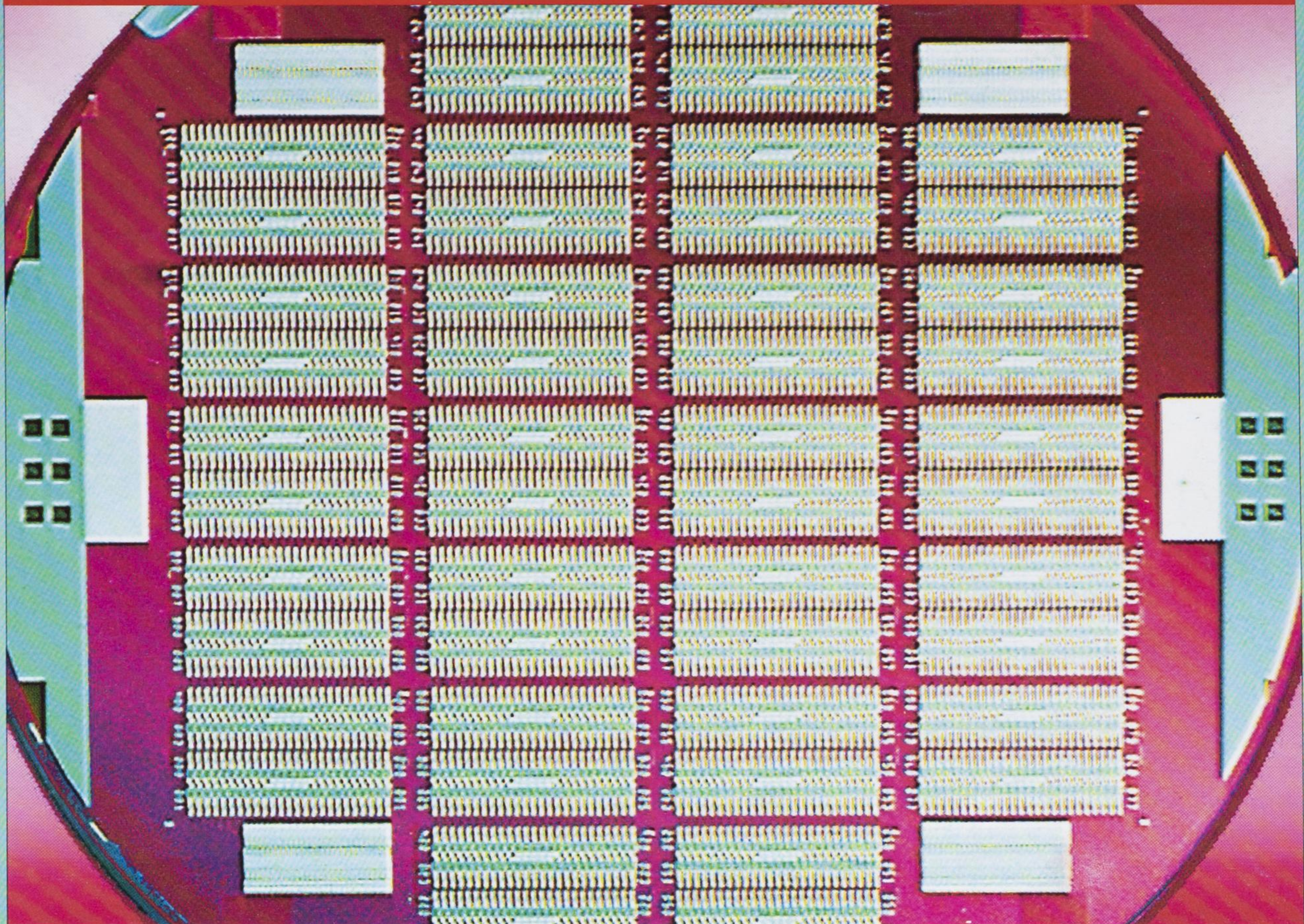


COMPOUND SEMICONDUCTOR

Three-Fives and Silicon Heterostructures

August 2005 Volume 11 Number 7



INDIUM PHOSPHIDE
**Does a foundry model add up
for InP optoelectronics?**

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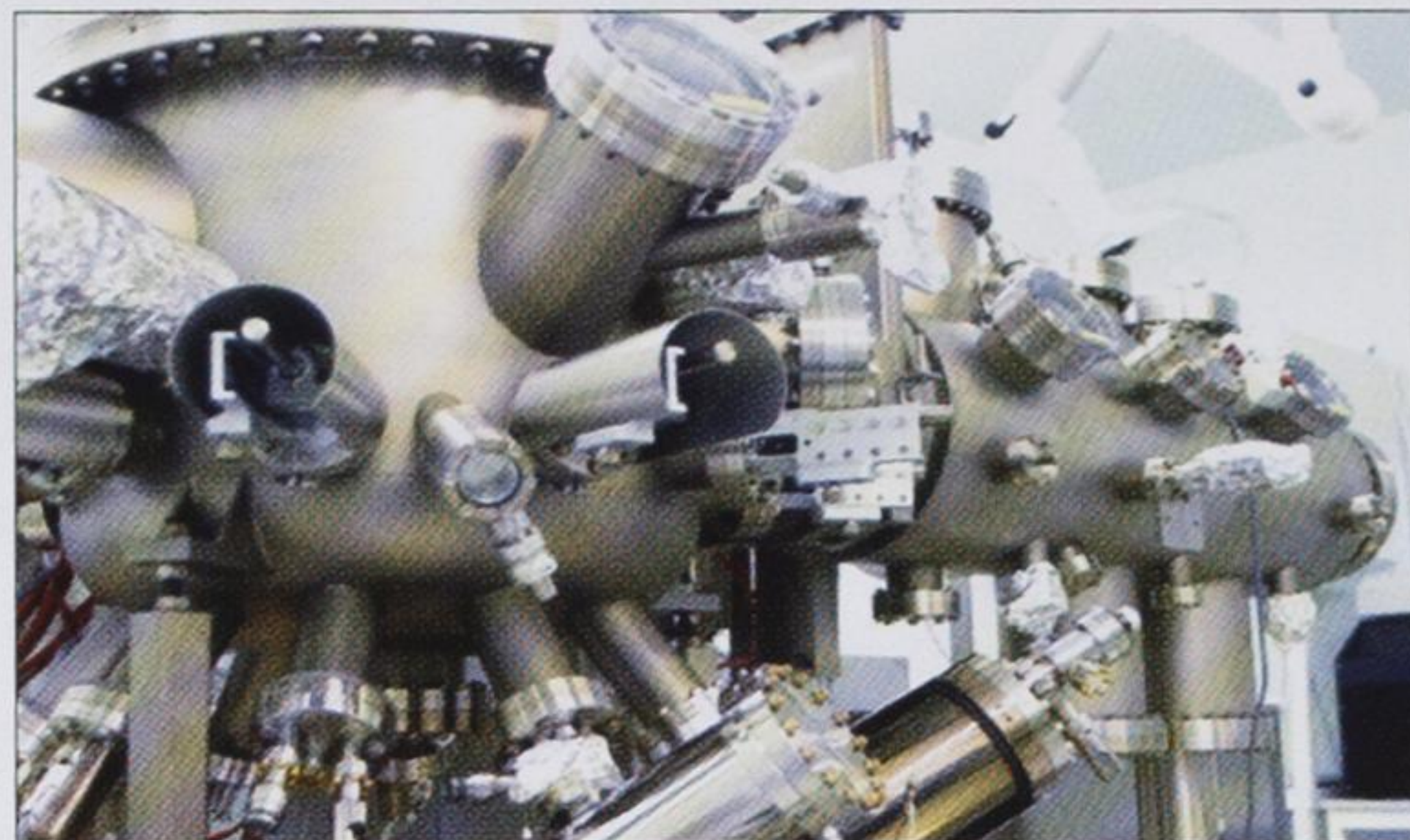
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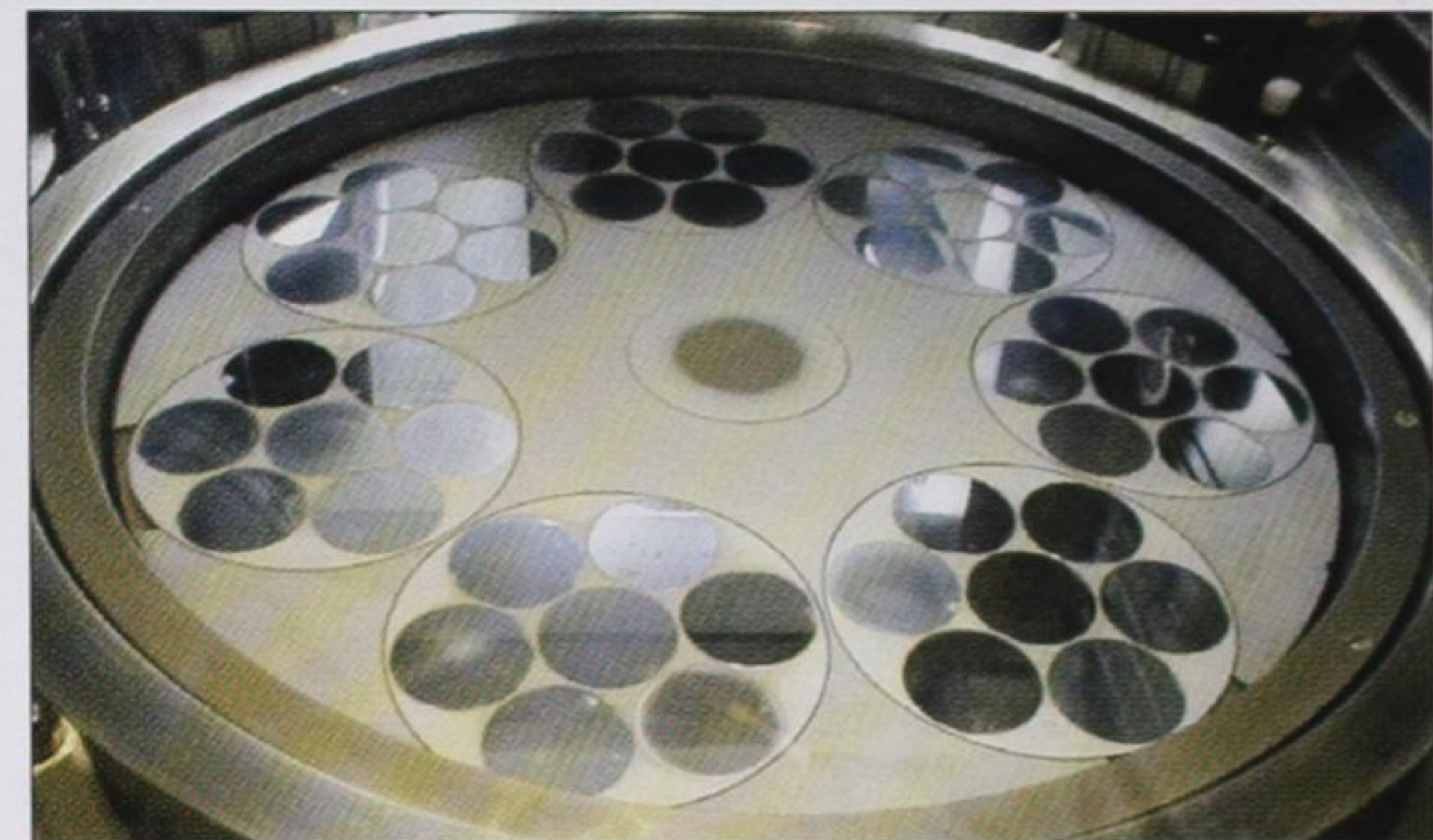
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Wake-up call: The InP sector needs a foundry-based model, says Michael Lebby. **p5** and **p17**



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Improving metal-organic material efficiency was key in Aixtron's new MOCVD design. **p25**

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New executive director of the OIDA Michael Lebby is sounding a wake-up call to optoelectronic chip manufacturers. Michael Hatcher talks to him about a foundry-based industry model for InP optoelectronics.

21 NGST transforms InP transistor manufacture

With its cost-efficient InP HEMT and HBT processes on 100 mm substrates, NGST is well positioned to produce power devices for next-generation cellphones. That was the message from Richard Lai, NGST's manager of microelectronics products, at a recent conference.

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Swedish start-up Comlase has developed an ingenious technique for boosting the durability, output power and reliability of all types of laser diode. Oliver Graydon reports on the company's Nitrel treatment.

14 Wafer-making advances fuel InGaAs camera sales boom

InGaAs cameras are penetrating new markets, driven by the availability of cheaper, higher-quality InGaAs material. Martin Ettenberg of Sensors Unlimited reports.

25 Cost of ownership dictates new MOCVD reactor design

Rainer Beccard explains how throughput, yield and the deposition of expensive metal-organic precursors have driven the design of Aixtron's latest planetary reactor.



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On the cover: On the cover: Manufacture of InP-based optoelectronics and microelectronics comes under the spotlight in this month's issue. The cover image shows a 3 inch InP wafer full of integrated optoelectronic devices (image courtesy of Bookham). See pages 17 and 21.

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Wireless gets its buzz back



It's been a retro kind of month for the wireless business. But this isn't the premature, pre-millennial fizz of late-1990s hype. It's the real-world, post-bubble emergence – finally – of that great white hope, 3G.

Yes, the technology has been with us for a while, but now it's starting to catch on. And that spells good news for the high-tech chip industry. So where's the evidence? First, to the market forecasters. Granted, they aren't always right, but bear with me.

Initially Gartner had reckoned on 720 million phones selling this year. Then in May it raised that figure to 750 million. Now, it says, 780 million of the chirruping gizmos will be snapped up – and the billion-mark will be surpassed in 2009. More interestingly, 100 million phones offering 3G services will sell in 2006. And that means more GaAs content per phone.

It's a theory backed up by fellow crystal-gazer Strategy Analytics, which expects 71% annual growth in 3G services over the next five years. Its latest report predicts 43% growth in shipments of semi-insulating GaAs substrates in the same time-frame, to around 20 million square inches in 2009.

Now, how about chip manufacturers? Well, Texas Instruments (TI) also seems to be getting the hots for wireless. In its latest trading update, the Dallas-based silicon churner said revenue from the sector spiked 8% due to what it called the fast-growing 3G market. That's good news for TI shareholders, who can now look forward to a 20% hike on their October dividends.

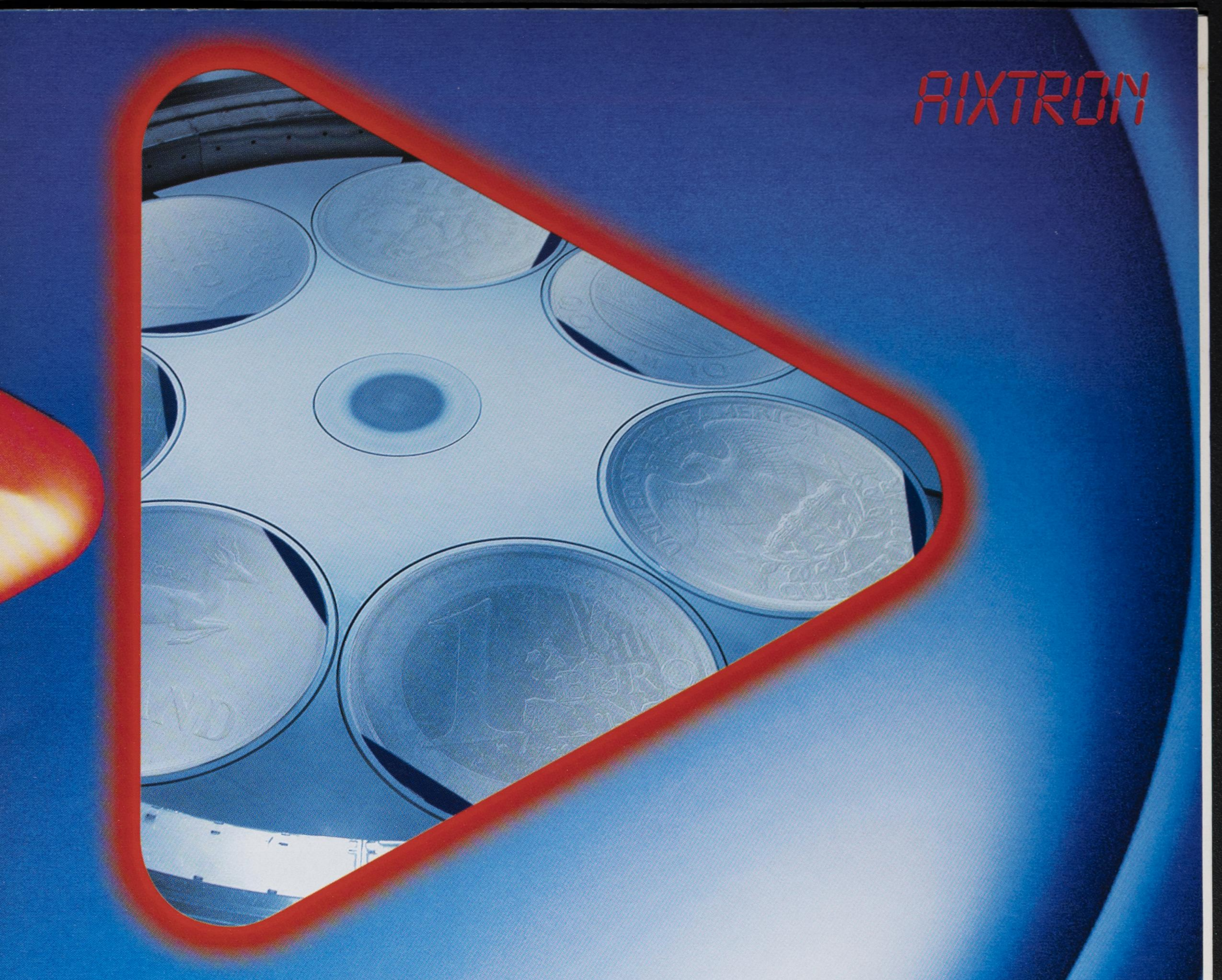
Next, to the phone makers themselves. Motorola, on a high all year thanks to the success of its RAZR product line, is gearing up for 3G development with spin-off Freescale and plans to mass-manufacture 3G components in 2008.

Satisfied yet? Well then, how about a shiny new IPO to get excited about? It's been a while, but up to the plate has stepped RFIC manufacturer Hittite Microwave with its offer of 4.5 million shares at \$17 a pop. As *Compound Semiconductor* went to press, those shares were trading at around \$18.50. Hopefully, this is a sign of confidence in a sector that now promises to deliver the broadband access networks and services we've been waiting for.

Michael Hatcher

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Report on InP sector is a 'wake-up call'

By Michael Hatcher

Co-operation among InP-based optoelectronic device manufacturers and the establishment of a foundry model are crucial to the future success of the photonics industry.

That's the conclusion of a roadmap for the InP industry compiled by the Optoelectronics Industry Development Association (OIDA).

Mike Lebby, the OIDA's executive director, said: "The roadmap sounds a wake-up call for the industry. We need to act soon to accelerate the development of an InP foundry model."

According to Lebby, who co-founded Ignis Optics and moved to Bookham when it

acquired the company, the optoelectronics industry is at a crossroads. "Unfortunately, [chip manufacturers] are forced to remain vertically-integrated because of the competitive advantage they get in their InP optoelectronic device designs," he said.

The clear solution, believes Lebby, is co-operation among device manufacturers and the adoption of a common foundry model. A key recommendation of the OIDA report is that the InP industry should mirror the silicon semiconductor manufacturing industry infrastructure.

To date, InP device manufacturers have

used the unique properties of the material to develop proprietary designs to tailor device performance, using specific epitaxial growth, fabrication, testing and packaging procedures.

The excess manufacturing capacity that has resulted has become a huge drain on both capital and operating expenditure. But according to the OIDA roadmap, the picture will only change very slowly: "2009 will be the beginning of a time when the key vendors will look toward the foundry model as a solution and an economic advantage – as opposed to a threat," predicts the report.

● See interview with Michael Lebby, p17.

Toyoda rubbishes doping patent claim

A patent infringement lawsuit concerning LED manufacturing brought by a Columbia University professor against Toyoda Gosei has been dismissed by the Japanese company.

Prof. Gertrude Neumark filed the suit in the US District Court, Southern District of New York, citing Toyoda Gosei, its US subsidiary and two of its LED distributors. However, Toyoda Gosei has rubbished the academic's claims, saying that the two patents in question are "based on a hypothetical logical formula and lack both novelty and inventiveness".

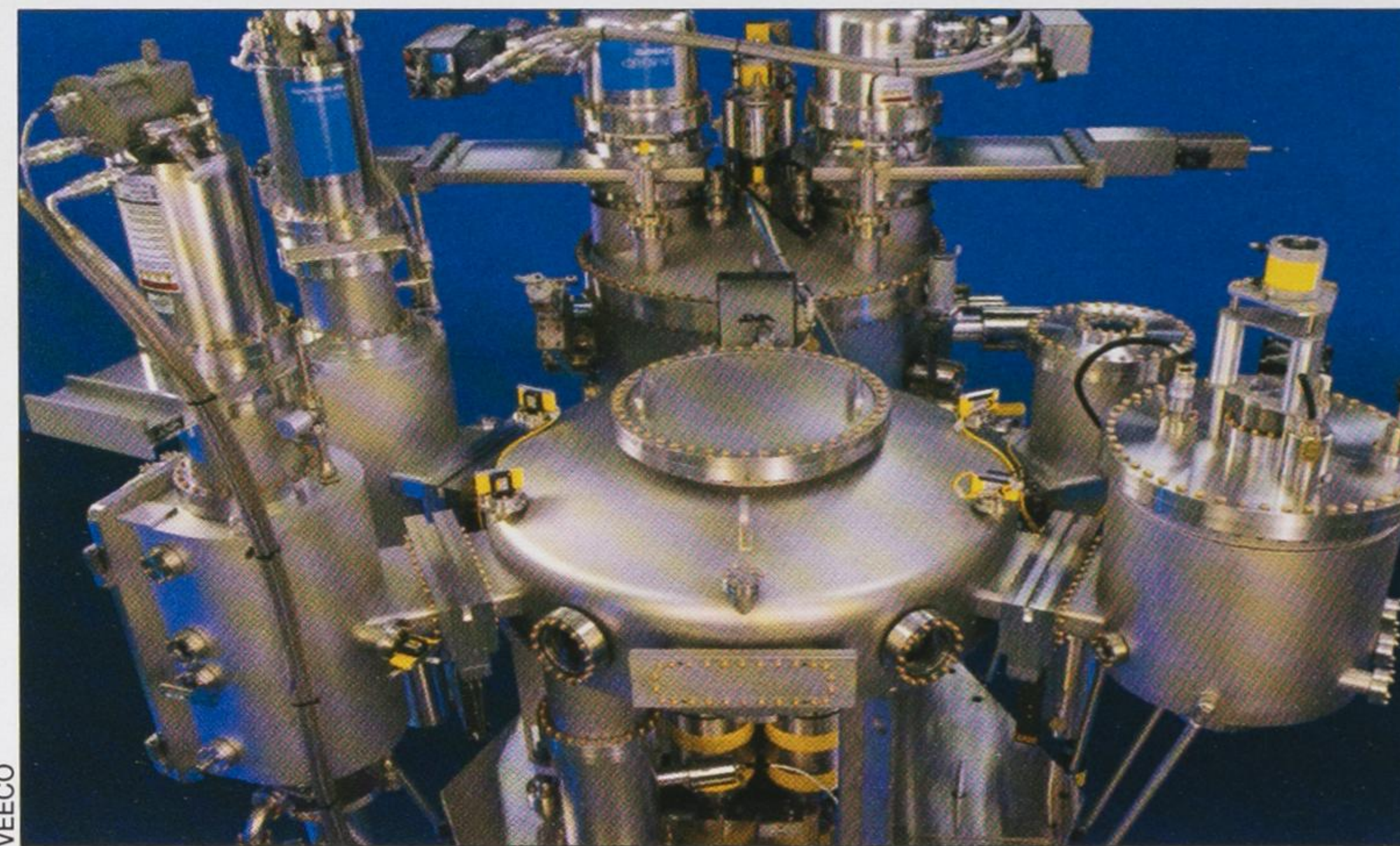
One of the patents concerned details a process for doping wide-bandgap semiconductors. Awarded in 1990, US patent 4,904,618 describes how crystals of ZnSe and ZnTe can be doped with nitrogen and lithium. In it Neumark says that ZnSe may be p-type doped using a lithium-rich melt and liquid-phase epitaxy, or by using ammonia gas. The second patent – US number 5,252,499 – was awarded in 1993 and also concerns doping.

