15.7 (+73%)	+0.9	4.66 (3.33 – 9.00)	n/a
Skyworks Solutions	SWKS	207.4 (+27%)	+13	8.87 (6.98 – 12.68)	n/a
TriQuint	TQNT	92.6 (+27%)	+0.3	4.08 (3.20 – 9.93)	136.00
LEDs					
Cree	CREE	91.0 (+42%)	+21	25.42 (14.90 – 29.00)	33.01
Fiber optics					
Avanex	AVNX	31.9 (n/a)	-21.6	2.42 (1.95 – 7.57)	n/a
Bookham*	BKHM	38.8 (+11%)	-35.6	0.71 (0.68 – 3.55)	n/a
Emcore	EMKR	21.2 (+25%)	-12.5	2.39 (2.24 – 7.93)	n/a
JDS Uniphase	JDSU	174.5 (+8.7%)	-24.3	3.20 (2.84 – 5.89)	n/a

*Nasdaq listing: Bookham will list its shares on the Nasdaq exchange only after it switches corporate domicile to the US from the UK.

Source: Yahoo Finance

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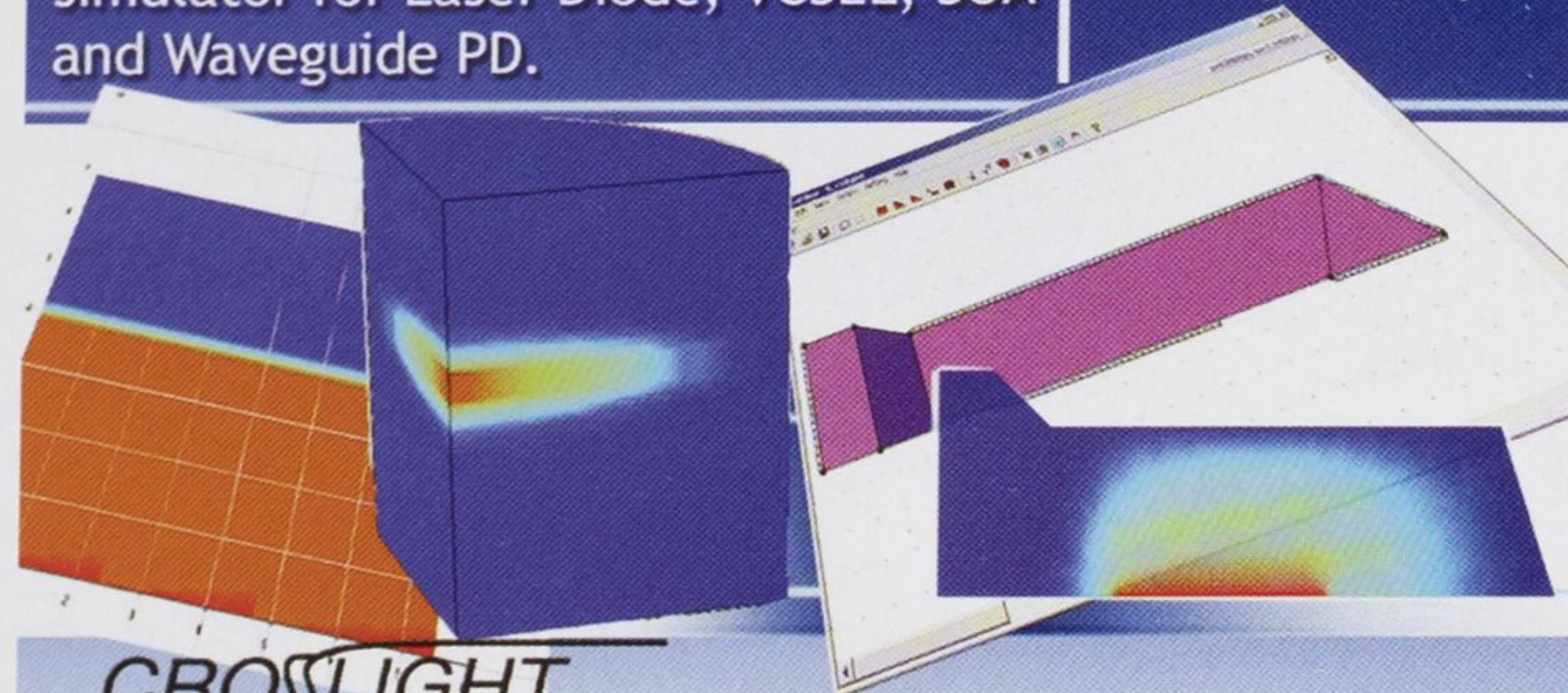
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segment at the moment. "Skyworks Solutions remains our top pick among our RF component suppliers, as we believe the company is well positioned for additional market share growth over the next several quarters," he said, adding that Skyworks' guidance for the September quarter exceeded that from its rival RFMD. Of TriQuint, Lum believes that continued softness in the opto segment will hamper its profitability, although the CIBC analyst foresees continued strength in wireless infrastructure through 2005.