Toyoda says that back in 1999 it had discussed the patent claims with Neumark. But the LED manufacturer alleges that an agreement could not be reached because her demands were "beyond common sense".

Not only does Toyoda believe that it is not infringing the patents as it does not use any such method, it also regards the patents to be invalid, and lacking in what it calls patentability.

"Toyoda Gosei is confident that our LED products do not infringe the patents named in the lawsuit. It will take legal measures to reply to the complaint, and intends to defend its position," concluded the company in a statement.

Veeco and Picogiga team up for GaN-on-silicon substrate project



Picogiga plans to end up with a GEN200 MBE reactor similar to this one – but specifically designed for its GaN-on-silicon epiwafer manufacturing process – when the development program it is undertaking with Veeco is complete.

Epitaxy equipment vendor Veeco Instruments and French substrate specialist Picogiga are joining forces in a bid to speed the commercialization and volume production of GaN-on-silicon substrates.

The firms have set up a development program to create the first industrial MBE reactor set up specifically for Picogiga's patented GaN-on-silicon manufacturing process.

Development work will take place at Veeco's process integration center in St Paul, MN. Once it has been built, Veeco will deliver and install the reactor at Picogiga's Les Ulis production facility in France, where it will be used to fabricate GaN-on-silicon epiwafers of up to 6 inches in diameter.

Jean-Luc Ledys, Picogiga's COO, says that the agreement will pave the way for the production of competitive GaN-on-silicon

substrates on which devices such as high-electron-mobility transistors (HEMTs) can be fabricated.

A whole host of companies are currently developing GaN transistor technology, with most initial production taking place on SiC substrates or, to a lesser extent, so-called "native" substrates such as GaN or AlN.

Although the key advantage of GaN is the extra output power that RF devices based on the material can produce, the substrate technology used until now has proved to be relatively expensive.

Veeco and Picogiga believe a silicon base will give better thermal conductivity, reduce procurement costs and allow production on larger-diameter wafers than GaN substrates.

Among the leading GaN-on-silicon HFET device developers is US company Nitronex.

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GAAs & WIRELESS NEWS

European Commission expands Wi-Fi spectrum

The European Commission has made two frequency bands in the radio spectrum available for wireless access systems (Wi-Fi). Wi-Fi and broadband wireless communications technologies such as WiMAX are seen as key future markets for GaAs-based RF semiconductors.

The decision to open up the 5.15–5.35 GHz and 5.47–5.725 GHz bands is accompanied by a move to introduce “innovative spectrum management approaches”, which the Commission believes will protect other RF spectrum applications, such as military radar and satellite services, from damaging interference.

“The decision will help industry to create innovative services, such as voice over IP, for a single European market,” said Viviane Reding, the Information Society and Media Commissioner. “High-speed electronic communication networks are essential to Europe’s competitiveness.”

According to a Commission statement, the so-called i2010 initiative will pave the way to an open, competitive single market for Wi-Fi in the European Member States.

“Access to this spectrum with common

rules will make equipment cheaper and alleviate the growing overloading of spectrum already used for this purpose. It will facilitate the take-up of wireless systems, from corporate networks to hotspots in airports, train stations, shopping malls and hotels.”

Estimates put the number of worldwide Wi-Fi users at 120 million, including 25 million in western Europe. More than 500 million worldwide users are expected by 2008.

In a recent presentation to the European Institute in Washington, DC, the commissioner said that the time had come for policy convergence to match technology convergence.

According to Reding, flexibility of spectrum use is a key issue. “A debate is under way on a common spectrum approach for all wireless transmission platforms providing electronic communications services,” she said.

Reding added that the European Commission has plans for the efficient management of the radio spectrum. In another move that will affect the RF spectrum and devices used in broadcast applications, it is proposing to switch off analog terrestrial television by 2012.

RFMD undaunted by \$5 m charge

Power amplifier and RF chipset supplier RF Micro Devices (RFMD) has posted revenue for the quarter ending June 30 of \$159.4 million.

Although RFMD was hit by a \$5 million cash charge for the period for delayed shipments, the figure exceeds the “mid-\$150 million” revenue guidance it issued in April.

The Greensboro, NC, company announced that it had experienced stronger-than-expected

orders in the June quarter for its power amplifiers, Polaris Total Radio transceiver chipsets and Bluetooth products. It added: “[RFMD] believes its wireless end markets are continuing to show strong growth rates.”

Some of that growth has been driven by design wins for Polaris at Motorola, and RFMD’s transceiver will feature strongly in Motorola’s forthcoming cell-phone handsets.

Efficiency drive boosts profits at Skyworks

Skyworks Solutions has reported revenue for the third fiscal quarter ended July 1 of \$191.5 million, up \$1 million sequentially, but down \$15.9 million year-on-year.

Third-quarter profit for the US-based RF chip maker was \$7.4 million, lower than the \$13 million reported one year ago, but an improvement on the \$1.2 million income in the previous quarter.

Gross margin for the recent quarter was 40.7%, a rise of 2.5% sequentially.

According to Skyworks’ CEO David Aldrich, the improvement in gross margin was driven by a combination of further diversification into linear products, higher levels of integration, and greater operational efficiencies. The company believes that further improvements in these areas could lead to a gross margin of at least 45% in 2006.

Skyworks anticipates that its fourth fiscal quarter revenue will be between \$191 million and \$202 million.

Raytheon in \$580 m GaAs radar deal with Boeing

US defense contractor Raytheon has won a \$580 million contract to produce GaAs-based radars for use in Super Hornet fighter aircraft flown by the US Navy.

Under the five-year production contract, Raytheon has agreed to deliver 190 active electronically scanned array (AESA) APG-79 systems to Boeing.

The first such radar was delivered to Boeing Integrated Defense Systems in January.

"The APG-79 program is on a roll this year," said Erv Grau, vice-president for air

combat avionics at Raytheon's space and airborne systems division. "APG-79 will provide aircrews with unequalled combat capability and play a critical role in supporting the Navy's vision in how it intends to operate in the future."

The AESA APG-79 system will enable the US Navy's fighter aircraft to track other aircraft at longer ranges, provide higher-resolution synthetic aperture radar maps, and allow near-simultaneous air-to-air and air-to-ground sensing.

Chip maker TriQuint sees 20% drop in year-on-year revenue

RF chip manufacturer TriQuint Semiconductor has posted revenue of \$67.9 million for the second fiscal quarter ended June 30. The revenue excludes any contribution from the company's InP optoelectronics business, which it sold to CyOptics on April 29.

TriQuint has recalculated its financial results for the current and prior quarters by reclassifying the results from its optoelectronics business as "discontinued operations".

Following this adjustment, second fiscal quarter revenue was up by \$1 million sequentially, but down by \$16.5 million year-on-year.

Although profit for the second quarter was \$6.2 million, that figure includes a one-time contribution of \$7.7 million from the sale of the company's optoelectronics business.

According to TriQuint, quarterly gross

margin has increased from 27.5% in the first quarter of this year to 30.7% for this quarter through improvements in the use of capacity in the high-volume factories.

"In our largest market, GSM/GPRS/EDGE handset products, we generated record quarterly revenue of over \$9 million on the strength of our new module products," remarked Ralph Quinsey, TriQuint's CEO.

Quinsey said that the company's CDMA orders have "rebounded" significantly from the low levels of the fourth quarter of 2004 and the first quarter of 2005.

The company says that it expects third-quarter revenue to rise to between \$73.3 million and \$76.7 million, through an increase in sales of products for wireless phones and broadband applications.

Samsung selects GaAs device suppliers

Leading GaAs device manufacturers Anadigics, RF Micro Devices (RFMD) and Skyworks Solutions have all claimed design wins in handsets made by the Korean electronics giant Samsung.

Samsung, which is ranked third behind Nokia and Motorola in terms of global unit cell-phone shipments, will use Anadigics' 3 x 3 mm cellular-band code-division multiple access (CDMA) power amplifiers (PAs) in a range of handsets.

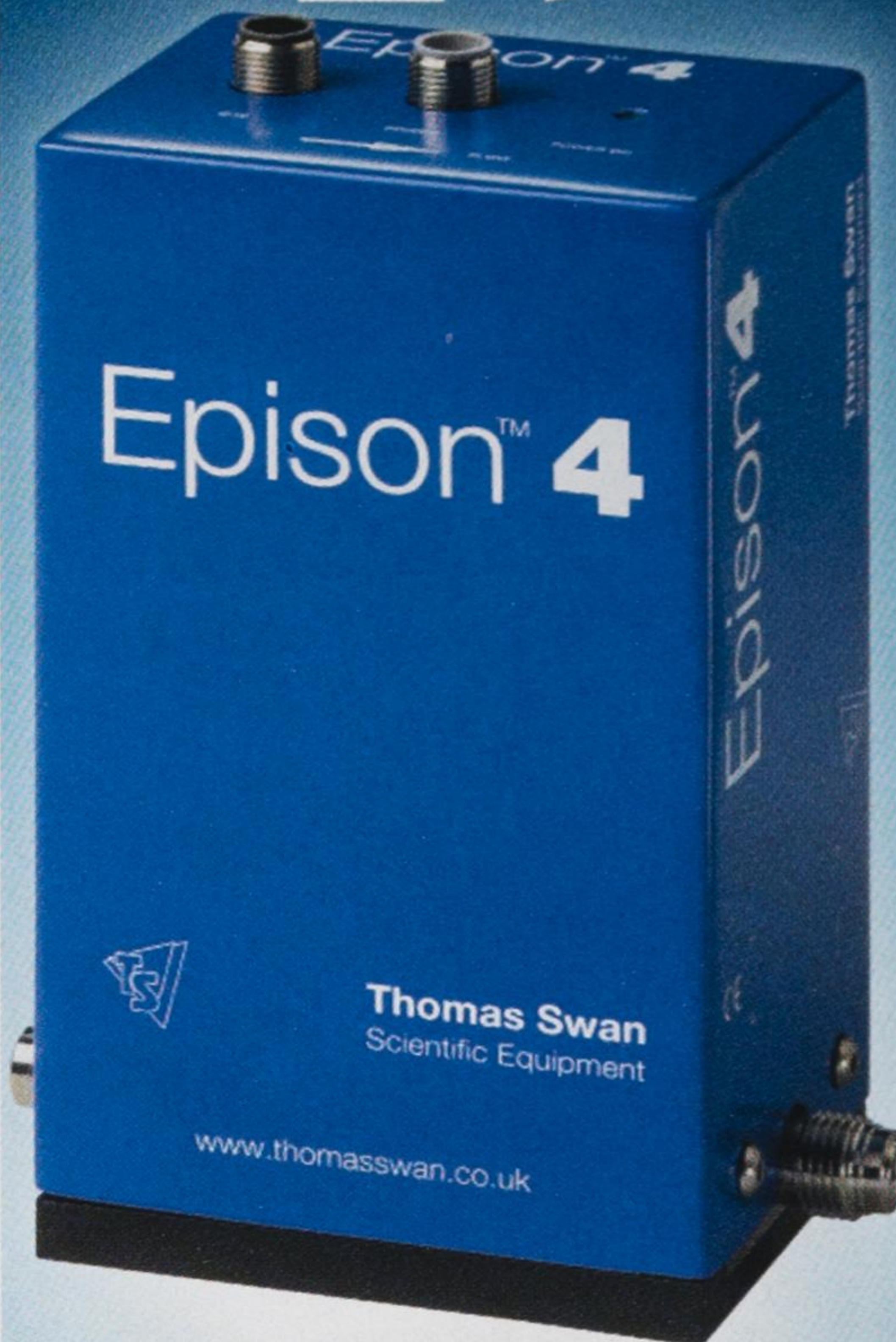
Anadigics supplies PAs to Samsung for GSM/GPRS, wideband-CDMA and Korean

PCS wireless communications applications.

Rival PA manufacturer RFMD says that it is now shipping PA modules designed for CDMA phones to Samsung. Although the Greensboro, NC, chipmaker has already delivered more than 100 million RF components to Samsung, this latest design win marks the first shipments of its CDMA PAs to the company.

Meanwhile, RFMD's leading rival in the GaAs IC industry, Skyworks Solutions, will see its Helios RF product for EDGE applications designed into a new range of high-end Samsung handsets.

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Patent guidance to speed LED lighting

By Tim Whitaker

LED development in the US has received a boost from the Department of Energy (DOE). New guidance on intellectual property (IP) will see the industry benefit from breakthroughs made in solid-state lighting (SSL) research at DOE laboratories, academic institutions and small businesses.

Inventions arising under the DOE's Solid-State Lighting research program will now be covered by a so-called Exceptional Circumstances Determination. Referring to the Bayh-Dole Act, this determination places guidance on IP generated under the Core Technology Research program area. This program area creates technology breakthroughs that can be widely applicable to future SSL products.

The Exceptional Circumstances Determination is supported by Congress and the DOE, and will facilitate more rapid use of new SSL technology that has been developed through the DOE program.

Small businesses and non-profit organizations (such as universities) working under US government funding cannot be made to give up IP rights that they might acquire unless exceptional circumstances apply.

The new IP arrangements allow members of the Core Technology Program (organizations that are working on solutions to technical barriers for SSL and that are engaged in funding agreements with the DOE) to retain title to inventions made under their SSL Program awards.

However, these innovators must offer each member of the SSL Partnership (a collection of companies that have the capacity to manufacture SSL systems) the first option to enter into a non-exclusive license. These open-license offers to SSL Partnership members must continue until at least one year after the date that the US patent was issued. After this time the inventors are free to enter into licenses in any field of use with any interested party that is involved in the development of SSL.

The agreement does not provide royalty-free access – the negotiations would be in good faith for royalty at a reasonable rate.

Tim Whitaker is editor of LEDs Magazine (www.ledsmagazine.com).



PHILIPS LIGHTING

Ede, a town in the Netherlands, is the first location to deploy street lights using LED luminaires from Philips Lighting. The Philips Equinox street lights comprise two optical modules. Each contains 18 white and amber LEDs that are a combination of Luxeon I and III products. With a lifetime of 50,000 h, the LED lamps should not have to be changed for another 12 years if they are lit for an average of 11–12 h a day.

Patterned laser lift-off simplifies fabrication of GaN-based LEDs

Taiwanese researchers from National Cheng Kung University and the We-Fung Institute of Technology have fabricated vertical-structured GaN-based LEDs using nickel electroplating and patterned laser lift-off (*Appl. Phys. Lett.* **87** 011111).

These devices, the output power of which is more than twice that of a standard LED, will help the development of high-brightness sources for cost-effective solid-state lighting.

According to the researchers, sapphire substrates, which are a common choice for GaN LED production, have poor thermal and electrical conductivity, and this prevents heat from dissipating efficiently.

In addition, conventional GaN LEDs have their positive and negative electrodes on the same side of the wafer, which causes severe

current crowding and reduces the emitter's internal quantum efficiency.

The team addressed both of these issues by using a patterned laser lift-off technique to simultaneously define the device area and separate the GaN epilayer from the sapphire substrate. Nickel is subsequently deposited onto the p-type GaN, followed by layers of silver, titanium and aluminum, to form a metallic substrate that reduces current crowding and improves the device's heat dissipation properties.

Using laser lift-off to enhance GaN LED performance has been demonstrated before. However, according to the Taiwanese team, previous efforts have required complicated fabrication processes that could impact on production yields.

Chip heavyweights renew supply contract

Chip manufacturer Cree of Durham, NC, has signed a three-year LED supply deal with Germany-based Osram Opto Semiconductors.

The contract covers Cree's entire LED chip product line, including standard, mid-bright and XBright LEDs. Details of volumes, pricing and product mix have been agreed for an initial period, and will be reviewed regularly between now and June 2008.

The two companies last signed a supply deal in October 2003. Osram bought at least

500 million LED chips under that agreement.

"Osram fulfilled its previous purchase commitment far earlier than expected and this [new] agreement reflects the way in which the two companies have conducted business over the past several quarters," said Cree CEO Chuck Swoboda.

According to Swoboda, the new deal is structured in such a way to allow both parties to react quickly to sudden changes in demand from customers.

Finland establishes photonics cluster

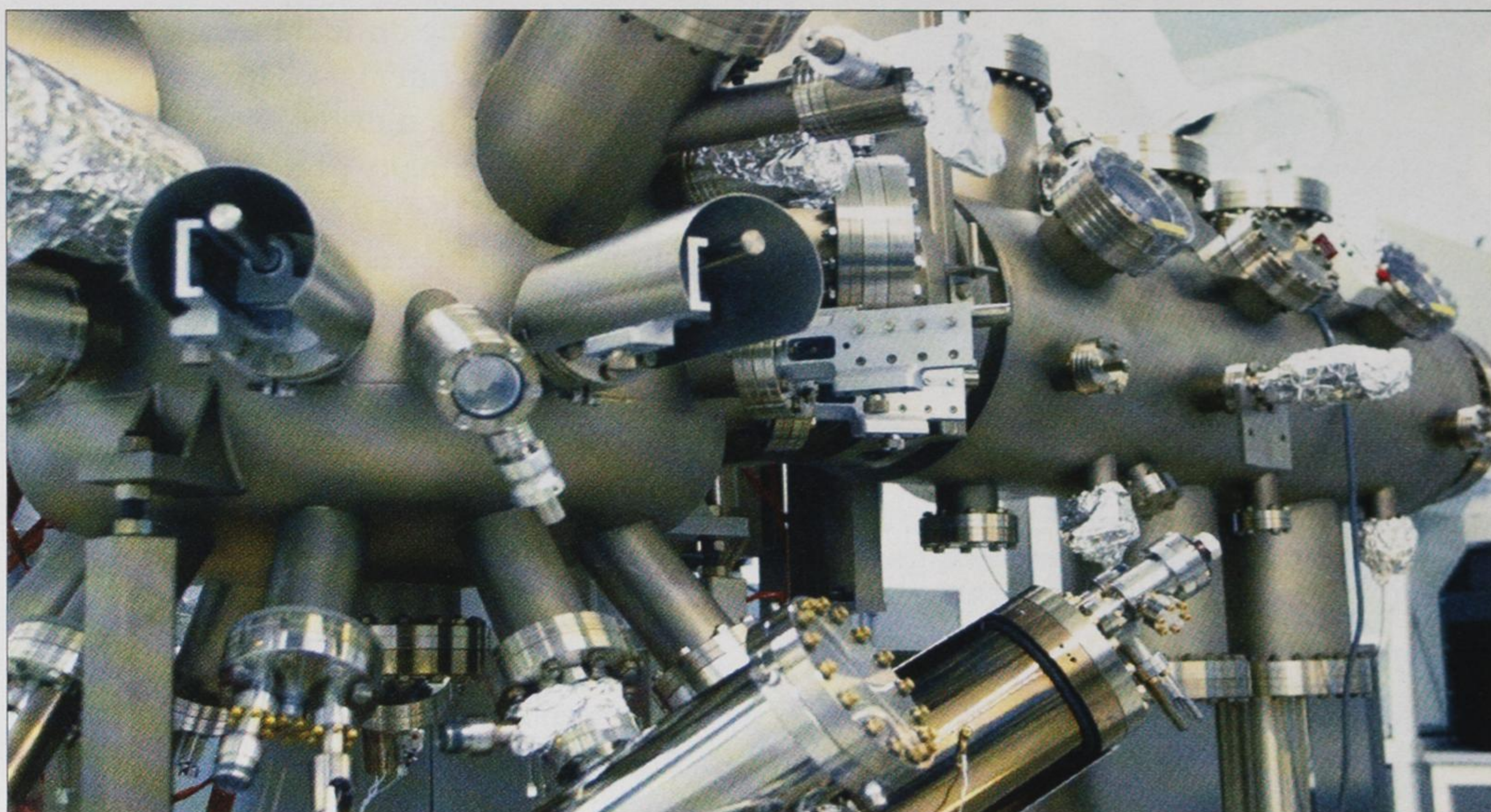
By Oliver Graydon

The photonics community in Tampere, Finland, has formed a local cluster to unite academic research with companies and aid the development of diode lasers and fiber lasers in the region.

"The Laser Competence Centre [LCC] Finland was established on June 7 and aims to speed up technology exploitation and support company needs," Markus Pessa, director of the Optoelectronics Research Centre (ORC) at Tampere University of Technology (TUT), told delegates at the LASER 2005 show held in Munich in June.

He added: "Already 20 companies have paid a membership fee of €3500 [\$4200] per year to join, and we expect another 20–30 companies to join before the end of the year." Local firms that have already signed up include laser manufacturers Coherent Finland (formerly Tutcore Oy) and Modulight, and epiwafer supplier and custom optoelectronic device manufacturer EpiCrystals. Well known names from further afield include Nokia, Heptagon and Oxford Instruments.

LCC's activities include laser development, integration of lasers with production equipment and end-user training. It has been donated a V90-type molecular beam epitaxy



A powerful MBE reactor will shortly be installed at Tampere University, thanks to the LCC.

(MBE) reactor, worth €1.5 m, by Coherent.

The reactor will be installed at the ORC this autumn and has a production capacity that is three times that of the ORC's six existing MBE reactors. It is the only reactor of its type in a European university and will be able to manufacture III-V optoelectronic components in larger batches than were previously possible.

"The Finnish laser industry will certainly

benefit from this donation," said Pessa. "There is a unique link between research and production in Tampere. A new branch of export industry – the industrial manufacture of epitaxial semiconductors and semiconductor and fiber lasers – has emerged quickly."

Oliver Graydon is editor of Optics.org and Opto & Laser Europe magazine.

Superluminescent LED enables early dental diagnosis

A medical imaging technique that uses an InP-based superluminescent LED (SLED) is being used by dentists to detect the early stages of disease in teeth. The result could be earlier, less-damaging treatment of dental problems.

US firm Lantis Laser has developed an optical coherence tomography (OCT) imaging instrument based around an SLED supplied by Singapore-based firm DenseLight Semiconductors. According to dentists who have trialed the technique at the University of Pennsylvania (UPenn) School of Dentistry, OCT can detect oral problems before a conventional X-ray image can.

This is because the spatial resolution of the three-dimensional images produced by OCT is 10 times better than that of X-ray images. X-ray detection of tooth decay depends on a variation in material density – a sign that damage

has already been done – but OCT relies on more subtle variations in optical characteristics.

OCT requires a broadband light source, and Denselight's Sunil Phatak believes that it is the particularly "clean" power output of his company's SLEDs that benefits the dentists. "Customers keep clamoring for clean power – useful optical power with low coherence noise, high polarization and wider spectral bandwidth."

Denselight's SLEDs produce over 50 mW output, with a spectral width of more than 70 nm. "We have tried several broadband light sources. The Denselight 1310 nm SLED is clearly superior and performs consistently well in generating exceptionally clear images," said UPenn dentist Linda Otis.

Lantis Laser will now look to commercialize the technique and gain clearance from the Food and Drug Administration, the regulating body in the US. "OCT has a very definite function in dentistry," said Lantis's Stan Baron. "Lantis Laser is ready to embark on developing pre-production prototypes and then address market introduction in 2006."

nLight manufactures 3 W NIR diode laser

High-power semiconductor laser manufacturer nLight has released a near-infrared (NIR) diode laser that emits 3 W continuous-wave power from a single, 100 µm broad area emitter.

The 808 nm laser is claimed to be an ideal pump source for solid-state lasers, and an excellent heat or illumination source for medical and industrial applications.

nLight's single-emitter diode laser has an operating current of 2.8 A and a compliance voltage of 1.85 V. Full-width half-maximum (FWHM) values of beam divergence are less than 36° × 10°. The laser can also be accompanied by a cylindrical lens to collimate the divergence of the fast axis to below 2° FWHM with more than 95% power transmission.

nLight says that its high-power single-emitter diode lasers are based on its proprietary MOCVD-grown laser structure and facet passivation technology, which produces highly reliable, long-lifetime products.

Crystal growing



Production system for sublimation growth of 2 / 3 inch 4H- and 6H SiC single crystals for optoelectronics, power- and high temperature electronics. Allows the precise control of process conditions (temperature field, gas pressure, gas composition). Tmax 2300 °C.



Bridgeman 3 zone vertical tubular furnace with graphite heater for directional / and single crystal solidification of metals under protective gas atmosphere. With quenching baffle. High precision translation. Program controller: SE 502. Max. furnace temperature: 1.800 °C. Max. heating power: appr. 20 kW. Linear unit: 0,1 mm/h to 1.000 mm/h. Fast cooling: appr. 100 mm/s.



Micro-Crystal growth system for pulling of single crystalline fibers from the melt under inert gas or air. Fiber dimensions: $\varnothing = 0,2-2,0$ mm, $l_{max} = 250$ mm. Up to 5000 mg of starting material is melted in a platinum crucible (for high-melting compounds also Ir-, W-, Mo- crucibles) and a fiber crystal is pulled down through a capillary nozzle with a secondary heater around the nozzle. Power supply: primary heater 80 W (max. 500 W), secondary heater 30 W (max. 200 W).

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Merged NeoPhotonics is 'top-tier'

NeoPhotonics, the optical module supplier and chip manufacturer based in San Jose, CA, has completed its merger with the Photon Technology Company of Shenzhen, China.

According to the US firm, the acquisition positions the merged entity, which retains the name NeoPhotonics, as a "top-tier" optical component manufacturer. Revenue is expected to exceed \$50 million in 2005, while the company now boasts more than 1200 employees and 100 customers, including some key network equipment suppliers.

Set up in 1993, Photon Technology was said to be China's largest active component manufacturer in the fiber-optic sector. NeoPhotonics became the largest shareholder in the company earlier this year when it acquired one-third of all outstanding shares formerly owned by the Chinese state.

NeoPhotonics specializes in planar light-wave circuits (PLCs) featuring integrated components, which are designed for long-haul, metropolitan and access networks. It is the access area that NeoPhotonics' CEO Tim Jenks is particularly excited about: "The

merged company [has] a complete line of active and passive modules – from the core to the edge of the network – and a particularly strong portfolio for the booming fiber-to-the-premises [FTTP] sector," he said.

Jenks says that FTTP is already a market worth close to \$1 billion worldwide, and the economies into which the high-speed access technology appears to be penetrating fastest are those of Taiwan, China and Korea.

NeoPhotonics says that its photonic integration will ultimately drive down costs and improve the efficiency of optical networks, allowing faster deployment of new, high-bandwidth services. "Key market opportunities include the integration of active lasers with passive filtering, and alignment on PLC substrates for low-cost triplexers used in 'triple-play' FTTP access networks," claimed the firm.

The merged company's headquarters will remain in San Jose, where NeoPhotonics has a 10,000 ft² wafer fabrication facility. The bulk of device assembly will take place in Shenzhen, while research and development activity will continue in San Jose, Shenzhen and Beijing.

Hitachi and OpNext work on power-saver

OpNext and its parent company Hitachi have developed a semiconductor laser for high-speed optical networks that is said to be simpler in structure than competing devices and far less power-hungry.

According to a report in the *Nihon Keizai Shimbun*, the new device consumes less power because it integrates the laser with a modulator that does not require complex cooling.

The report adds that OpNext, which uses

wafer fabrication facilities formerly belonging to Hitachi, plans to commercialize modules that will incorporate the new devices in the first half of next year.

Set up by Hitachi as a fiber-optic components unit in 2000, OpNext took over the firm's semiconductor and opto-device division in 2002. As well as lasers for optical networks, it also makes laser diodes used in optical data-storage applications and bar-code readers.

Emcore set to grow as Cisco deal expires

The growing market for 10 Gbit/s fiber-optic networks and the end of an exclusive supply deal with Cisco Systems spells good news for Emcore, says an investment bank.

According to research by Jefferies & Co, the end of the Cisco agreement, which expired on June 30, 2005, will give Emcore access to a raft of new customers.

"Starting on July 1, Emcore will be able to pursue other customers," said Jefferies prior to the deal's expiration. "Potential customers include Force10 Networks, Extreme Networks, Foundry Networks and Huawei Technologies."

The bank also points out that Emcore will

continue to be Cisco's key supplier as the 10 Gbit/s market grows. With other customers now available to Emcore, the Somerset, NJ, chip maker will ramp manufacture of its LX4 product, which optically combines four separate uncooled distributed-feedback lasers operating at 1275, 1300, 1325 and 1350 nm.

Cisco recently announced plans to deploy an optical network containing these transceivers at the Memorial Sloan-Kettering Cancer Center in New York. Jefferies reckons that the expanding market, and Emcore's strong position within it, will drive 50% year-over-year growth in sales of these products.

AmberWave sues Intel

AmberWave Systems, the Salem, NH, company that specializes in developing strained-silicon device manufacturing technology, has filed a lawsuit against Intel, the world's foremost silicon chipmaker.

According to AmberWave, Intel's latest Pentium processors, which are manufactured using 90 nm technology, infringe US patent numbers 6,881,632 and 6,831,292.

In both of these patents, AmberWave details ways to increase carrier mobility in n-type and p-type channels by introducing strain into the silicon lattice. The litigation arose after Intel refused to negotiate a "commercially reasonable" license agreement, claims AmberWave.

"Because Intel has been using these proprietary technologies without a license from AmberWave, we have no choice but to defend our intellectual property rights," said AmberWave CEO Richard Faubert.

Patent 6,881,632, which was awarded in April this year, details a method developed by Amberwave's Eugene Fitzgerald, also a pro-

fessor at Massachusetts Institute of Technology, and Nicole Gerrish.

In it, they describe how a compositionally-graded buffer layer can be used to accommodate the lattice mismatch between a relaxed SiGe film and a silicon substrate. A silicon layer under biaxial tension can then be deposited on top of the SiGe film, thus improving both hole and electron mobility.

Devices made using the method can operate faster while the input power is kept constant, for example in processor chips for desktop computers where speed of operation is the crucial attribute.

Alternatively, the chips can run at their normal frequency but draw less power – a useful attribute for portable electronic applications.

The earlier patent details silicon and SiGe-based structures featuring an "impurity" gradient. At the furthest point of a strained-silicon layer from the semiconductor substrate, the concentration of the impurity, or dopant material, is zero.

In brief

- SiGe foundry **Jazz Semiconductor** has appointed Brent Jensen as its vice-president and chief financial officer (CFO). Jensen's financial career began in the early 1980s with National Semiconductor, and he now leaves AMI Semiconductor, where he has held various positions including senior vice-president and CFO.

In mid-June, Jazz told the US Securities and Exchange Commission that it was withdrawing plans for an initial public offering of its stock.

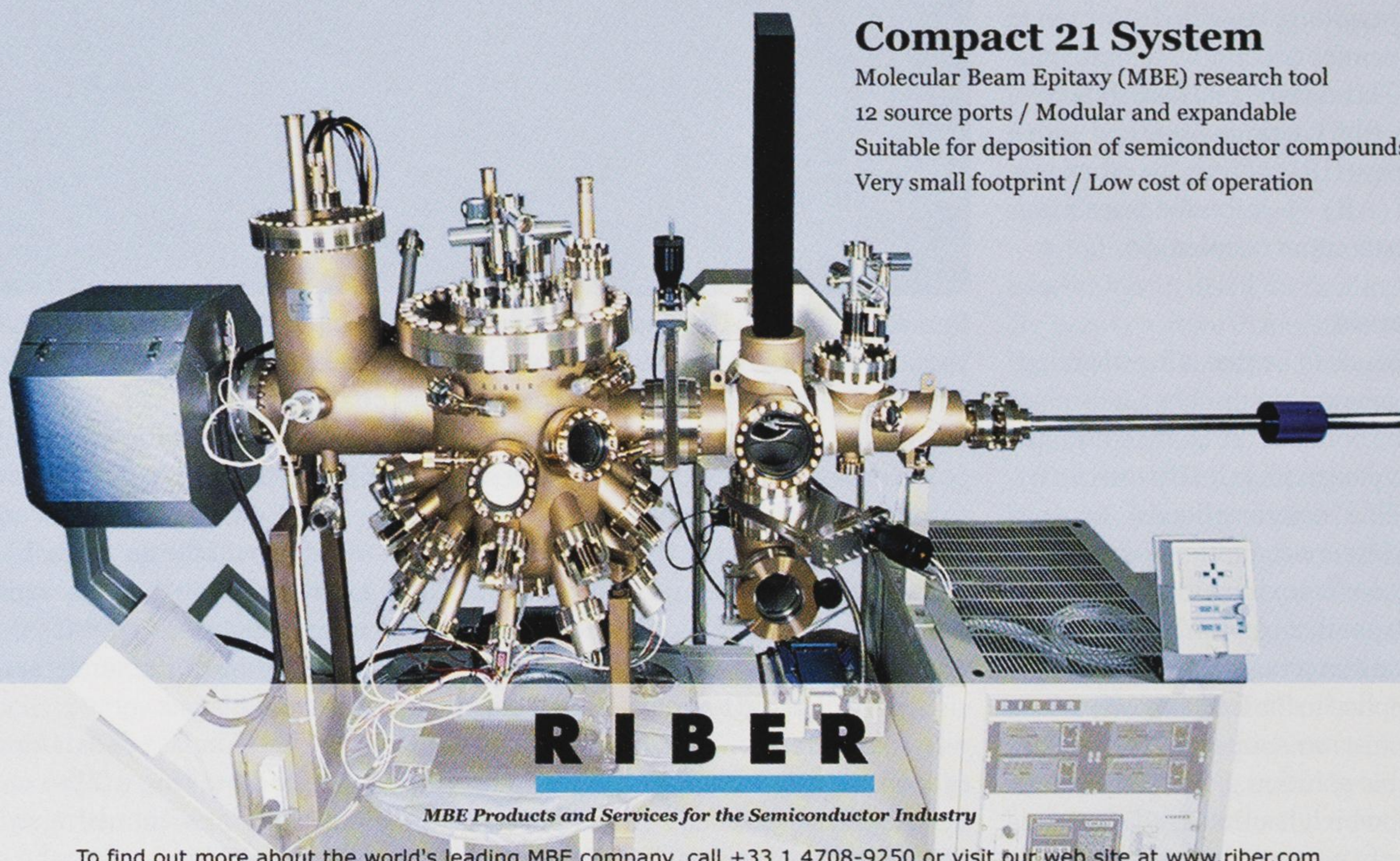
- **Peregrine Semiconductor**, a manufacturer of circuits based on silicon-on-insulator technology and featuring sapphire substrates, has appointed Brian Hurst as vice-president of worldwide sales.

Hurst was formerly vice-president of worldwide sales and marketing at Anadigics, and has also held the position of general manager of sales and marketing for the Americas at National Semiconductor.

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Nitrel ion beam treatment increases laser lifetimes

Swedish start-up Comlase has developed an ingenious technique for protecting the surface of semiconductor laser chip facets. **Oliver Graydon** reports on the company's Nitrel treatment, which promises to boost the durability, output power and reliability of all types of laser diode.

A small Swedish firm believes that it has found a way to fabricate semiconductor lasers that can be driven, without failing, at much higher temperatures and output powers than ever before. If the claim of Stockholm-based Comlase turns out to be true, it could have dramatic consequences in fields ranging from data storage and telecoms to fiber pumping and laser welding.

Until now, the maximum output power and temperature of operation of high-power laser diodes has been severely limited by the onset of a failure mechanism called catastrophic optical mirror damage (COMD). This irreversible thermal damage to the surface of the laser chip facets, which act as mirrors, is often caused by facet oxidation or manufacturing defects that absorb light and act as "hotspots". It is the principal reason for the poor manufacturing yield of high-power lasers.

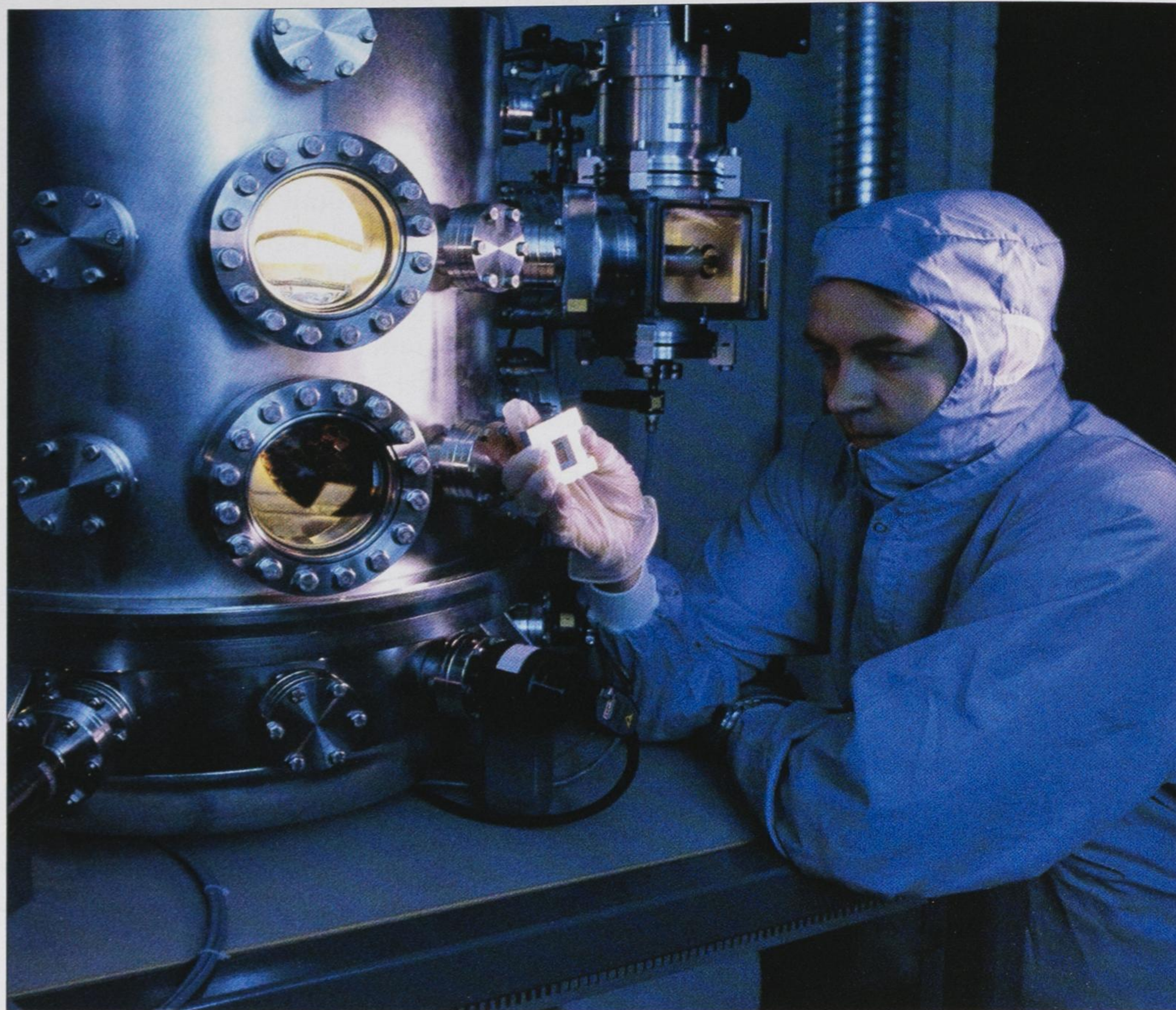
Today, edge-emitting laser diodes are made by cleaving a semiconductor wafer into individual chips. The cleaved ends are then covered with thin-film coatings – one end with a high-reflectivity (HR) coating, the other end, antireflection (AR) – to form the laser's rear mirror and front output coupler.

Dangling bonds

The problem tends to be that, after cleaving, the exposed facets are highly chemically reactive because the bonds of the atoms in the surface layer have been physically torn apart, creating so-called "dangling bonds". On contact with even low concentrations of moisture or oxygen, these areas oxidize to create a light-absorbing hotspot that can lead to COMD.

Although the conventional thin-film coatings that are applied to the facets do offer some protection against moisture and oxygen, they are not a durable solution. For example, aluminum oxide, which is often used as a coating, is relatively permeable to water and is prone to moisture ingress over time.

To date, approaches to overcoming the



Special treatment: Comlase's reactor for performing its Nitrel process. The ultra-high-vacuum chamber features a nitrogen ion gun to prevent facet oxidation and several electron guns to produce the necessary facet coatings.

problem have focused on depositing a passivation layer, such as silicon (in Bookham's E2 process), on top of the raw facets to protect them prior to depositing the thin-film reflection coatings. However, this process is only effective at certain wavelengths.

"Applying a thin layer of silicon works very well for lasers operating at 900–980 nm, but as soon as you go to shorter wavelengths, you get negative effects," explained Alfred Feitisch, Comlase's CEO. "Our 'Nitrel' passivation process is applicable to any semiconductor material – going all the way from

GaN in the blue to the infrared."

The Comlase Nitrel process uses nitrogen to tidy up all the dangling bonds on the raw facet surface so that they cannot oxidize and act as a catalyst for COMD. Conventional HR and AR thin-film coatings are then applied to the treated facets.

"What Comlase does is atomically seal the surface by taking off the oxygen and substituting it with nitrogen atoms," said Feitisch. "This renders the surface chemically stable so that it cannot react."

The process is performed in a specially

designed ultra-high-vacuum chamber (reactor) that features two electron guns and an ion gun for bombarding the facets of the laser with a stream of nitrogen ions. The nitrogen ions polish the surface smooth, remove any oxides and then seal it with a nitride layer. The electron guns are then used to deposit the HR and AR thin-film coatings onto the rear and front facets by e-beam evaporation.

“The reactor has a carousel that puts a stack of 50 laser bars in front of the ion gun at a time. We then flip them over and do the reverse side. Then we lay down the HR and AR coatings,” said Feitisch. “We are now building a new high-volume chamber that will have at least three electron guns and will be able to process 800 laser bars in a single run.” Heading up this development is Olof Sahlén, Comlase’s new vice-president of engineering.

Improved degradation

The benefits of the process are substantial, according to lifetime test data collected by Comlase. It says that multimode 805 nm AlInGaAs laser diodes fabricated with the Nitrel process showed no degradation in performance over a period of 9000 h when driven at 60–80 W with a junction temperature of 90 °C. In comparison, untreated diodes driven under the same conditions degraded rapidly, with three-quarters of the batch failing before reaching 6000 h.