Cree shines on

Perhaps the brightest spot in the compound semiconductor portfolio is Cree, the vertically integrated LED and RF device maker (figure 1). In a typically bullish conference call, CEO Chuck Swoboda described "soaring" LED sales and Cree's plans to invest more than \$100 m in fiscal 2005 to double its LED production capacity. The company is looking at expanding its existing sites or building new ones in the US or abroad.

Of course, Cree has every right to brag about its success: the company has seen its top-line revenue grow at an astonishing rate over the last four years, particularly when you consider the difficult economic climate of the past few years. Revenue has almost trebled from \$109 m in fiscal 2000 to \$307 m in the recently completed fiscal 2004 (figure 2).

In its guidance for the first quarter of its new fiscal year, which ends September 30, Cree predicted further revenue increases of 4–6%, while the bottom line is set to benefit as the company moves LED manufacturing from 2 inch to more cost-effective 3 inch production. This is expected to be completed within a year.

High-brightness LEDs comprise an increasingly large proportion of Cree's revenue, representing 54% of LED proceeds in the three months until June 30 – up from 50% in the previous quarter.

With its decision to invest heavily in ramping up LED production, plus its new focus on "replacing the light bulb" with a new range of LED products, Cree will inevitably incur some escalating costs, but if its revenue continues on the current growth pattern the record full-year profit of \$58 m reported for fiscal 2004 will no doubt be eclipsed.

Lum and his colleagues at CIBC World Markets immediately slapped their approval on Cree's stock, upgrading earnings estimates for fiscal 2005. With Cree booked up to the hilt (85% of the September quarter guidance figure was booked at Cree's fiscal 2004 year-end, as compared with 65% the previous year) and producing LEDs at near 100% capacity, Lum commented: "We find the shares attractive and would accumulate at current levels." Lum has increased his revenue estimate for Cree to \$431 m in fiscal 2005 and \$594 m in fiscal 2006 (figure 2). If Cree gets close to that 2006 estimate it would seal a remarkable decade of growth, representing a 20-fold increase in revenue and a 30-fold increase in net income.