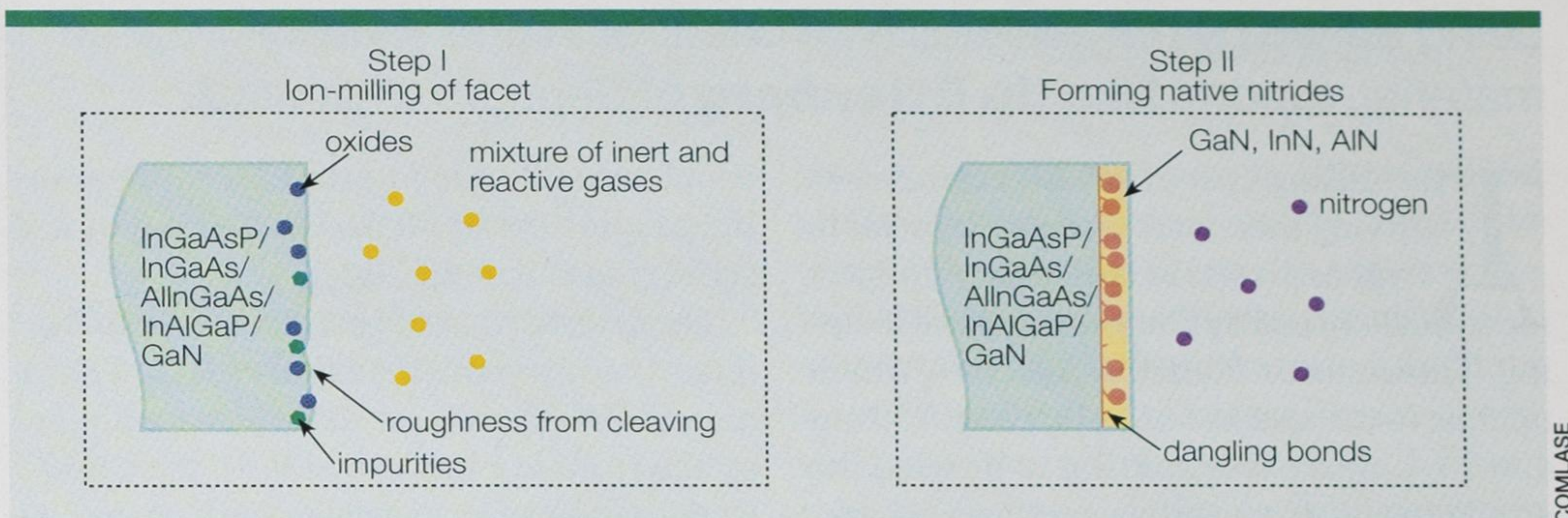
Tests with InGaAs diodes at the longer wavelength of 980 nm also showed great improvements in performance. “We’ve put them on life tests at 180 mW/μm [emitter width] and seen no degradation over thousands of hours,” said Feitisch. “In short, what this means is that if you take a 100 μm-wide single-chip emitter, [it] would be a reliable 18 W laser chip, which is enormously important for pumping high-power fiber lasers.”

As far as applications for the process are concerned, Feitisch says that it would be ideal for making high-power infrared (IR) lasers for pumping solid-state lasers, such as the US military’s proposed mobile 100 kW laser weapon. The ability to run diode lasers at much higher temperatures (90 °C, instead of room temperature) and higher output powers should dramatically simplify the cooling requirements for the pumps and minimize the number that are needed.

“In theory, you could run everything on a car-engine cooler, rather than using refrigeration equipment,” explained Feitisch. “We have set up a US subsidiary in Delaware so that we can deal more easily with the US

Materials that can benefit from the Nitrel process

Wavelength range	300–520 nm	620–750 nm	780–980 nm	>980 nm
Material	GaN AlGaIn InGaIn	InGaP AlInGaP	AlGaAs AlInGaAs InGaAsP InGaAs	InGaAsP:InP InGaAsSb:InP GaInNAs:GaAs



A stream of nitrogen ions is used to protect the facet from oxidation and create a smooth, flat surface that is free from any impurities or roughness. The ions then form a thin nitride (GaN, InN or AlN) layer that seals the surface, giving a chemically stable, durable base that blocks oxygen and moisture ingress. Optical thin-film coatings are then deposited on top.

military and government.”

Fiber lasers and thin-disc lasers could also benefit from diodes with improved reliability and power levels. Ultimately, the technology could result in bright, compact diode bars that are ideal for performing direct diode welding and surface treatment.

The improved reliability of the lasers could also be a big benefit for other mission-critical applications. “We are in talks with the European Space Agency to design and qualify a special laser bar for spaceborne applications, and hope to have a project started next year,” said Feitisch. “After all, if a laser fails on a satellite in space, it’s a big problem.”

Other potential applications include raising the output power of blue and red lasers used in the optical storage industry. The result could be faster writing and reading of data onto CD-ROMs, DVD and BluRay discs. Comlase says that it has already received enquiries from Sony and Hitachi, who are both interested in the technology.

Although the company is initially focusing on applying its process to semiconductor lasers, Feitisch says that there is no reason why the Nitrel process couldn’t be applied to semiconductor photodetectors, such as avalanche photodiodes (APDs) and *pin* diodes, to help reduce their noise. “These devices have dark current [noise] issues that our process should be able to eliminate,” said Feitisch. “Nitride is an electrical insulator and can prevent elec-

trons from flowing over the surface of these devices, which causes the dark current. We want to investigate this idea further.”

In the case of APDs, the Nitrel process allegedly lowers the risk of voltage breakdown over the junction region, thereby reducing the likelihood of device failure. And that’s not all – Feitisch says that the process could potentially be used to protect glass components such as fibers and crystals. “For example, you could treat the end of optical fibers before laying down an AR coating, in order to get extremely good adhesion and remove any surface imperfections.”

Another possibility is treating borate crystals, which are used for nonlinear optics, but are very sensitive to moisture (hygroscopic). By creating a thin, protective film of nitride on the surface of a crystal, it could be protected from water vapor.

Comlase has no shortage of possibilities for its technology, but with a staff of just 20, the firm is having a tough time deciding which applications to pursue first. “Before we explore other opportunities, we need to get some traction with laser manufacturers and secure revenue,” said Feitisch. No firms have licensed the Nitrel process yet, but he says that it is currently being trialed by three parties and he is optimistic about the outcome.

Oliver Graydon is editor of Opto & Laser Europe magazine.

Wafer-making advances fuel

InGaAs cameras are now being used to find bruising in fruit, sort plastics for recycling, and help the glass-bottle manufacturing industry detect defects. This penetration into new markets is being driven by the availability of cheaper, higher-quality InGaAs material, reports **Martin Ettenberg** of Sensors Unlimited.

The falling cost of InGaAs cameras is driving their increased deployment in areas as diverse as spectroscopy, object identification, and military and thermal imaging. These more affordable detectors, which operate in the spectral band between 750 nm and 2.6 μm , are just starting to be used for applications as varied as sorting plastics, determining fill levels in opaque plastic bottles and imaging under starlight conditions.

Improvements in material quality have accompanied these increases in sales, leading to devices with greater uniformity and lower dark current, and room-temperature-operation imaging arrays with greater sensitivity. Further advances are expected to follow, fueling the trend for higher volumes, improved performance and falling prices that Sensors Unlimited Inc. (SUI) of Princeton, NJ, has witnessed for over a decade.

Straining to increase coverage

SUI's detectors cover the 900–2600 nm spectral range with various $\text{In}_x\text{Ga}_{1-x}\text{As}$ alloys, and the company has recently developed a new processing technique to extend this range down to 400 nm at the blue end of the visible spectrum. The detector uses three alloy compositions: $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$, which is lattice-matched to InP (referred to simply as InGaAs); strained $\text{In}_{0.71}\text{Ga}_{0.29}\text{As}$; and strained $\text{In}_{0.82}\text{Ga}_{0.18}\text{As}$. Varying the InGaAs composition allows the camera to detect emission at wavelengths of up to 2.6 μm , far beyond the 1 μm cut-off associated with silicon-based imagers (see figure 1).

Lattice-matched InGaAs has seen the greatest improvements. During the last six years dark currents have fallen by 95% and pixel operability (the proportion of working pixels) has risen substantially. This unstrained material has also generated the highest increase in demand for new applications.

InGaAs arrays also contain a CMOS read-out integrated circuit (ROIC). The InGaAs device converts incident photons to electrons, and the ROIC amplifies and stores the elec-

trical signal, which permits simultaneous light-collection by all the pixel elements and serial read-out of the signal.

The detectors have a linear response to light intensity over more than five orders of magnitude. However, these detectors are limited by the storage capacitor size on the CMOS ROIC, which places an upper limit on the collected signal and dictates acceptable dark current values. Dark current cannot be eliminated, but reducing this unwanted signal improves signal-to-noise ratios. Changes to structural design and processing improvements have significantly improved the dark current in standard *pin* detectors, and typical dark currents for an InGaAs pixel in a 320 $\times$ 256 array with a 25 μm pitch are now below 75 fA at reverse biases of 300 mV.

High-performance detectors also demand uniform dark current, because it is the pixel with the highest dark current that determines the detector's longest integration time or the largest gain. SUI has improved its detector uniformity, and dark current variations are now below 20% for a 640 $\times$ 512 InGaAs array measuring 16 $\times$ 12.8 mm. In this device containing more than 325,000 separate detectors, over 99.5% of the pixels are operable. Linear arrays with 1024 pixels and a 25 μm pitch have even higher operability figures of 100%.

Detecting the enemy

Military imaging is the largest application sector for shortwave infrared (SWIR) detectors, followed by spectroscopy, the sorting of products and materials, and thermal sensing. Each application places different demands on the detectors, and fulfilling these requirements has driven the production of higher-quality, lower-cost imagers.

During the last few years improvements in InGaAs material quality have raised the detector's performance to such a level that it is now starting to penetrate the military market.

These instruments allow both imaging and the transmission of digital pictures under

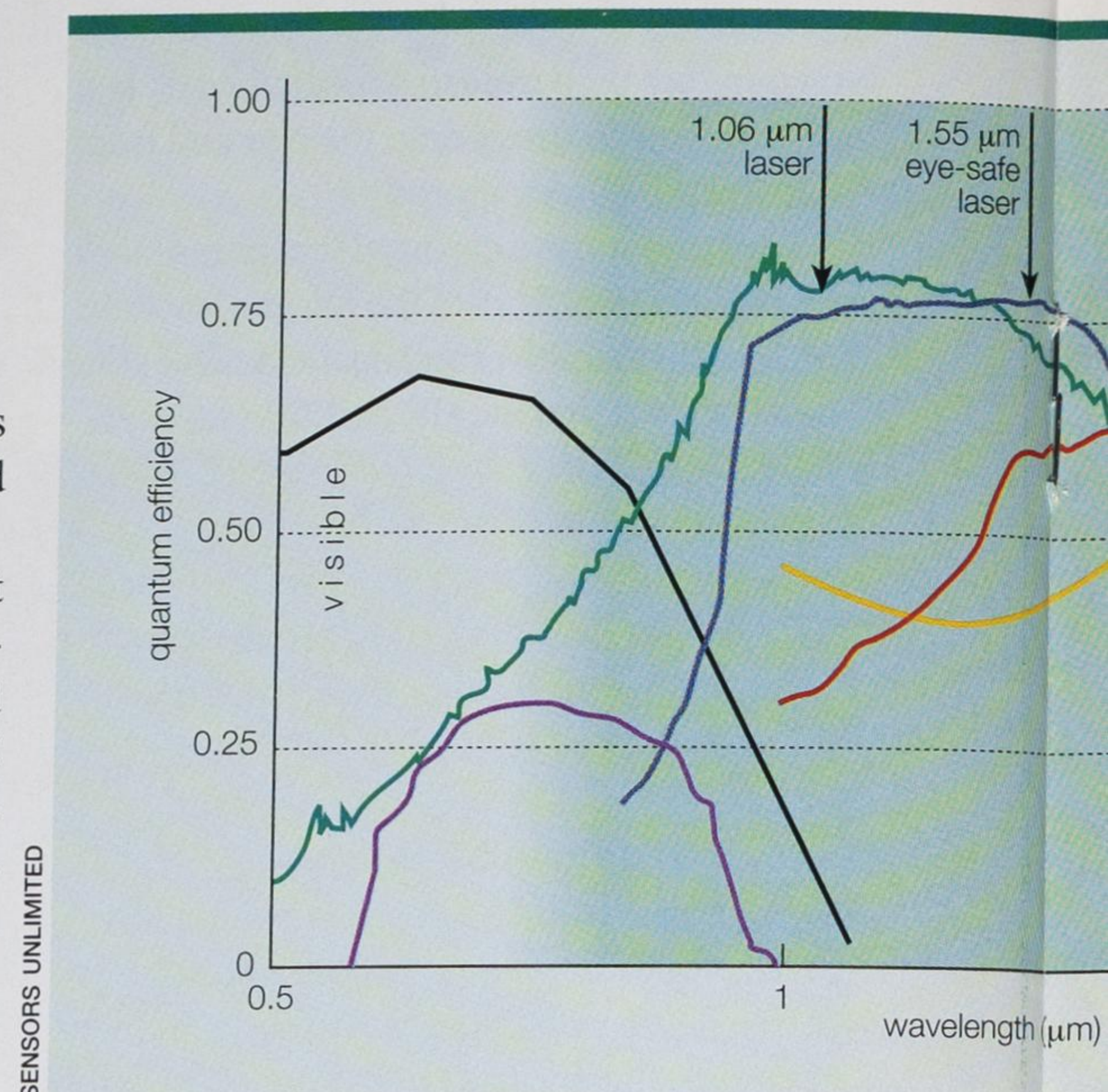
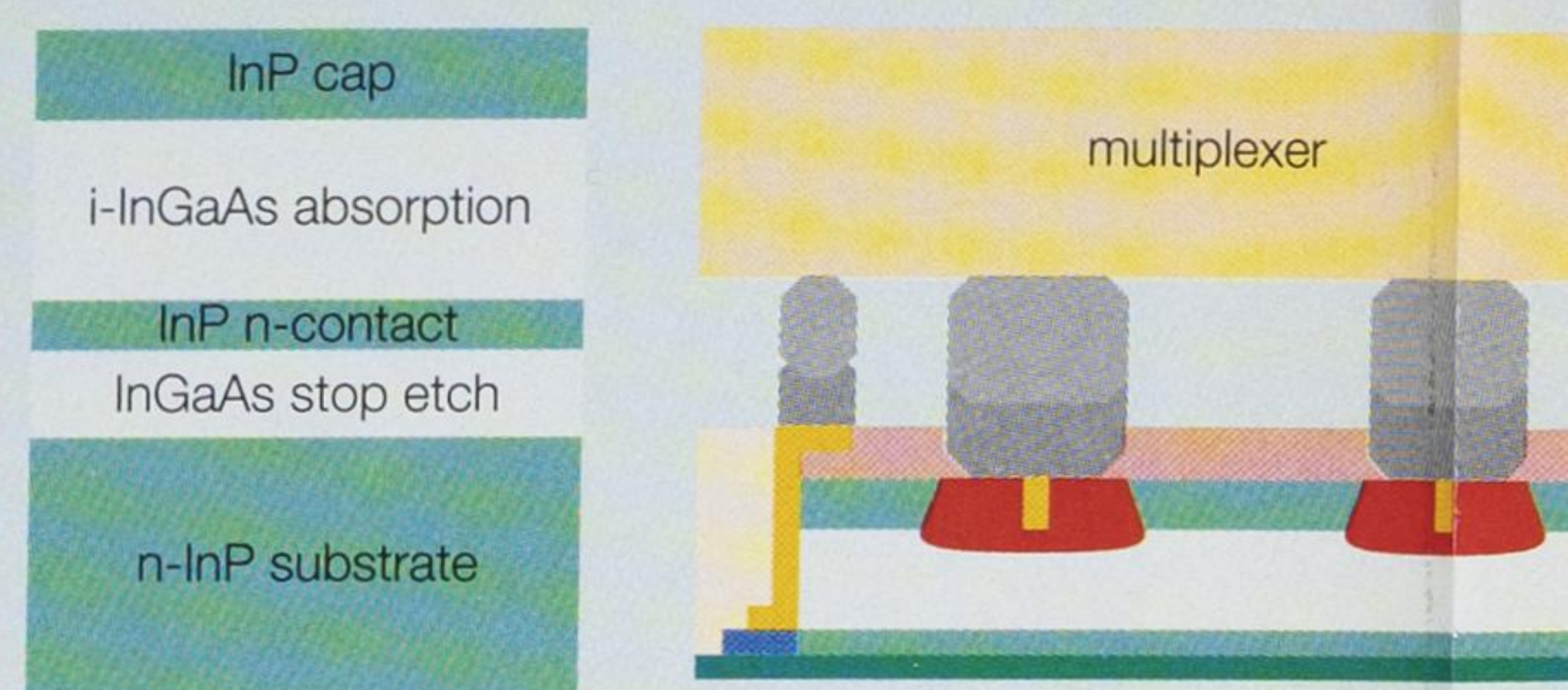


Fig. 1. By adjusting the InGaAs strain and removing the absorption barrier, Sensors Unlimited's imagers can cover the spectral range from 0.4–2.6 μm . 1.06 μm and 1.55 μm lasers used by the military.

Extending detection to visible wavelengths



InP layers prohibit InGaAs detectors from performing in the visible spectrum. The problem is highly absorbing at these wavelengths. Sensors Unlimited solved the problem by incorporating etch-stop layers into the device (left) combined with the CMOS read-out integrated chips to form a complete imager. The InP and InGaAs etch-stop are removed by chemical etching.

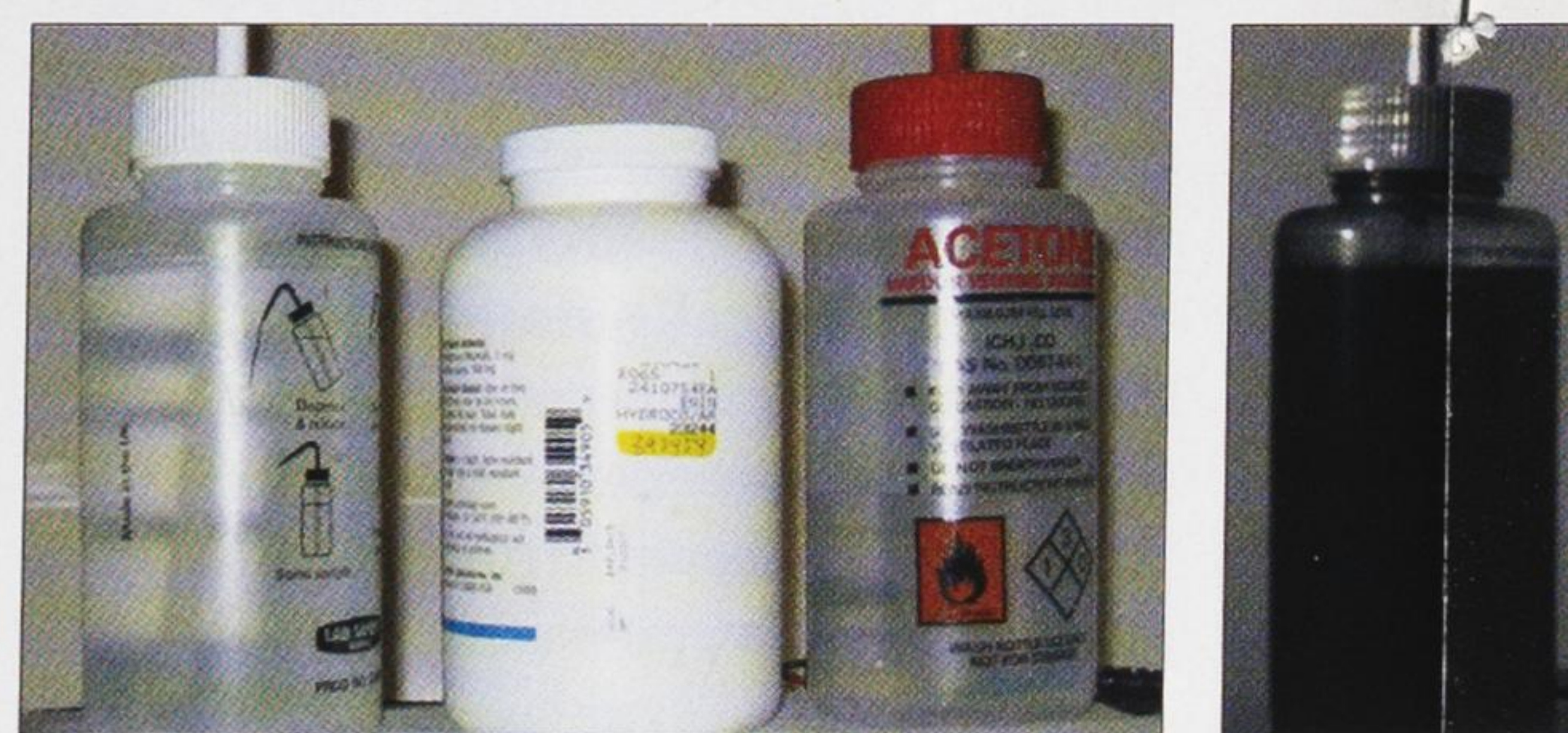
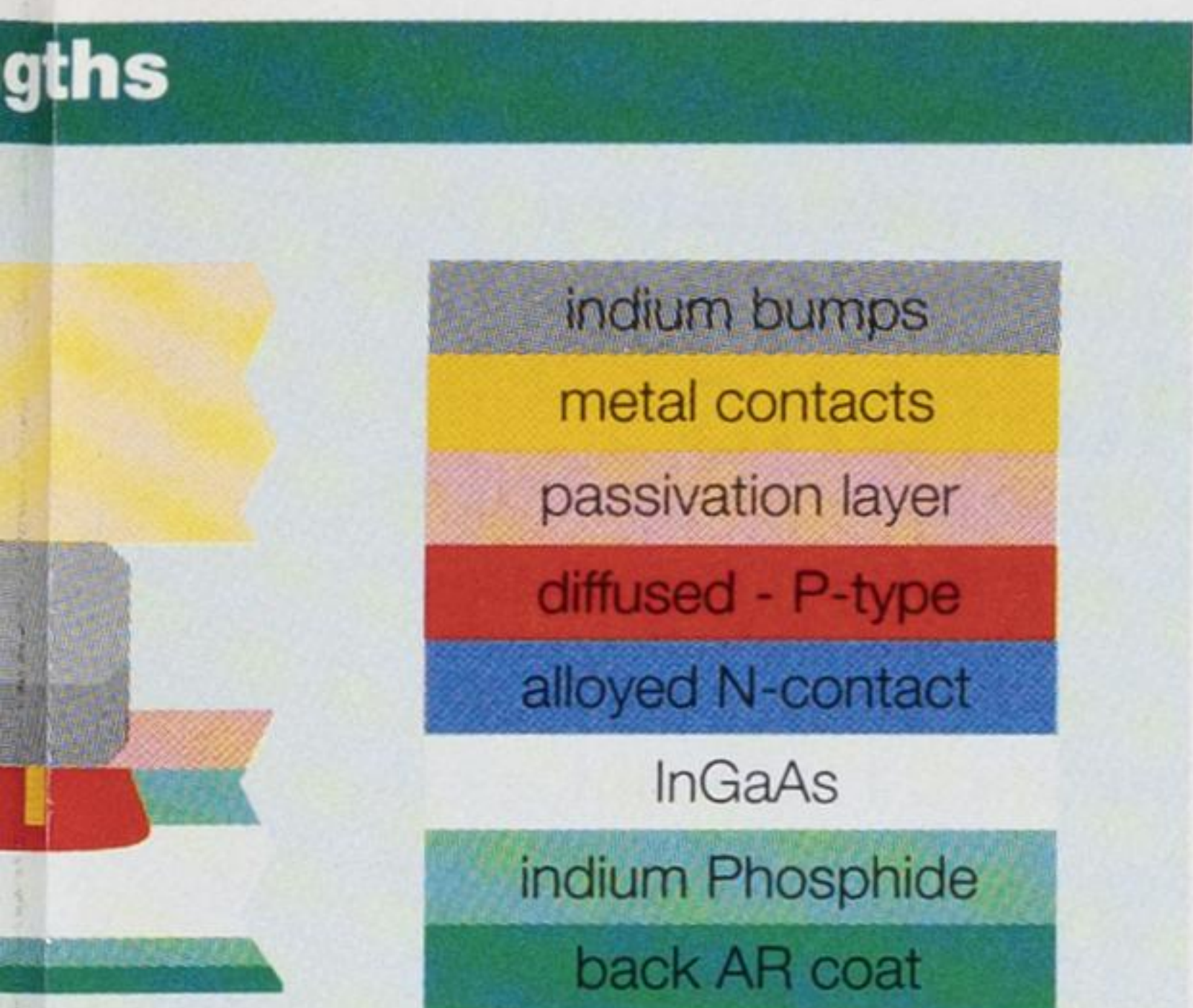


Fig. 2. Short-wave imaging (right), unlike visible imaging (left), can see through plastic and determine liquid levels inside opaque containers.

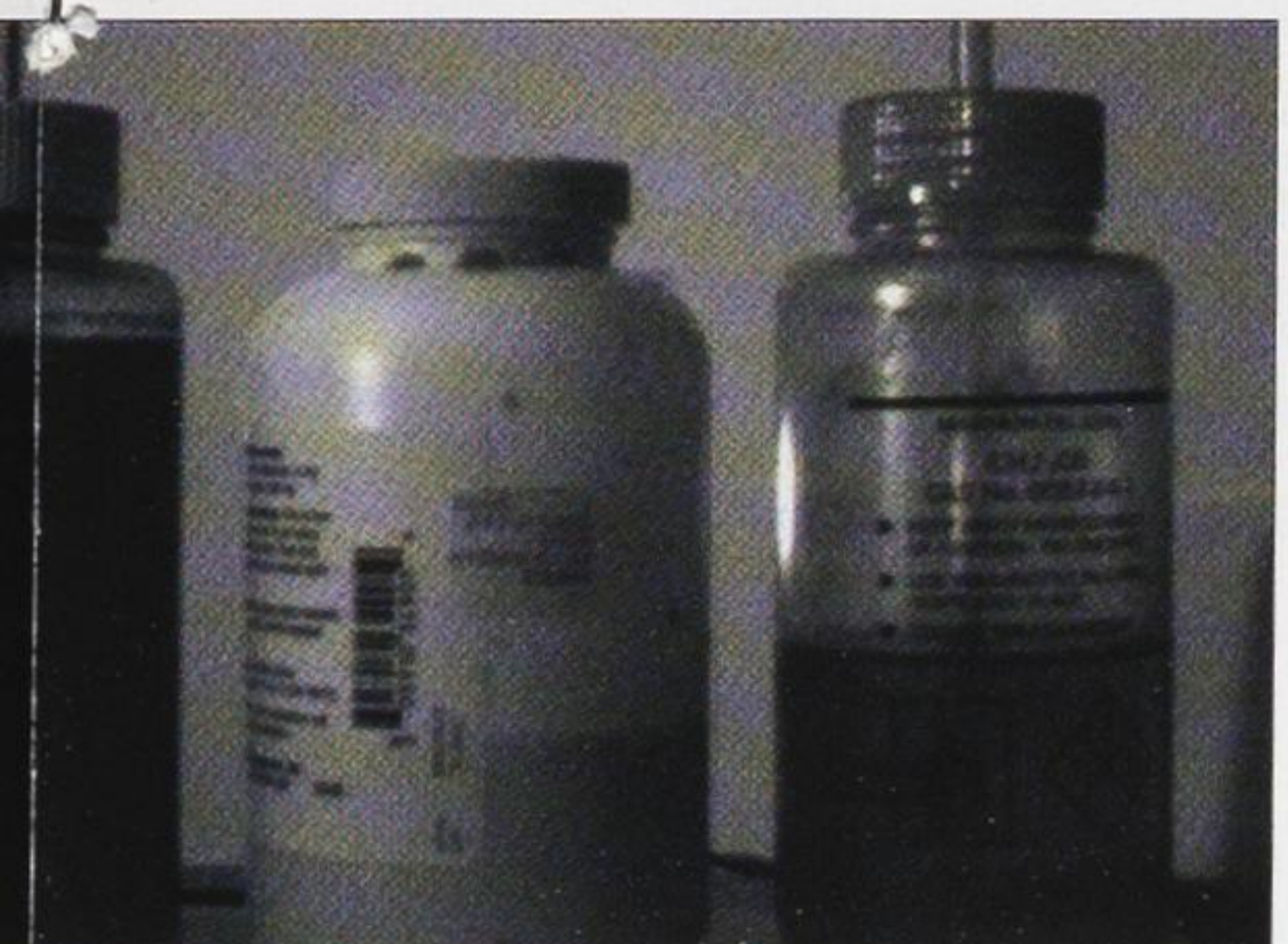
InGaAs camera sales boom



absorbing InP substrate, Sensors Unlimited has solved this problem (left). This structure is then etched to form detector arrays (right) before final etching.



the visible region because the Sensors Unlimited has solved this problem (left). This structure is then etched to form detector arrays (right) before final etching.



g (left), can be used to see through containers.

Developments in InGaAs manufacturing

Sensors Unlimited was the first optoelectronic company to have a 4 inch line, but most InGaAs/InP detector fabrication facilities still use 2 or 3 inch InP substrates. 4 inch wafers offer high-volume processing with improved uniformity, although the strained InGaAs material required for longer-wavelength detectors is often only available on 2 and 3 inch substrates.

Production quantities have increased in recent years, and a reduction in epitaxial defects has led to a ten-fold reduction in dark current. Longer-wavelength strained InGaAs material, which has a higher dark current, is now more common, and many linear arrays incorporating this material are now available off-the-shelf.

The refinements in material quality and processing have reduced the dark current, which benefits applications involving the detection of weak signals such as spectroscopy. The reduction in dark current has also improved the yield of higher-speed devices, which has in turn lowered the cost of cameras used to track moving objects, such as those used in machine-vision arrays.

Lower sales prices have in turn driven greater application and increased wafer volumes, thereby continuing the trend of better performance, lower costs and larger product volumes.

SUI has also extended the response of its 2D arrays to

visible wavelengths by removing the InP substrate, which absorbs light below 920 nm. Removing the substrate using the InGaAs etch-stop layer allows for backside-illuminated detectors with a thin ($<1 \mu\text{m}$) InP layer for an n-side contact (see "Extending detection to visible wavelengths"). Light can then penetrate InP and reach the InGaAs absorption layer, allowing visible light detection.

SUI's detector prices have been in continual decline, as demonstrated by the sales history of its linear array detectors to the optical telecoms market. In 1997 256-element linear arrays with a $50 \mu\text{m}$ pitch and 99% pixel operability cost \$6000 in single-piece quantities. Five years later, similar arrays sold for \$1300 each in quantities of 1000 and delivered 100% operability.

This trend has been mirrored in the 2D array market. In 1993, SUI sold its first 128×128 ($60 \mu\text{m}$ pitch array) InGaAs camera offering room-temperature operation. The camera weighed over 2 kg, had a pixel operability of 98% and cost \$25,000 in single-piece quantities.

Today 320×256 InGaAs imagers with just a $25 \mu\text{m}$ pitch, in a camera the size of a matchbox and weighing less than 70 g, cost \$22,000 in single-piece quantities. For 100-piece quantities the cost of each detector is reduced to \$11,000.

High-performance InGaAs material is now starting to penetrate the military market.

starlight-only conditions, so images can be shared between soldiers on the battlefield (see figure 3). This feature is not possible with the standard-issue night-vision goggles which only allow direct viewing. InGaAs arrays can also image nearly all types of battlefield laser, including the newer $1.55 \mu\text{m}$ eye-safe sources. Other technologies can provide digital images at night, for example electron-bombarded active pixel sensors and image-intensified charge-coupled devices. However, both these detectors have a small dynamic range and don't allow the user to see $1.55 \mu\text{m}$ eye-safe sources.

Although the latest thermal weapon sights ($8\text{--}12 \mu\text{m}$ detection range) currently being developed and deployed can also detect people or military vehicles, they have several drawbacks. They are unable to see laser target designators and ranging devices, cannot image through glass windows, and suffer from inferior performance at dawn and dusk. SWIR imagers can complement these thermal imagers, and images can be fused together to generate a very informative picture.

The spectroscopic detector market is dominated by linear arrays, but recently there has been a surge in the use of their 2D counterparts, which can record spectroscopic information on one axis, while using the other to detect spatial information. InGaAs arrays are already the first choice for monitoring the optical output from telecom networks using dense-wavelength division multiplexers, while the research market has seen steady growth over the last decade as detector performance has improved.

Spectroscopy can also be used to sort materials, and it has been used for several years in recycling plastics by analyzing reflected light intensity at different wavelengths. One camera is used for each wavelength, and specific plastic types can be identified by comparing these images. This "machine vision" application requires high-speed cameras to minimize blurring, which demands a detec-

tor with high uniformity, high speed and fast read-out.

Developing instruments to cater for the two vastly different applications of spectroscopy and imaging under low light-levels has led to performance improvements that are proving useful outside these specific applications.

Imaging on the production line

For example, InGaAs cameras are just beginning to be used to measure the fill levels of liquids in containers. In the last year, SUI has installed detector systems within the pharmaceutical industry to replace slower and simpler methods such as using scales to determine container fill levels (see figure 2).

The food industry is also now starting to use InGaAs detectors as an affordable alternative to silicon-based cameras to reveal the level of bruising in fruit.

The smallest market, thermal imaging, has been dominated by microbolometers or detectors containing mid- and long-wavelength infrared materials ($>3\ \mu\text{m}$ detection range) such as HgCdTe and InSb. Although these instruments are good solutions for imaging



Fig. 3. InGaAs cameras can give soldiers the edge during night-time combat by delivering clear images, even in the darkest conditions.

room-temperature objects, InGaAs detectors offer distinct advantages above $120\ ^\circ\text{C}$. This feature has led to SUI selling InGaAs cameras to the glass manufacturing and smelting industries during the last four years.

One advantage InGaAs cameras have over their competitors for thermal imaging is their compatibility with glass optics, which circumvents the need for germanium or sapphire windows. This means they can be used

in factories in already-qualified standard protective enclosures, to image through plain glass windows that were built for visible cameras which was the previous state-of-the-art technology. In glass manufacturing, the camera measures the glass temperature during cooling and checks for defects on the inside of glass bottles. This application doesn't work with a traditional thermal imager because glass is opaque at longer wavelengths, so internal defects can't be seen. The InGaAs imagers do not require cooling, so running costs are lower than those of many other imagers that require either liquid nitrogen or multi-stage thermo-electric coolers. Some of the cheaper thermal imagers that operate without cooling struggle to operate at high frame rates, making them unsuitable for machine-vision applications.

InGaAs cameras are already suitable for a wide variety of applications. And as their cost continues to drop, they are in a strong position to penetrate these markets further still. ●

Martin Ettenberg is director of imaging products at Sensors Unlimited.

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Foundry model could be key to InP industry future

New executive director of the Optoelectronics Industry Development Association Michael Lebby is sounding a wake-up call to optoelectronic chip manufacturers. **Michael Hatcher** talks to him about a foundry-based industry model for InP optoelectronics and the roadmap to profitability.

Michael Lebby says that the InP industry is at a crossroads. The co-founder of Ignis Optics is currently putting together a roadmap highlighting several key recommendations to improve conditions in a sector that is shackled by the heavy overheads of running internal InP fabs with excess capacity.

His central message is this: optoelectronics companies need to drive a common foundry business model, just like the silicon industry did 20 years ago. But how similar are the silicon and InP industries, and just how exactly would such a foundry model be set up?

Michael Hatcher: What's the idea behind the InP industry roadmap?

Michael Lebby: I'm adding a lot of urgency and vibrancy to an organization [OIDA] that has huge potential. The OIDA represents the optoelectronics industry, and I'm beginning to tackle what I think are some of the industry's biggest issues. One of them is the InP foundry situation, and I'm trying to address a real interest in this hotly-debated issue.

MH: How strong are the parallels between silicon and InP?

ML: They're really strong. The silicon guys have been through their woes with foundries and the message is that we're just like they were 20 years ago. One of the reasons why silicon went to a foundry model was that they were going through a down cycle and there was overcapacity – a lot of fabs were empty and they had huge overheads. So they were driven to look at creative and innovative solutions to the problem.

I think we're in a similar situation with InP. We now have this overcapacity and it's going to drive us to think creatively and innovatively. The situation is a little bit worse [for InP], in that the different silicon CMOS



It's a vision thing: Michael Lebby will be working with the InP industry to accelerate the development of a foundry-based chip manufacturing model.

"We have a lot of influence with government agencies, and I'm connected with the venture-capital community."

**MICHAEL LEBBY, OIDA
EXECUTIVE DIRECTOR**

processes were fairly similar, whereas we still have a uniqueness problem in our device and material design. I think it will be more difficult [to agree on common processes], but there are some parallels that we can learn from.

MH: What is your key message?

ML: The roadmap sounds a wake-up call for the industry. We need to act soon to address these issues and accelerate the development of an InP foundry model. The OIDA will be work-

What is the OIDA?

The Optoelectronics Industry Development Association (OIDA) is a North American industry body with 50 members, including Bookham, JDSU and CyOptics. National laboratories and universities can also join.

The OIDA's mission is to promote optoelectronics worldwide and advance the competitiveness of its members. It serves as an industry voice to government and academia, liaises with other industry associations worldwide and provides a network for the exchange of ideas and information within the sector. It also facilitates the sharing of resources and the formation of joint ventures and partnerships.

Headquartered in Washington, DC, the OIDA conducts workshops to assess international market trends and technology roadmaps, develops worldwide trade statistics, and identifies issues. It develops a shared industry-government consensus on the problems in optoelectronics, and works to solve these issues.

The current emphasis is on strengthening the infrastructure and metrology for high-volume, low-cost manufacturing and facilitating R&D in critical areas of the technology. See oida.org for further details.

ing with its members and the community as a whole to make strides in developing a common foundry for the marketplace and identifying viable solutions to simplify the situation.

MH: What's holding the InP industry back at the moment?

ML: There's definitely a reluctance from the [InP chip] suppliers to consolidate. Also, they have to be vertically integrated to have a rea-

INTERVIEW

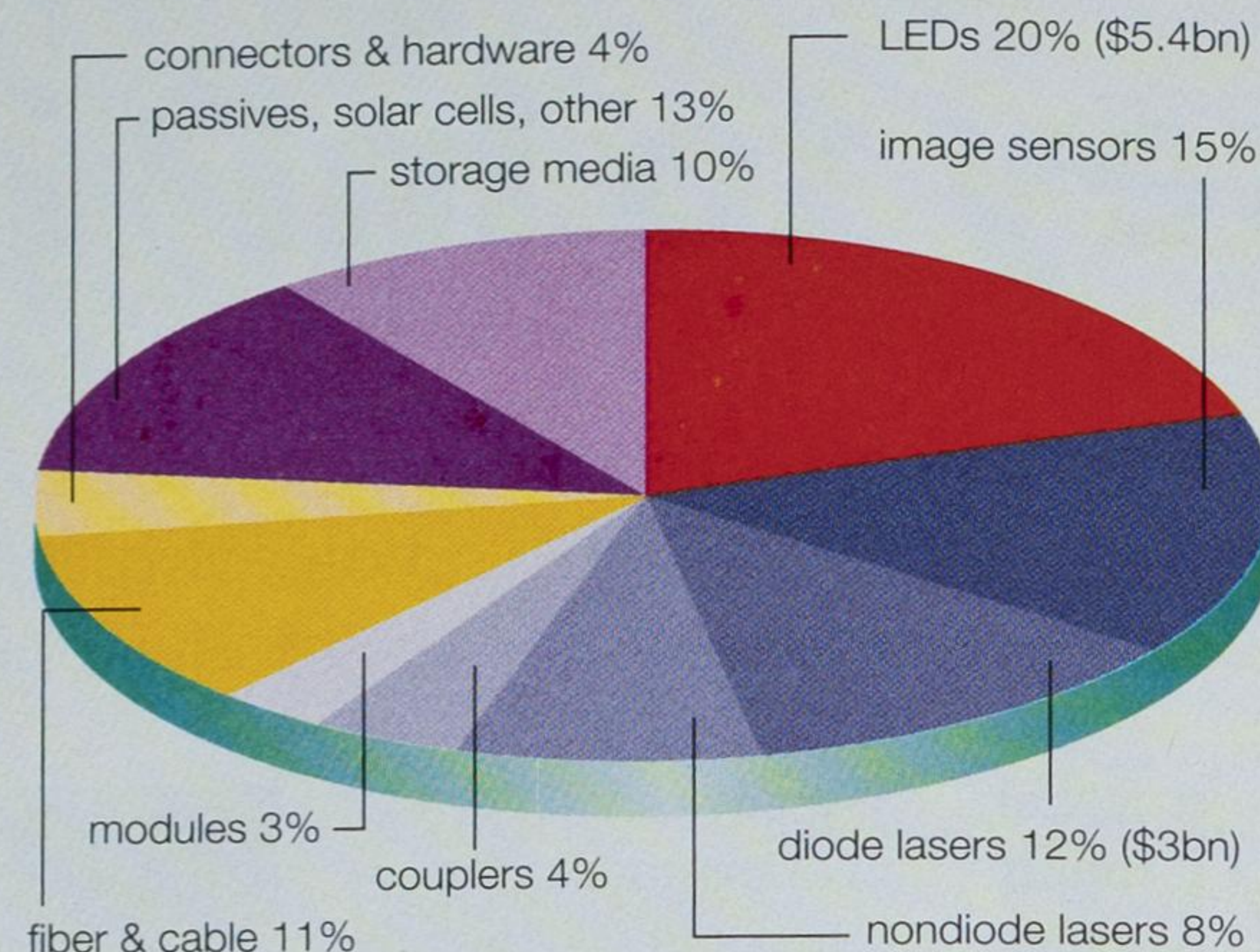
Optoelectronic components market and InP manufacturing status

Despite the slump in demand for III-V-based fiber-optic components since 2000, telecommunications still represents a growth industry. Lebbby says that the global market for telecommunications grew by 9% from 2003 to reach \$22 billion last year. According to figures compiled by the OIDA, diode lasers represented 12% of the \$27 billion global optoelectronic components business (excluding flat-panel displays) in 2004 – equivalent to around \$3 billion (see chart, right).

As shown in the table p19, almost all of the major InP chip producers have more than enough epitaxy and device processing capacity available currently, and all are struggling against massive overheads driven by the cost of running an underutilized semiconductor fab.

InP device foundries do exist, such as Global Communication Semiconductors based in Torrance, California, and Fremont-based Avanex launched an optoelectronic

Total value of optoelectronics market in 2004 = \$27bn excluding FPD



SOURCE: OIDA

foundry service in March.

One company that could one day act as a common foundry is CyOptics, the Israeli firm that acquired TriQuint's optoelectronics business earlier this year. With a 30,000 ft² cleanroom, CyOptics runs 120 wafer starts per week, and has options to expand this capacity with existing equipment and available space. Lebbby says that thanks largely to its heritage of Bell Laboratories, Lucent and TriQuint development, CyOptics has world-class crystal growth and materials

characterization expertise, and is a leader in many key fiber-optic component technologies.

Switching to a foundry model is not without risks, however. Transferring and requalifying processes would take time and money that many manufacturers are lacking. Lebbby's view is that the industry is not ready for such a switch today. But what he describes as the "slow trek" to an InP foundry solution should be aided by the OIDA, which will try to convince fab owners to standardize and consolidate.

sonable business model. They really want to be horizontally integrated (i.e. supply a wider range of products) but they can't afford to, and there doesn't seem to be any route to do that. The big question is how to get the traditional vertical integration models to work on a horizontal basis. That's what is driving the roadmap.

The next thing to address is how to simplify the complexities of the materials, devices, packaging, intellectual property (IP) and manufacturing processes. This is a huge issue. Some lasers have got two re-growth steps, others have got three. The IP is just incredibly detailed and there are probably 500 different patents on DFB lasers alone.

We also have an inflexible customer base. The big communications system companies

have got too many vendors to choose from. It doesn't matter if there's a standard or a multi-source agreement (MSA), they just choose the ones that they think have got the best price and the best performance. And if you don't meet it, then tough. Those inflexible customers are costing the livelihood of a lot of the vendors. The vendors have got no margins so they're driven down on price and way too hard on specifications. When you get driven on specifications you need unique devices, and you can't really work together.

MH: Will the industry support such a radical switch?

ML: From the engineering level they all understand it. At the CEO level they understand it too, but the thing that's holding it back

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Fab capacity at selected InP chip manufacturers

Company	Epitaxy	Devices	Packaged modules	Fab location	Test & assembly
JDS Uniphase	✓	✓	✓	US	US, China, Thailand
Avanex	✓	✓	✓	France	US, China
Bookham	✓	✓	✓	UK	UK, China
CyOptics	✓	✓	✓	US, Israel	US, Mexico
Finisar	✓	✓	✓	US	Thailand
Eudyna	✓	✓	✓	Japan	Japan, Taiwan
Agilent	✓	✓	✓	US, Singapore	Singapore, China
Mitsubishi	✗	✗	✗	Japan	Japan

✓ = available capacity; ✗ = limited capacity.

SOURCE: MICHAEL LEBBY

is that if you go out of the vertical integration mode then you jeopardize your business. And you can't do that when you're not profitable. And so the horrible dilemma [for chip/module vendors] is that until some of these companies become profitable and break even from a business standpoint, they're going to have to move slowly towards the horizontal business model.

Only the brave companies are going to move in that direction right now, and I don't see many of them doing that. The question [for chip vendors] is how long can you work with high overheads and inefficiency until you get to the point where you're forced to say "I've got to find a different solution"?

MH: How could an InP foundry model be established and how long would it take?

ML: For a foundry to be successful, the [chip] suppliers have got to run the show, because they're the guys that need to simplify things. What I see is baby steps over the next two years. I don't see a real, proper commitment until around 2009. Then the technology has to be transferred to the foundry. That will take 18–24 months. It took Bookham probably about 18 months to transfer its fab from Canada to the UK – and they did a good job. So you're not going to see a real silicon foundry-like operation for InP until 2010 or 2011.