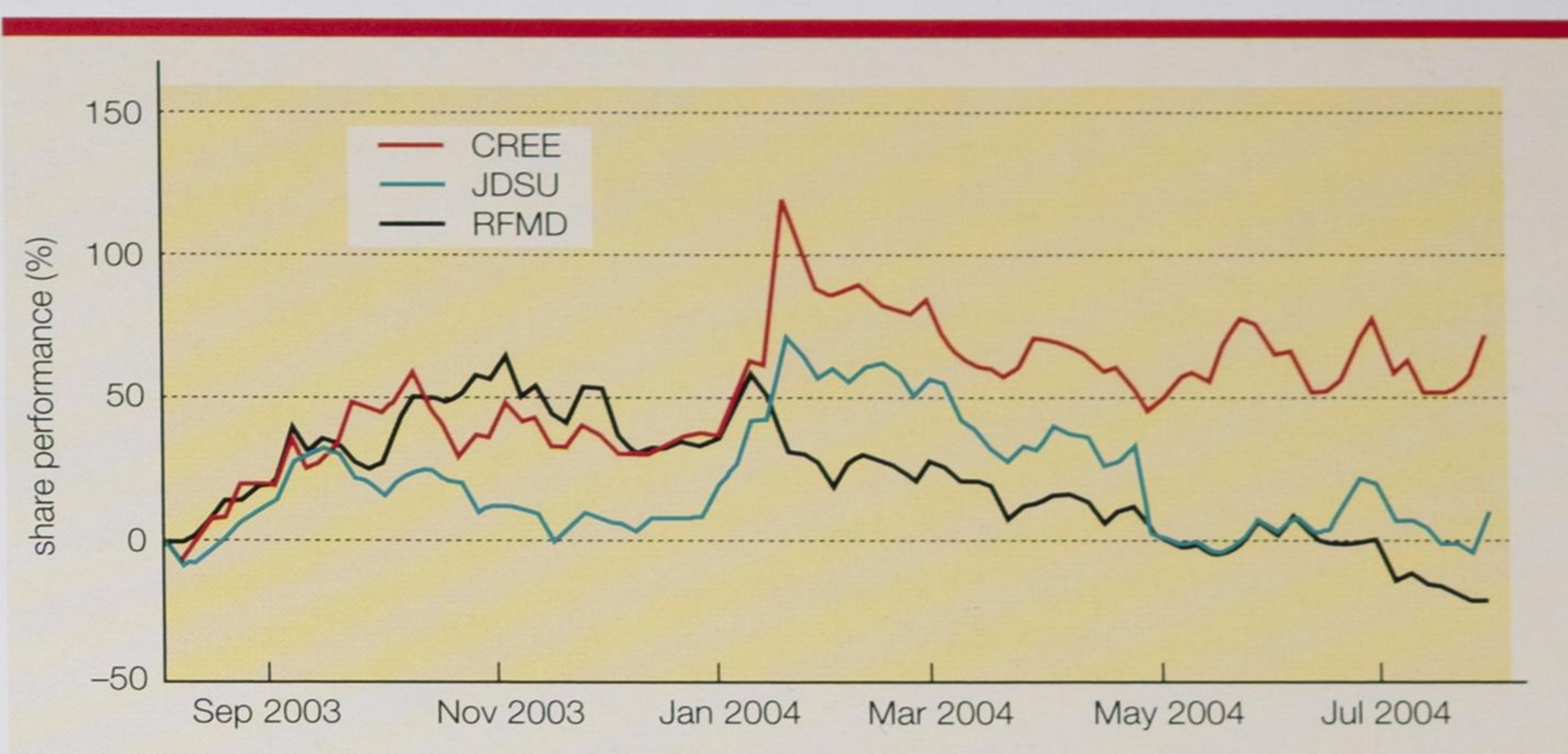


Fig. 1. The relative share performance over the past year of Cree, JDS Uniphase and RF Micro Devices, the three leading public companies in LED, fiber-optic components and GaAs IC manufacture respectively, shows that Cree is on top.

The recent quarter also saw the debut of LED-based lighting firm Color Kinetics on the Nasdaq. Its IPO, at \$10 per share, gave the company a market capitalization of around \$180 m, although the stock was down slightly at \$9.88 as *Compound Semiconductor* went to press. CIBC acted as managing underwriter on the Color Kinetics IPO.

Fiber hope springs eternal

How JDS Uniphase (JDSU) must envy the new darlings of the Nasdaq. But, like Cree, the company enjoyed its best bookings performance in recent history in the latest quarter – a hint that the long-awaited upturn in fiber optics has begun. JDSU has finally got its operations close to the break-even position, and with what it sees as "solid indicators" of market recovery, the company cheered the markets with its guidance of an 8–13% sequential increase in revenue. That sent JDSU shares sharply up, although, at \$3.20 on August 26, they were still well down on the 2004 peak of almost \$6 (figure 1). If the strong bookings performance turns out to mark an uptick in the sector, low-priced JDSU could be a stock worth tracking.