But if a good plan was put together, the capital markets in New York would fund it. And there will also be some help from the financial markets in terms of consolidation.

MH: What happens next?

ML: Until 2007, not going much at all. By 2009, there will be fewer, stronger, InP vendors – call it an oligopoly if you like. Those that figure out how to be profitable will have fab overheads to match the business they're running.

In 2009 the customer base will also be more flexible because there will be fewer suppliers to choose from. If there are fewer suppliers then customers have to go with the market price, and have to accept MSA specifications. That will reduce the complexity of devices and the difficulties of establishing a foundry.

MH: Who will be left standing?

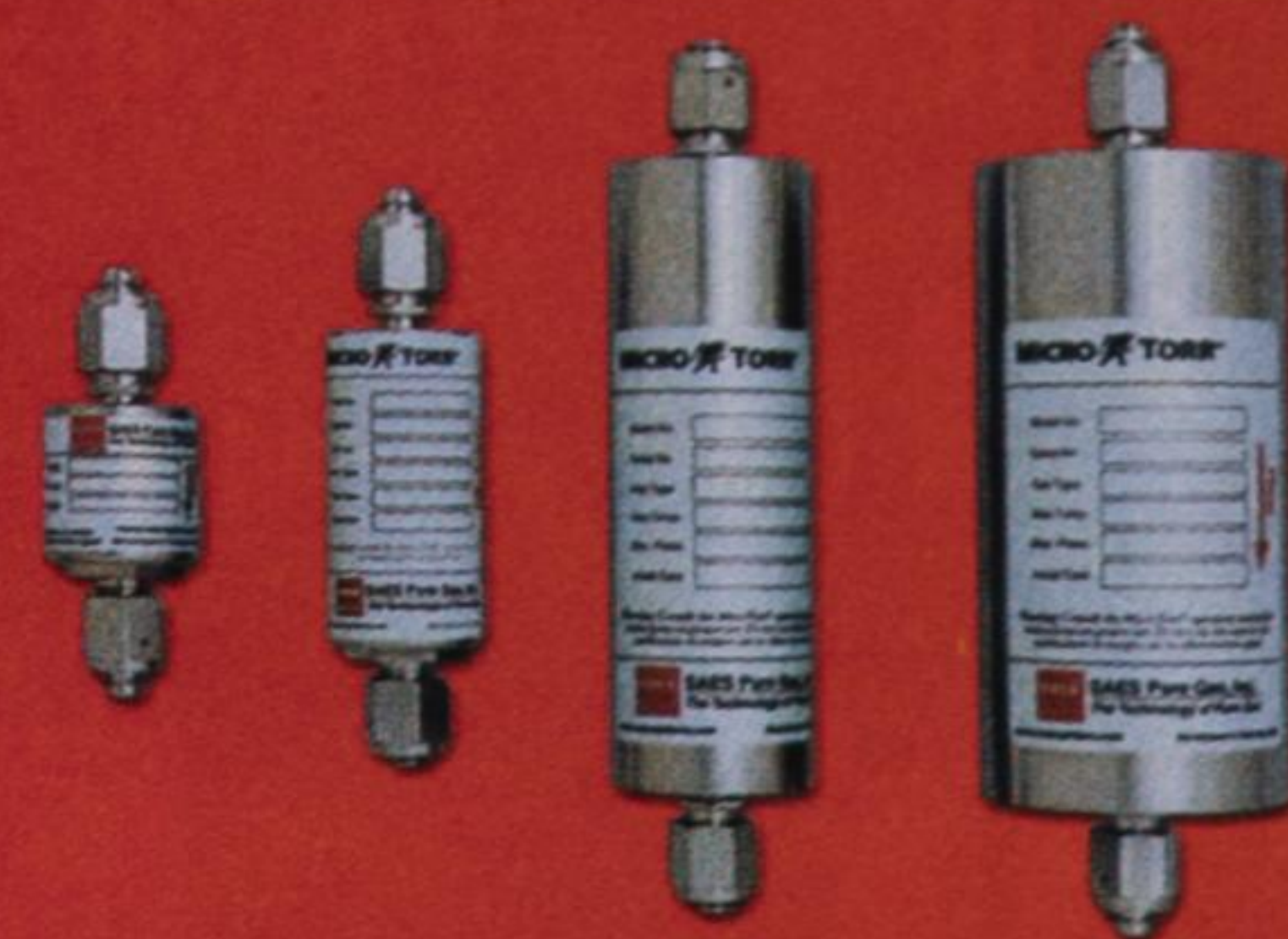
ML: I guess the guys that have got lots of money. That means Agilent and JDS Uniphase [Ed note: the future of Agilent's semiconductor business is uncertain and JDSU has recently bought the test and measurement company Acterna, which could signal a change in priorities]. The guys that don't have any money have got some really smart technology, and good differentiation, but they're stuck in this vertical business model just to keep the business going. Opnext and Mitsubishi are well positioned, because they have other technology running through their fabs, which reduces the cost of telecom component manufacture.

MH: How can the OIDA help?

ML: What you're seeing now is a message to the community saying that we're committed to go help you figure this out. Now, we'll play whatever role you want us to play. We have a lot of influence with government agencies who have a lot of money to spend, and I'm pretty well connected with the venture-capital community. So if there's a good solution, OIDA can help finance it and help companies go and do it. Our roadmap is going to be composed by industry experts who have a really good understanding of the technology and business issues.

Michael Lebby will be presenting an invited talk on this subject at the CS-MAX conference later this year. See compoundsemiconductor.net/csmax for details.

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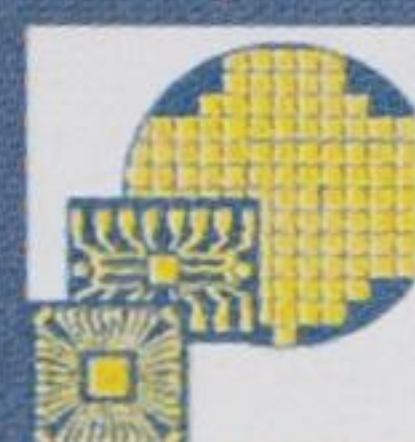
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INP MICROELECTRONICS

NGST transforms InP transistor manufacture

With its cost-efficient InP HEMT and HBT processes on 100 mm substrates, Northrop Grumman Space Technology (NGST) is well positioned to produce power devices for next-generation cellphones. That was the message from Richard Lai, NGST's manager of microelectronics products, to delegates at the recent Indium Phosphide and Related Materials conference held in Glasgow, UK.

NGST has been developing its InP technology for space, military and commercial applications for more than 15 years, and in the last two years has steadily transferred its production from 75 to 100 mm substrates. InP transistors are now produced on the same lines that are used for the production of its GaAs HEMT and HBTs.

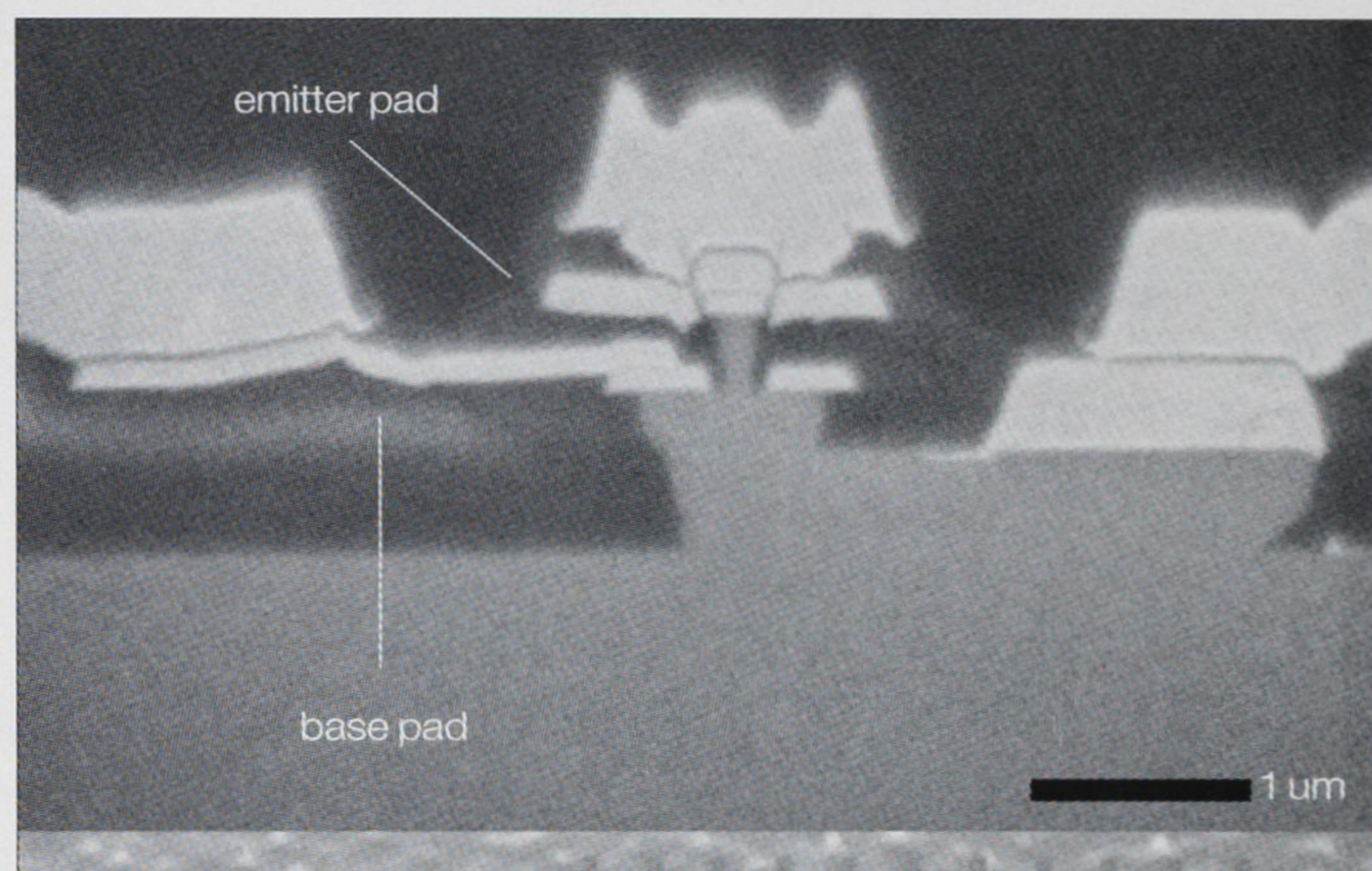
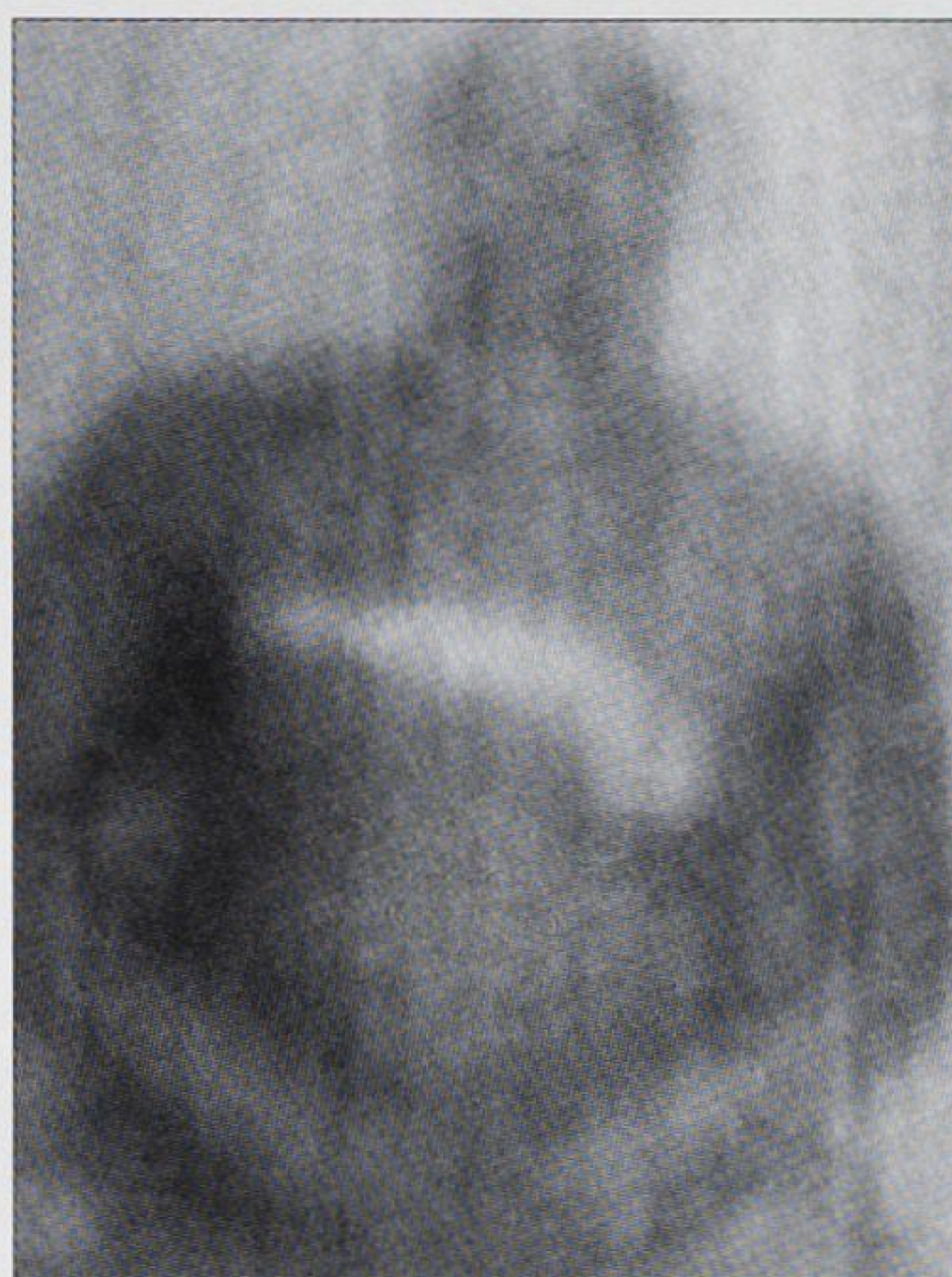
The company's InP HBTs have been used to build efficient, linear power amplifiers targeting the cellphone market, and its HEMTs have been incorporated into W-band low-noise amplifiers (LNAs) for improving the performance of passive millimeter-wave (PMMW) imagers that will be used to detect hidden weapons, for instance, at airport security.

NGST's Richard Lai says that InP devices offer several advantages over those made from materials such as GaAs, SiGe and silicon. These include superior gain, low noise (see figure 1), low power consumption and high efficiency, as well as the superior thermal conductivity that arises from the InP substrate.

Although InP transistor production is less mature than that of GaAs, the microelectronics product manager says that for RF devices, NGST's InP yield exceeds that of its GaAs transistors. This results from wider margins on RF performance set for InP devices. Because NGST makes the GaAs and InP transistors on the same 100 mm line, the devices have similar fabrication costs, and the only real drawback of InP is the relatively high substrate price.

InP HEMTs and HBTs are grown by solid-source MBE on a multi-wafer platform accommodating up to seven 100 mm substrates. The subsequent device fabrication shares many of the passive component and backside processes used for GaAs HEMT and HBT production, improving reproducibility and cutting costs.

NGST's HEMT and HBT processes use the



Top left: Detecting weapons hidden underneath clothing will help in the fight against terrorism. Higher-resolution cameras are needed, but the larger focal arrays required for this will increase the imager's cost, weight and power consumption. NGST says that detector size and weight could be reduced by imaging at higher frequencies using low-noise amplifiers based on the company's 150–215 GHz InP HEMTs. Top right: NGST is developing transistors that can operate at frequencies of over 300 GHz by scaling emitter sizes down to 0.14 μm . Above: PMMW cameras, which have greater sensitivity thanks to the use of InP-based low-noise amplifiers, can image airport runways in foggy conditions.

same steps for nitride deposition, thin-film resistor formation, interconnect metal deposition, and backside processing. The only major differences are in the etch chemistries used (and related resist processes), the metals deposited, and the anneal conditions.

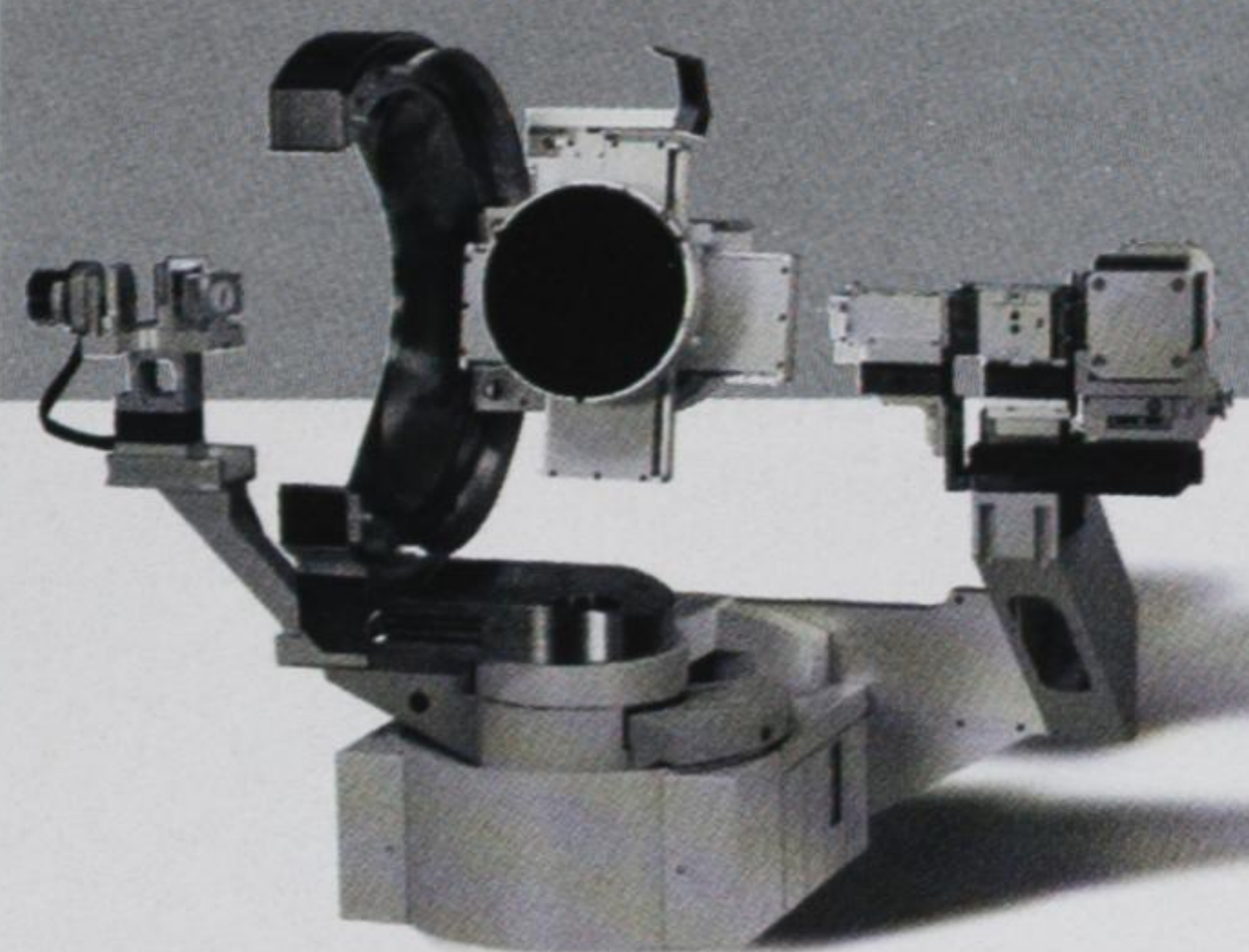
Lai believes that a good via etch process holds the key to the manufacturing of both InP HEMTs and HBTs. NGST's approach is to bond 100 mm InP substrates to 109 mm sap-

phire wafers, before mechanically grinding the InP substrate down to a thickness of either 50 or 75 μm . The through-substrate vias are then formed by reactive ion etching with a Unaxis system that can handle three wafers simultaneously. This process, which takes 90 min, produces etch uniformities below 3% across a three-wafer batch and a 100% via yield.

According to Lai, NGST's InP HBTs operate at double the frequency of their GaAs coun-

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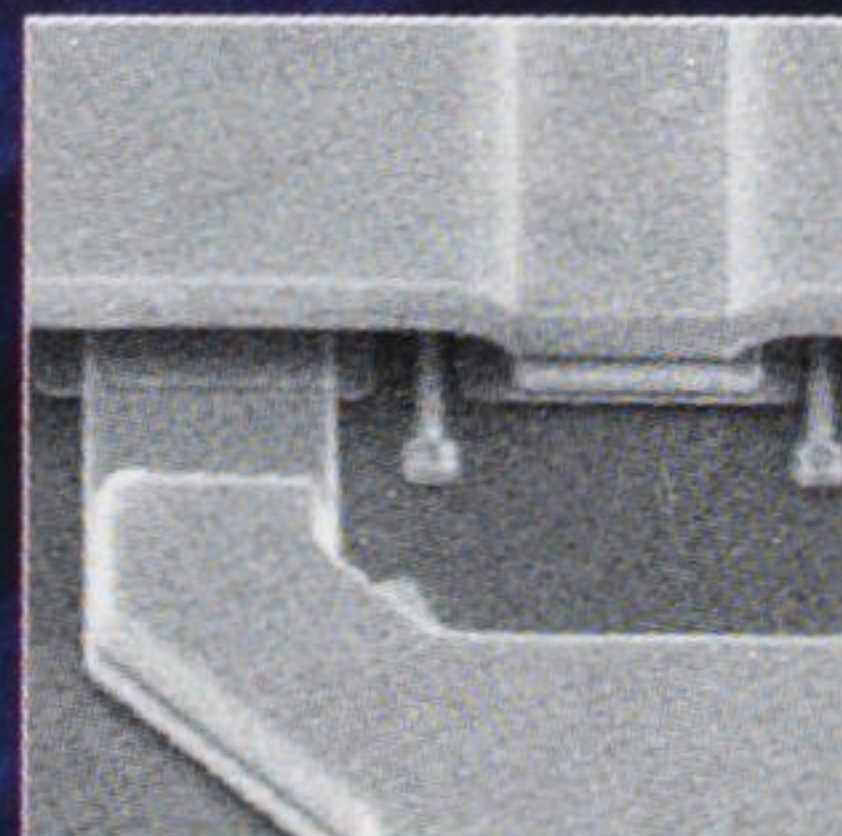
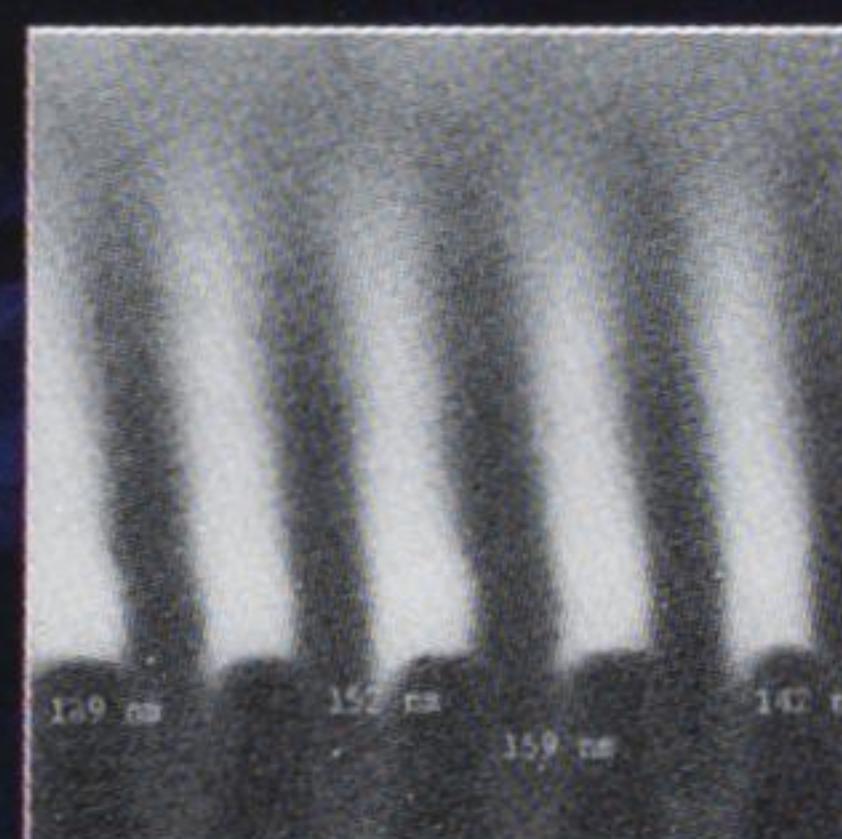
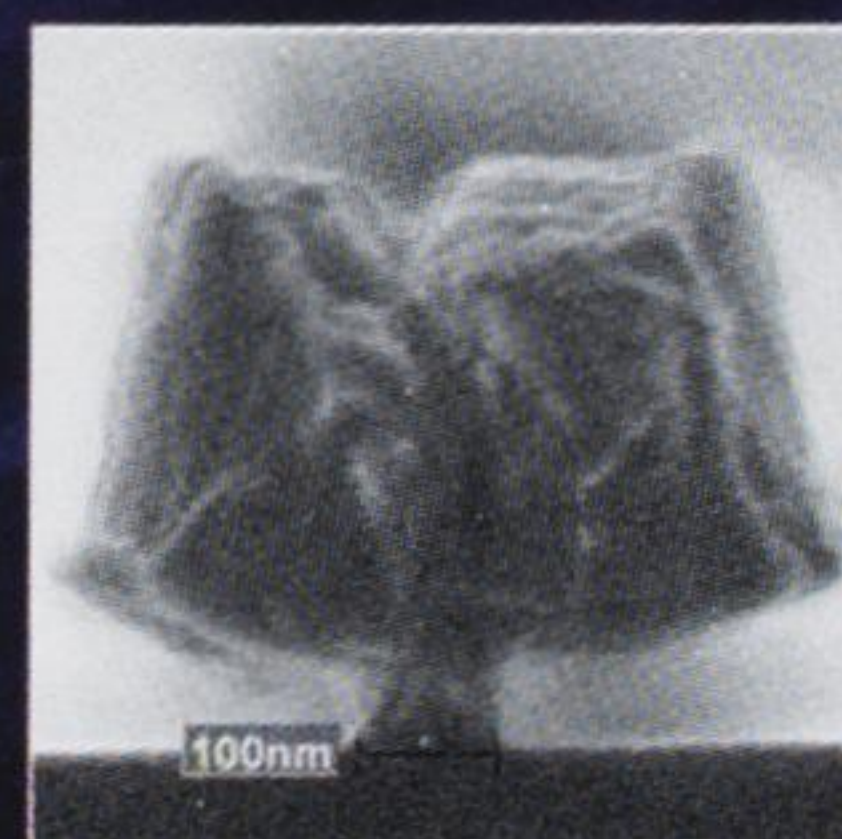
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terparts when using only 50% of the bias voltage. The InP device's higher-frequency performance results from its smaller, 0.8 μm -wide emitter. The company is also currently developing transistors with emitter widths of less than 0.15 μm that can operate at over 300 GHz.

NGST's InP HBT production line has an 85–90% device yield. Standard characterization tools such as bulk resistivity and X-ray diffraction measurements determine epiwafer quality, and ensure a repeatable growth process. In addition, thinner structures are grown twice a week to confirm layer thickness, doping and junction quality.

NGST produces two different HBT designs. One variant, targeting digital applications, uses a thin base and collector to deliver high-speed performance at a moderate breakdown voltage, and has values of 150 GHz for both f_t and f_{max} . The second HBT design is suitable for microwave power applications, and its thicker base and collector layers deliver a larger breakdown voltage and improved linearity. However, this device's high-frequency characteristics are inferior, with f_t and f_{max} values of only 80 GHz and 130 GHz respectively.

Cheap, efficient amplifiers

Lai believes that NGST's InP HEMTs could be used to produce cheap, highly linear and highly efficient amplifiers for the cellphone market. The company has built a "power cell" to operate at 2.4 GHz that uses $1.5 \times 30 \mu\text{m}$ transistors. This module has a power-added-efficiency (PAE) of 63.4%, and 20.8 dB gain at a current density of 31.9 kA/cm^2 . The technology has also been deployed in a single-stage MMIC with output power of 500 mW and a PAE of 50% at 1.95 GHz.

HEMT production on 100 mm substrates, which also boasts an 85–90% line yield, is an extension of NGST's space-qualified 75 mm process. Growth time for these structures is typically just 30 min, which is 4–6 times faster than that for GaAs HEMTs requiring the insertion of a metamorphic buffer layer. The higher wafer throughput and the lower labor-cost per wafer are claimed to offset InP's higher substrate costs.

Lai predicts that InP HEMT manufacturing costs will fall below those associated with their GaAs counterparts, so long as both transistor types are fabricated on the same-sized substrates, and that the cost of InP substrates falls as projected. He also points out that the company's MBE equipment and process line can accommodate 150 mm InP wafers with minimal tooling adjustments, although suffi-

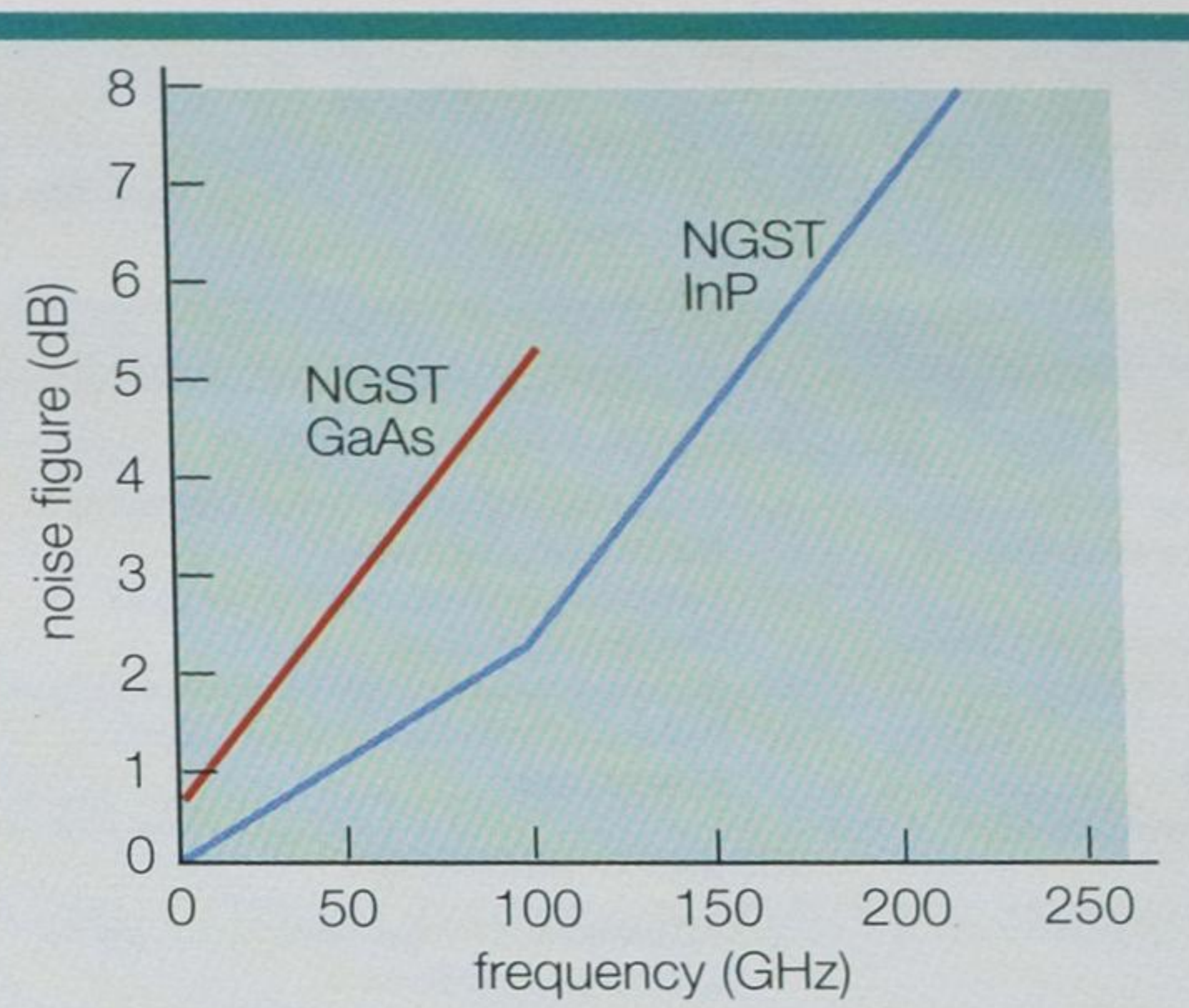


Fig. 1. InP-based low noise amplifiers suffer from less noise than their GaAs counterparts, enabling them to improve the sensitivity of millimeter-wave cameras.

cient quantities of high-quality 150 mm InP substrates have yet to become available.

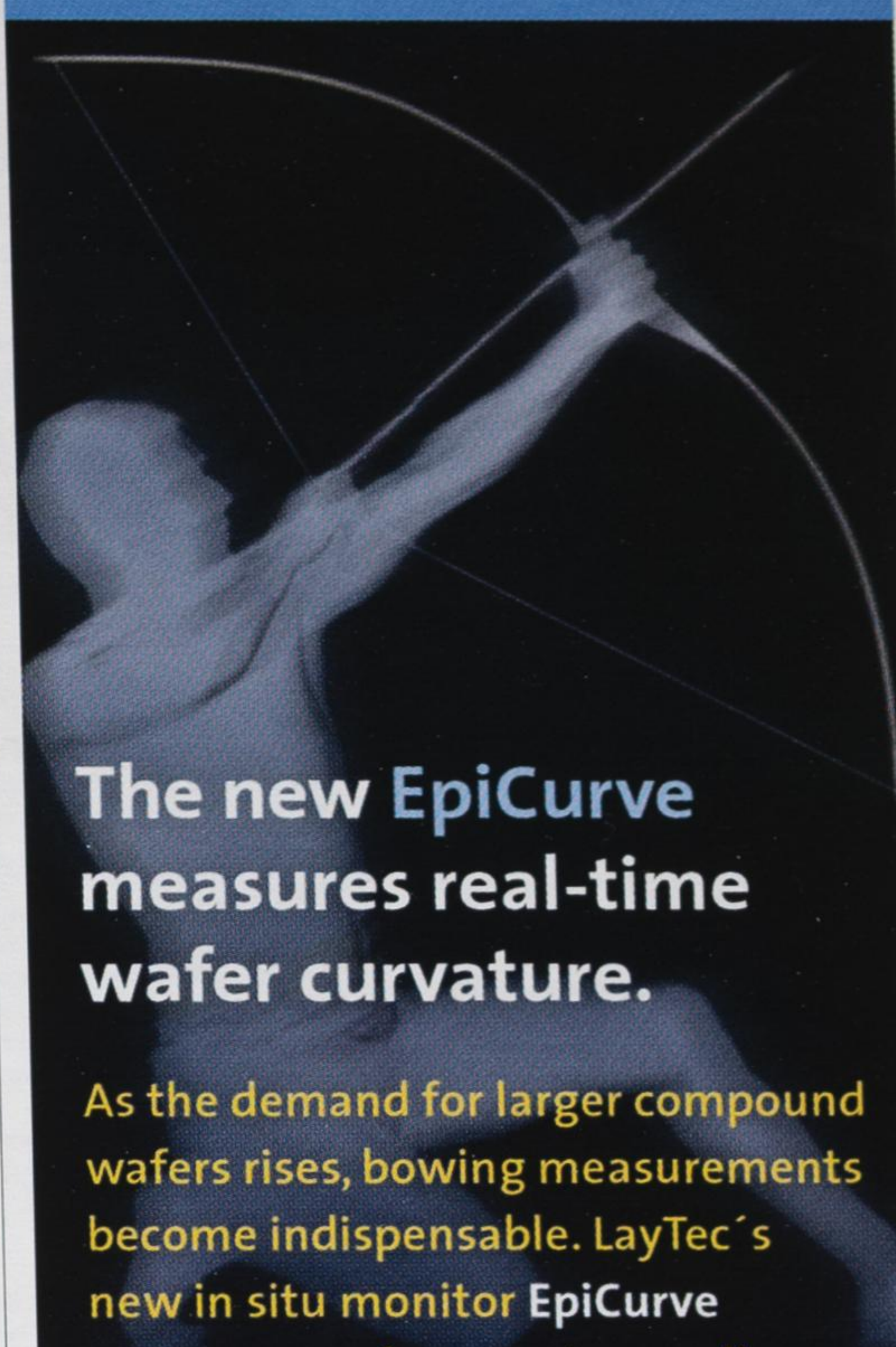
NGST produces InP HEMTs with an $\text{In}_{0.6}\text{Ga}_{0.4}\text{As}$ channel and relatively good noise characteristics, and higher-power, higher-efficiency versions with an $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ channel. Both can be produced with 0.15, 0.1 or 0.07 μm gate lengths, depending on the required frequency performance.

These InP HEMTs can be used in LNAs for millimeter-wave imagers operating in the W-band (75–110 GHz). According to Lai, InP HEMTs can increase camera sensitivity by three to five times, decrease power consumption by the same amount, and deliver a two- to three-fold size reduction. The LNAs produced by NGST have already been installed in millimeter-wave receivers in telescopes operating throughout the world.

Lai adds that because of the threat of terrorism, there is now a demand for millimeter-wave imagers with larger focal arrays that can provide sufficient detail for easy detection of concealed weapons. This will lead to increased efforts to reduce the imager's cost, size, weight and power consumption. He believes that these detectors will benefit from the high performance and reasonable price of LNAs based on InP HEMTs. Detector size and weight could also be reduced by increasing the HEMT operating frequency to 140 or 220 GHz, says Lai.

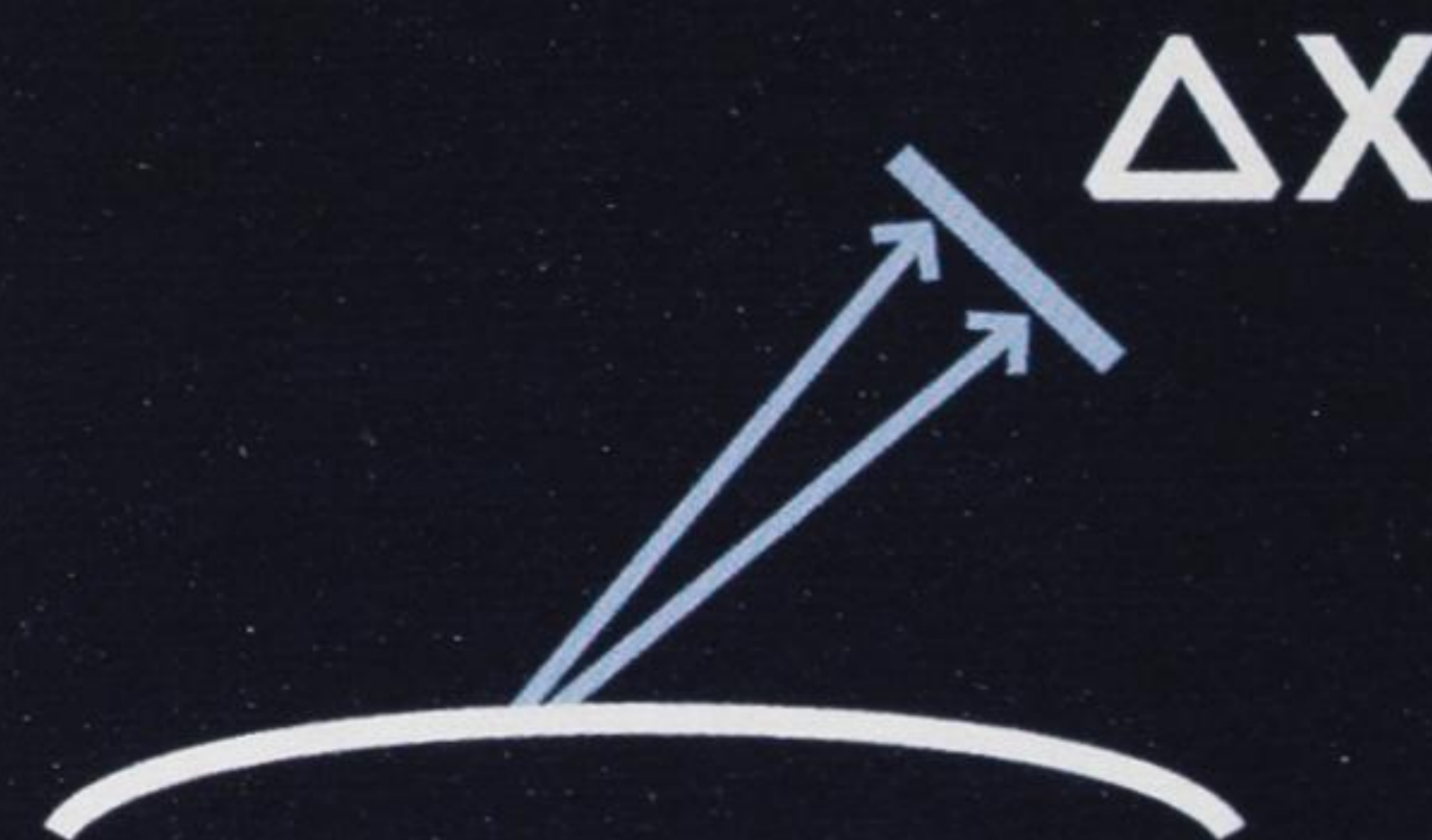
For many years InP devices have promised low noise with excellent performance at higher frequencies, but they have always been associated with higher costs. NGST's new 100 mm process suggests that InP device manufacture can approach that of GaAs, and that InP transistors will soon become affordable components used in next-generation cellphones and millimeter-wave cameras. ●

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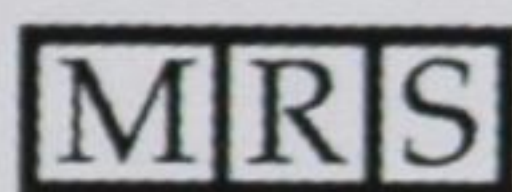
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BIO-ORGANIC/INORGANIC COMPOSITES

- I: Interfaces in Organic and Molecular Electronics II
- J: Biomimetic Polymers and Gels
- K: Engineering Biointerfaces via Cell-Interactive Materials
- L: Mechanical Behavior of Biological and Biomimetic Materials
- M: Flexible and Printed Electronics, Photonics, and Biomaterials

NANO- TO MICROSTRUCTURED MATERIALS

- N: Dynamics in Small Confining Systems VIII
- O: Nanoparticles and Nanostructures in Sensors and Catalysis
- P: Quantum Confined Semiconductor Nanostructures—Fabrication, Physical Properties, and Applications
- Q: Degradation Processes in Nanostructured Materials
- R: Assembly at the Nanoscale—Toward Functional Nanostructured Materials
- S: Nanomaterials and the Environment

SMART MATERIALS AND DEVICES

- T: Ferroelectric Thin Films XIV
- U: Multiferroic Materials
- V: Materials and Devices for Smart Systems
- W: Electroresponsive Polymers and Their Applications

MECHANICAL BEHAVIOR

- Y: Surface Interactions and Surface Engineering for Manufacturing Applications
- Z: Amorphous and Nanocrystalline Metals for Structural Applications
- AA: Micro- and Nanomechanics of Structural Materials
- BB: Mechanisms of Mechanical Deformation in Brittle Materials

ELECTRONICS AND PHOTONICS

- CC: Photophysical Properties of Monolayers on Nanomaterials and Surfaces
- DD: Materials for Transparent Electronics
- EE: Progress in Semiconductor Materials V—Novel Materials and Electronic and Optoelectronic Applications
- FF: GaN, AlN, InN, and Related Materials
- GG: Plasmonics—Nanoscale Optics and Photonics Based on Metals
- HH: Magnetic Sensors and Sensing Systems
- II: Fabrication and Characterization Methods for Novel Magnetic Nanostructures

GENERAL INTEREST

- X: Frontiers of Materials Research
- JJ: Actinides—Basic Science, Applications, and Technology
- KK: Solid-Solid Interfaces from Observation to Modeling
- LL: Combinatorial Methods and Informatics in Materials Science
- MM: *In-Situ* Electron Microscopy of Materials
- NN: Scanning Probe Microscopy in Materials Research
- OO: Growth, Modification, and Analysis by Ion Beams at the Nanoscale

SPECIAL FORUMS

- PP: Forum on Materials Science Education
- QQ: IP, TT, VC, IPO, and U

MEETING ACTIVITIES

SYMPOSIUM TUTORIAL PROGRAM

Available only to meeting registrants, the symposium tutorials will concentrate on new, rapidly breaking areas of research.