Also bouncing upwards on news of improved bookings were shares in Bookham Technology. Switching its fiscal year-end from December to June, the UK-based InP optical chip manufacturer fared better than had been expected after its guaranteed supply deal with Nortel Networks expired earlier in the year. Bookham now says that after an initial dip, demand from the Canadian system builder may return to historic levels, and it appears to have been this that sent the shares up by more than 10% initially. Like JDSU, however, Bookham's recent Nasdaq-listed share price of below \$1 is way off its year high of around \$3.40 back in February.

Of the other players in the fiber-optic segment, Emcore had a nightmarish quarter, registering a \$5.3 m dent in its accounts thanks to problems with contaminated material from a supplier that resulted in \$4 m of lost revenue from its transceiver product line. An additional

"We find the shares attractive and would accumulate at current levels."

Earl Lum on Cree (July 28)

\$1.3 m spend was required to resolve the problem.

Still, the outlook for Emcore does at least make more comforting reading. Despite the problems with its transceivers, the company says that it has \$10 m worth of purchase orders for this product line that will ship over the next two quarters. Revenue is set to increase 20% in the current quarter as a result.

Avanex, which swept up the optical components wings of Corning, Alcatel and Vitesse, is still accounting for those acquisitions, and reported a full-year revenue of \$106.9 m for fiscal 2004, up \$85.5 m on the previous year. Despite claiming to have "realized benefits from its manufacturing strategy", the Fremont, CA, company still has a huge amount of work to do before it can even approach profitability.

Operating costs far outstrip sales, with gross margin still heavily in the red. At the operating level, Avanex racked up a \$22.6 m loss on sales of \$31.9 m in the June quarter. Its guidance suggested a 10% bounce in the revenue figure for the September quarter, but Avanex would appear to need much more than simply the hope offered by JDSU's and Bookham's positive outlooks to comfort investors.

Still, Avanex's new CEO, Jo Major, appears to be in a positive frame of mind, and has set Avanex the goal of becoming the number-two supplier behind JDSU. ●

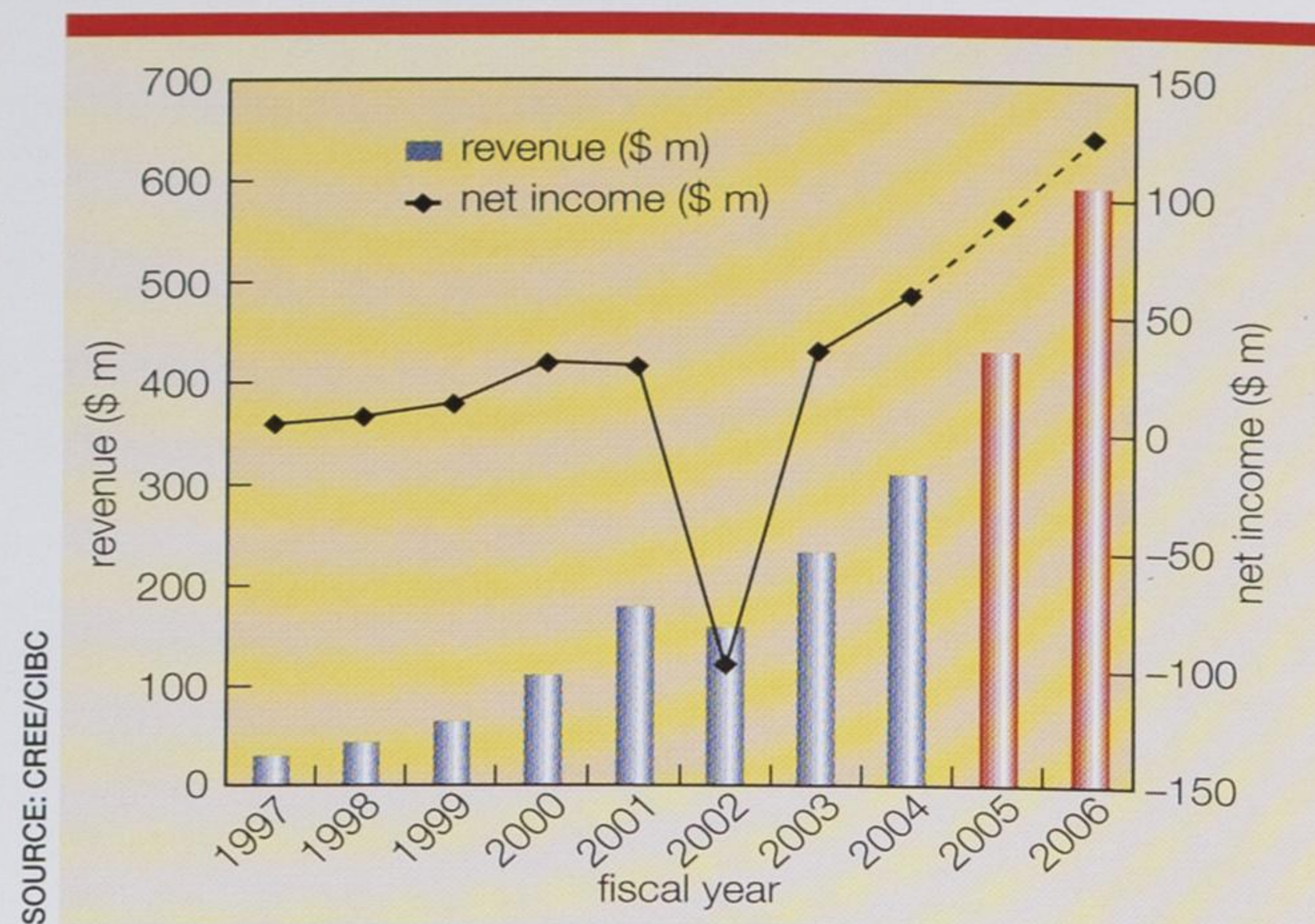


Fig. 2. Cree has enjoyed a profitable period since fiscal year 1997, aside from 2002. The figures for fiscal 2005 and 2006 are those projected by CIBC World Markets; income has been calculated from projected earnings per diluted share on the assumption that the number of Cree shares will remain constant.

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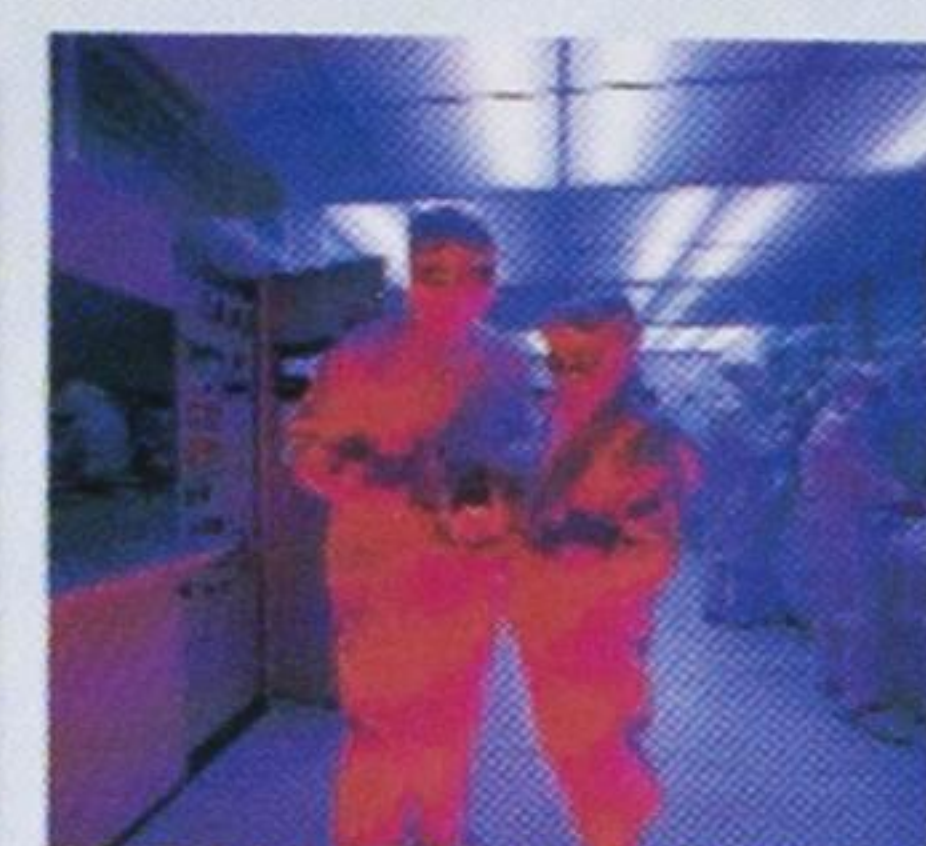
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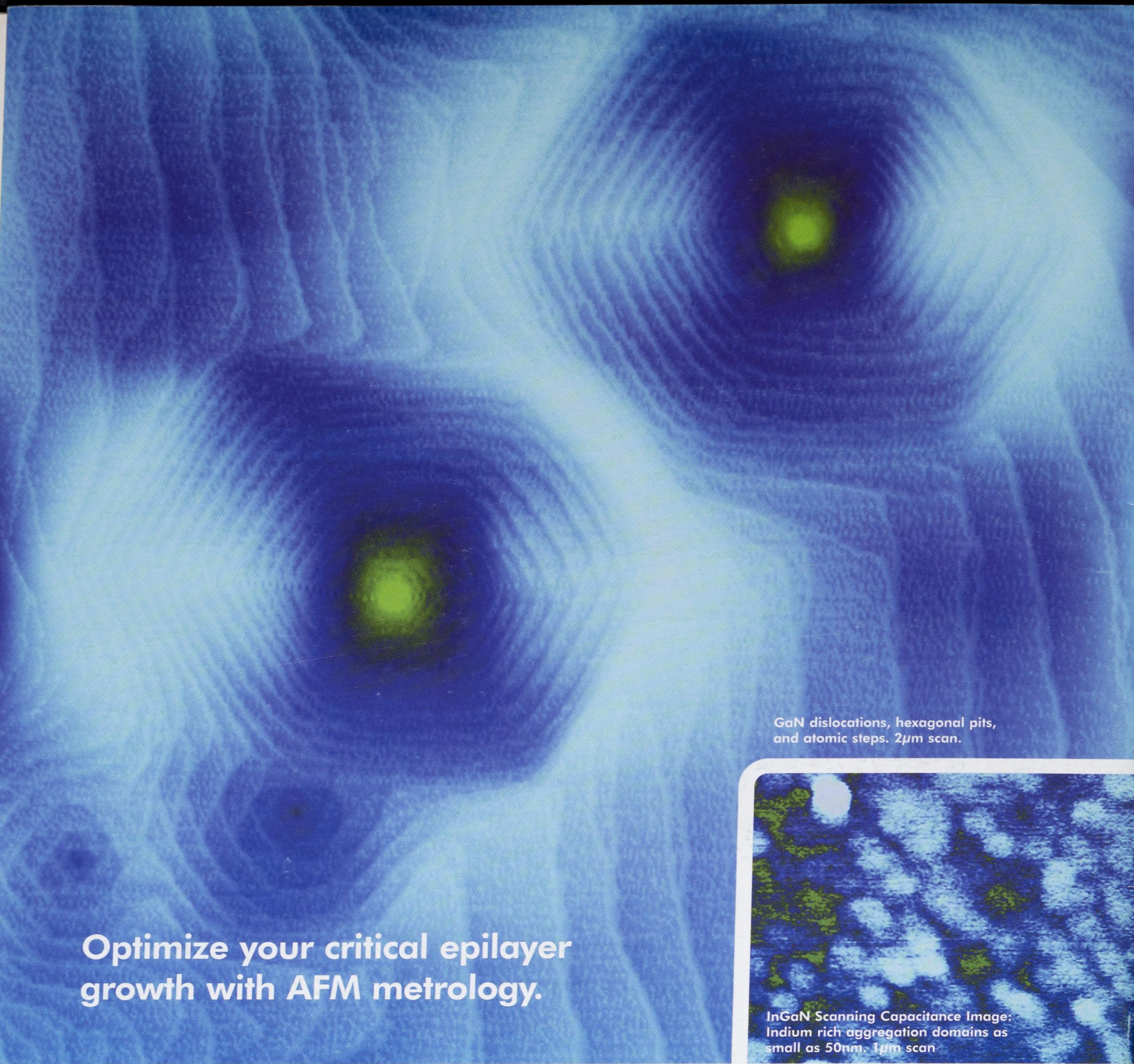
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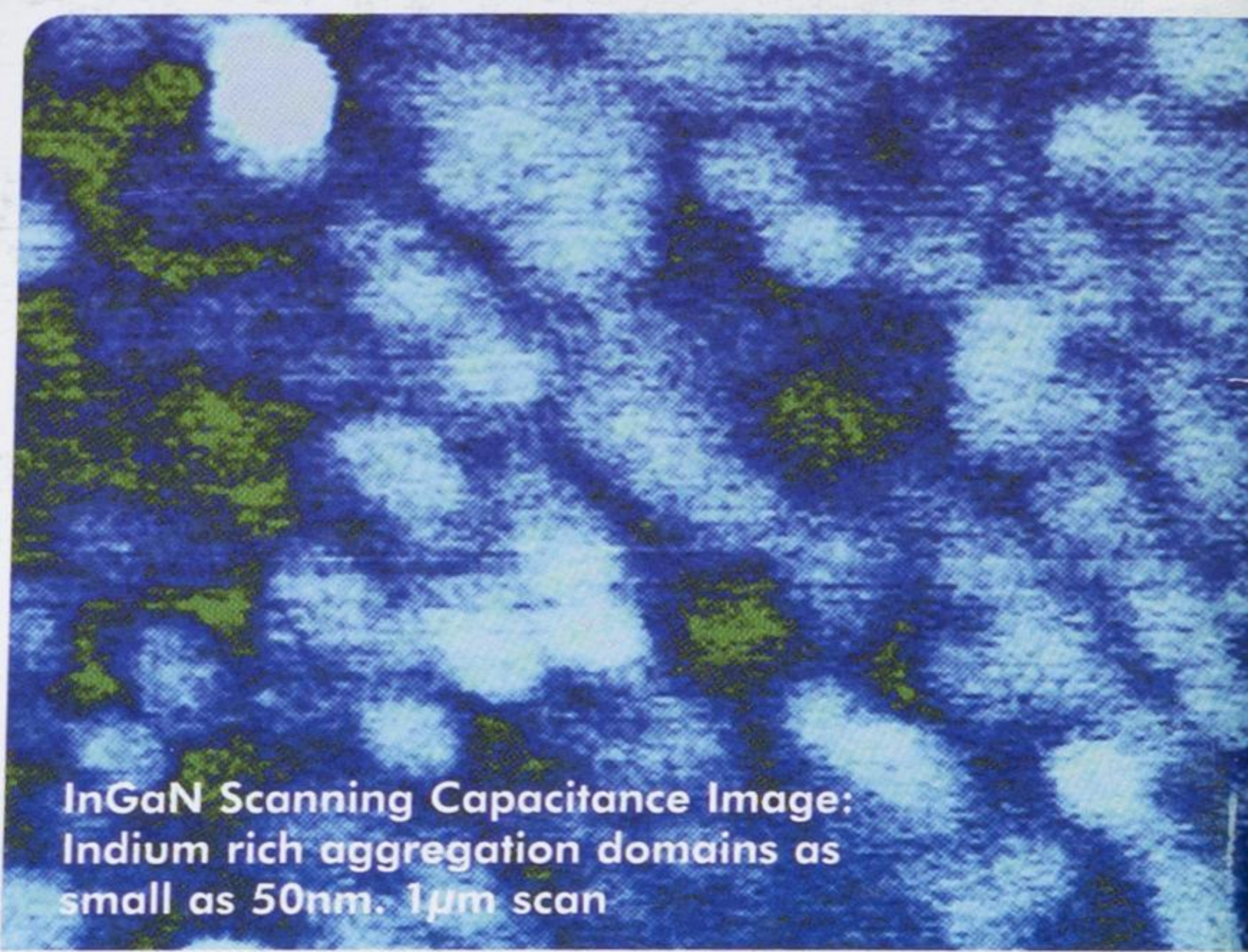
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