EXHIBIT AND RESEARCH TOOLS SEMINARS

A major exhibit encompassing the full spectrum of equipment, instrumentation, products, software, publications, and services is scheduled for November 29–December 1 in the Hynes Convention Center, convenient to the technical session rooms. Research Tools Seminars, an educational seminar series that focuses on the scientific basis and practical application of commercially available, state-of-the-art tools, will be held again this fall.

PUBLICATIONS DESK

A full display of over 860 books, plus videotapes and electronic databases, will be available at the MRS Publications Desk.

SYMPOSIUM ASSISTANT OPPORTUNITIES

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Cost of ownership dictates new MOCVD reactor design

Throughput, yield and the deposition of expensive metal-organic precursors dominate the cost of ownership of MOCVD reactors, according to research at Aixtron. **Rainer Beccard** explains how these three factors have driven the design of the company's latest planetary reactor.

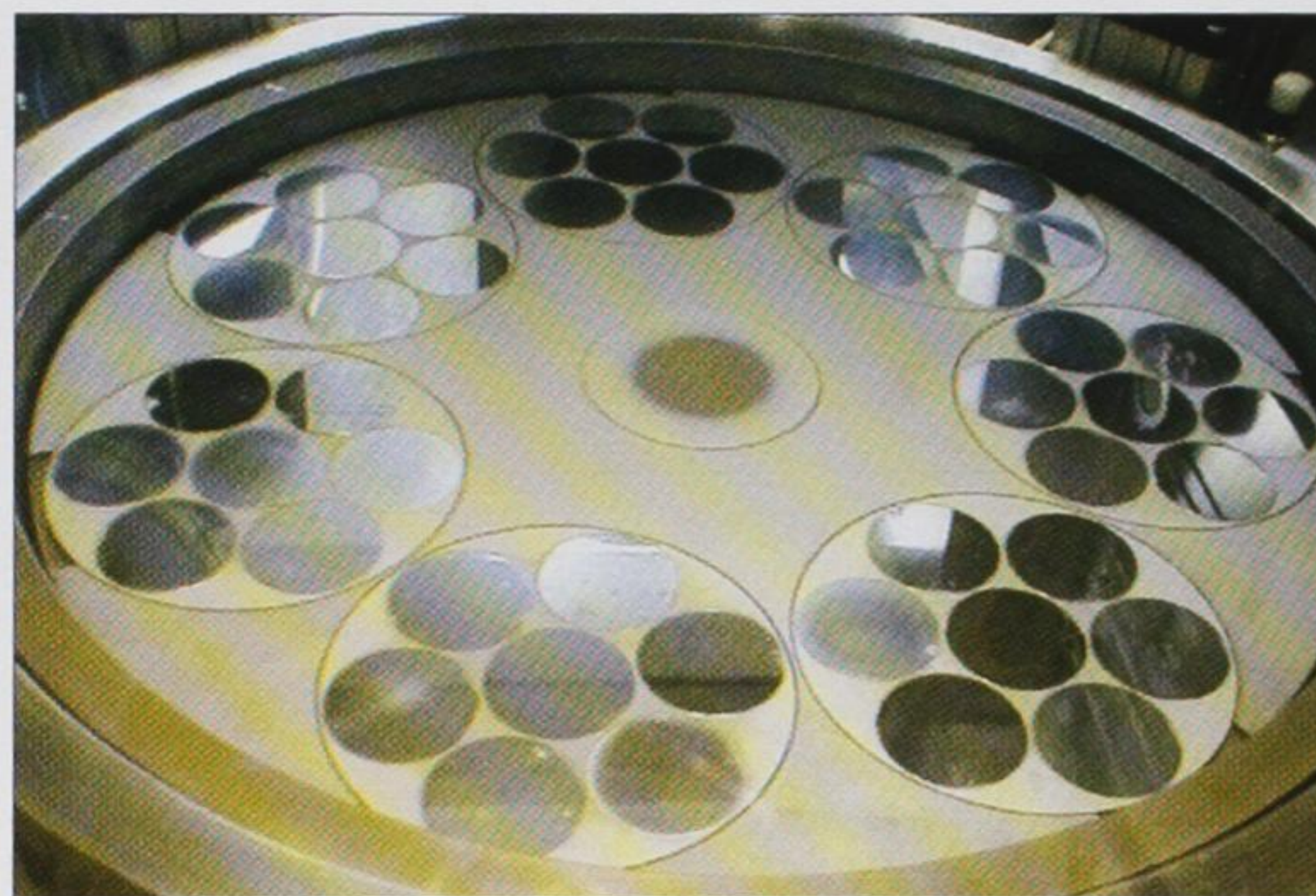
During the last 20 years the MOCVD process has matured from a technique used in research laboratories to a common method for manufacturing high volumes of compound semiconductor devices.

The driving force for new developments has also moved on from its original form, which was to demonstrate the suitability of an MOCVD process for a specific device. Today manufacturers employing MOCVD technology are concerned with high-volume manufacturing, and use multiwafer platforms such as Aixtron's planetary reactors to carry out simultaneous epitaxial growth on several substrates. This technique produces large quantities of epiwafers with good uniformity and has enabled the expansion of the LED manufacturing industry.

The industry is now entering a third stage of development that reflects the maturity of both MOCVD and LED technology. The focus is directed at reducing manufacturing costs, so that LED makers can achieve profitable margins despite the year-on-year falls in the average selling price of their devices. Since the MOCVD process is one of the key manufacturing steps, cutting costs here can reduce the cost of ownership (CoO) of an MOCVD reactor.

Aixtron has redeveloped its planetary reactor mass-production platforms to reduce the CoO of these systems. This approach has been applied to reactors for both GaInN-based blue, green and white LEDs, and AlGaInP-based red and yellow LEDs. There is much interest in red LEDs owing to their expected application in red, green and blue (RGB) backlighting systems for large LCD screens.

The design process began with an investigation of the CoO of existing reactors, using standards defined by the Semiconductor Equipment and Materials International organization. Calculations revealed that the key parameters were throughput, yield and the deposition efficiency of costly metal-organic precursors.



Aixtron's fully loaded 49 × 2 inch planetary reactor can produce epiwafers with uniformity suitable for LED manufacturing.

After defining a CoO target value, a detailed theoretical study of reactor and MOCVD system configurations was undertaken, including comprehensive numerical modeling of the reactor geometry. These efforts led to a reactor design that delivered CoO improvements verified by actual growth runs.

Increasing wafer coverage

Throughput is defined by the reactor's load capacity, the wafer size, and the time taken for a complete growth cycle.

Today most LED manufacturers work with 2 inch substrates, despite the promises of higher yield, reduced edge effects and greater wafer area offered by 4 inch material. Consequently, the reactor had to be designed for both 2 inch and 4 inch processes. The reactor geometry also had to optimize the growth area, which resulted in a design suitable for either a 12 × 4 inch or 49 × 2 inch configuration, and with a total wafer area of 150 inch². This represented an increase of 50% and 40% on the standard platforms of 8 × 4 inch and 35 × 2 inch, respectively.

To optimize throughput it is also necessary to minimize growth cycle times, which are a combination of the time taken for material growth, the loading and unloading of wafers, and the heating and cooling of the reactor. This

was partly accomplished by introducing a novel automated handling system to load and unload at high temperatures, which eliminated the time lost while the reactor cooled down. Although automatic loading has already been used for GaAs/AlGaAs-based HEMT and HBT processes, a refined version has been developed that is suitable for the much thicker AlGaAs/AlGaInP/GaP LED structures.

Another approach to reducing growth cycle times was to develop a reactor that could produce the same material quality more quickly. Previously, growth rates were limited by parasitic reactions that occurred before the gases reached the wafer surface, an effect that is more likely at higher precursor concentrations.

The second criterion that strongly impacts the CoO is yield, which can be considered either in terms of epiwafers or LED chips, although the latter are more appropriate as they are related to the final product. The MOCVD process influences the uniformity of LED properties on each wafer and from wafer to wafer. Efforts were directed to optimize the uniformity of film thickness, layer composition and doping for both 2 inch and 4 inch processes.

The third factor controlling CoO is the growth efficiency of the relatively expensive metal-organic precursors that are used for the epitaxial process. Efficiency was defined as the ratio of group III atoms incorporated into the grown layers to the number of group III atoms entering the reactor through the metal-organic sources.

Optimizing the reactor's growth efficiency for novel geometries is a time-consuming process that has to take into account details relating to both reactor hardware and process parameters. High efficiencies are frequently achieved by adjusting the parameters that also affect film thickness uniformity, so the solution must balance optimizing the efficiency while ensuring high levels of uniformity for all relevant materials within the LED structure. →

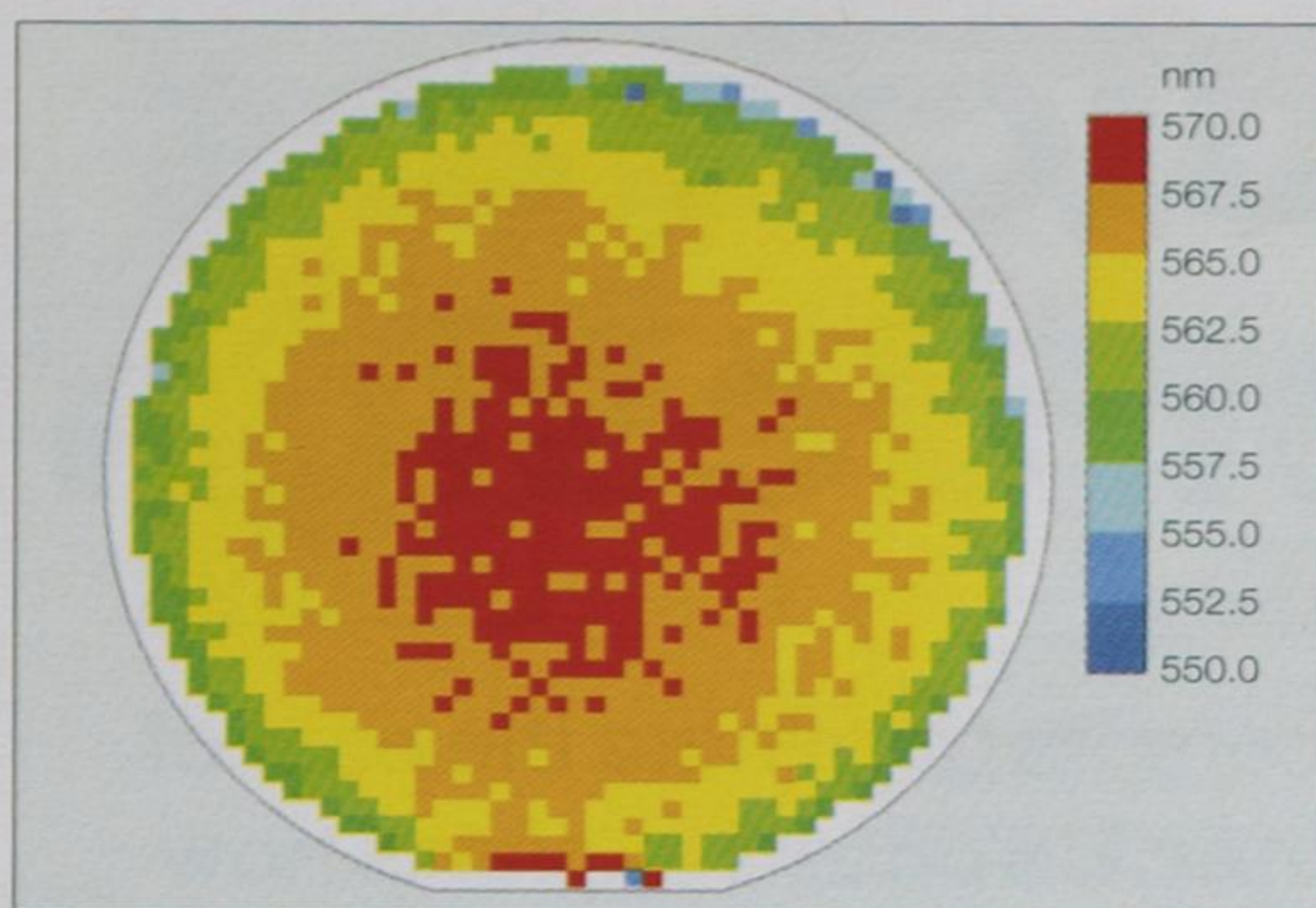


Fig. 1. The reflectivity from an AlGaAs/GaAs distributed Bragg reflector deposited on a 4 inch wafer reveals thickness uniformity values required for LED production.

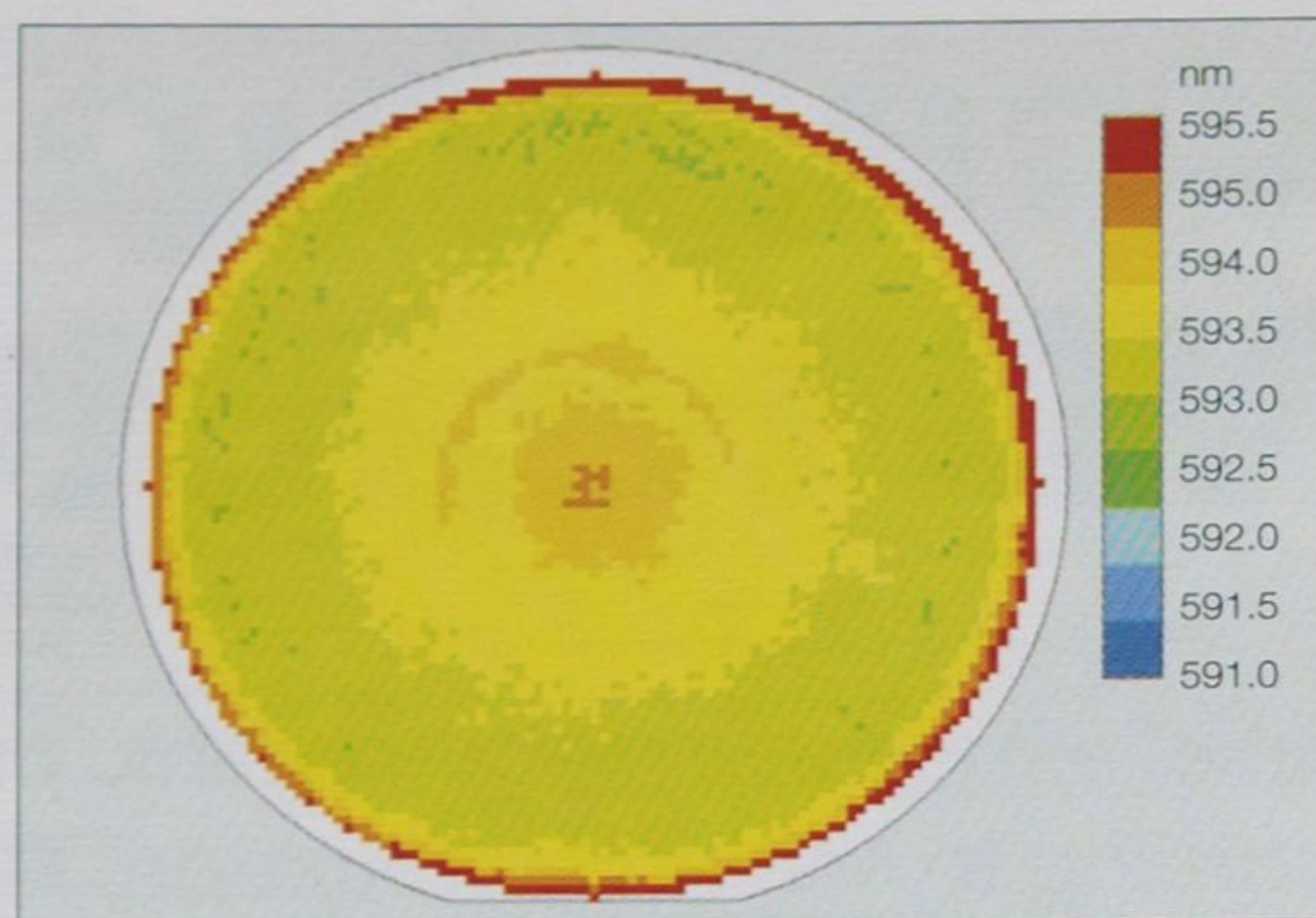
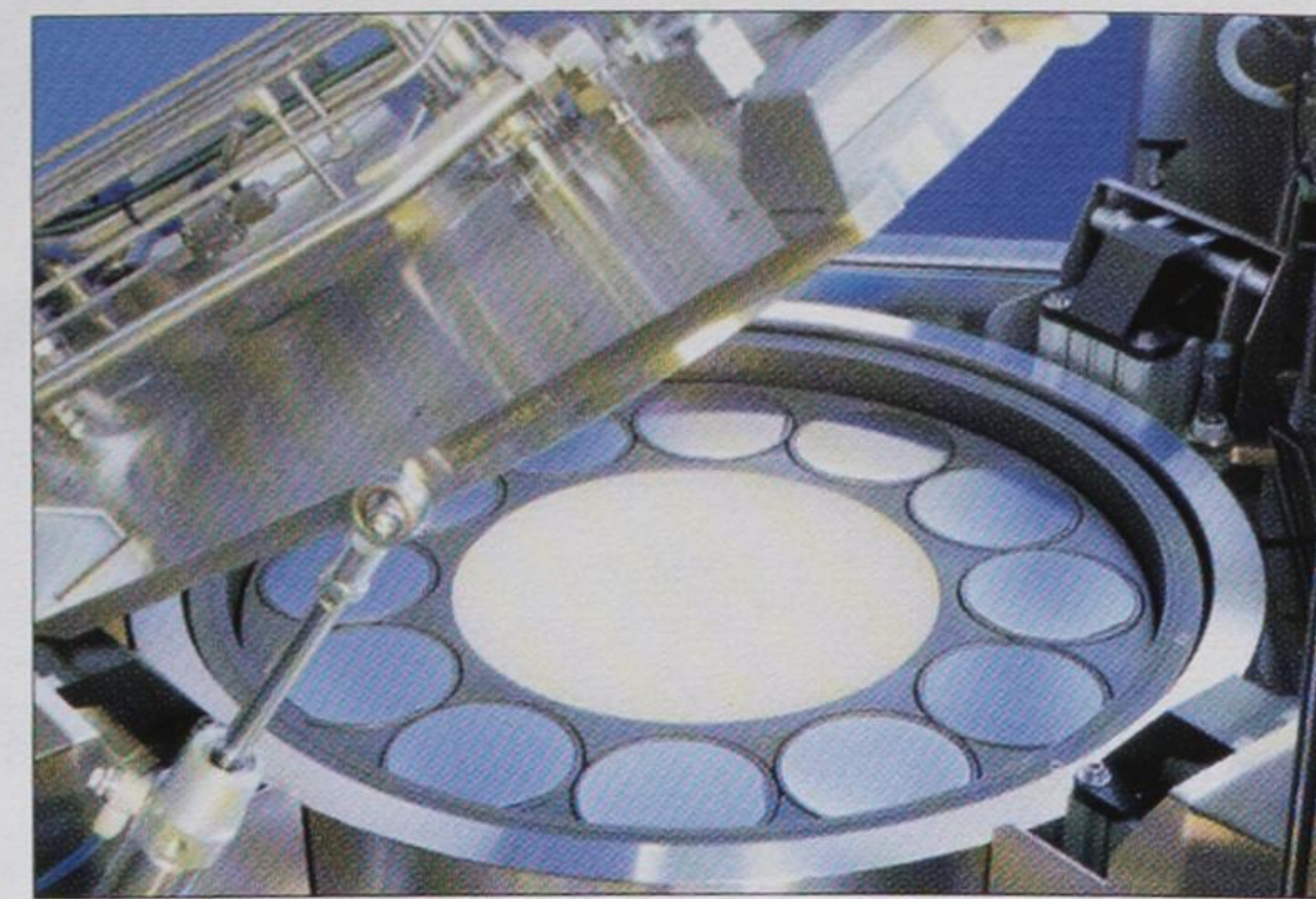


Fig. 2. Photoluminescence uniformities of <0.45 nm across these 4 inch wafers, grown on AlGaInP, indicate this reactor's excellent growth temperature homogeneity.



Aixtron's latest design uses either a 12 × 4 inch or a 49 × 2 inch configuration to deliver growth on substrates with a combined area of 150 inch².

Table 1: Metal-organic deposition efficiency

	AlGaAs		AlGaInP	
	12 × 4 inch	49 × 2 inch	12 × 4 inch	49 × 2 inch
TMGa	36%	43%	38%	44%
TMAI	36%	44%	39%	45%
TMIn	n.a.	n.a.	28%	30%

Metal-organic precursors are one of the top three contributors to the total production cost of LED epiwafers, and so increasing the efficiency with which they are used can reduce the cost of MOCVD reactor ownership. The 12 × 4 inch and 49 × 2 inch configurations are calculated to deliver an improvement of over 20% in growth efficiencies of the metal-organic precursors trimethylgallium (TMGa), trimethylaluminum (TMAI), and trimethylindium (TMIn). These calculations use precise measurement of the growth rates and assume nominal consumption of the metal-organic precursors according to the adjusted carrier gas mass flows and the given vapor pressures of the metal-organic chemicals. The vapor pressure data for TMGa and TMAI were provided by the material's suppliers, but data for TMIn was taken from O Kayser *et al.* (*Chemtronics* 1988 **3** 90).

The novel reactor design is based on Aixtron's earlier 2600 planetary platforms but uses different hardware including an improved gas inlet geometry. Measurements of composition and thickness on all of the materials used to produce red and yellow LEDs (GaAs, AlGaAs, AlGaInP, GaInP and GaP) verified that the reactor's growth process fulfilled the theoretical predictions. The reactor's capability was assessed for both the 12 × 4 inch and 49 × 2 inch configurations, and the effect of the standard p- and n-type dopants, tellurium and magnesium. Results revealed that the reactor can meet and even surpass the typical epiwafer specifications for doping uniformity, thickness and so on demanded for LED production.

LEDs contain distributed Bragg reflectors – alternating GaAs and AlGaAs layers – that reduce light loss into the substrate. The thickness uniformity of these layers is revealed by their reflectivity profiles (figure 1). Uniform-

ities across a 4 inch wafer and between wafers from the same growth run are better than 0.5%, assuming an edge exclusion zone of 3 mm, showing that the process is suitable for producing LED material.

Although the growth and uniformity of GaAs and AlGaAs layers depend predominantly on the reactor's flow dynamics, other LED materials such as AlGaInP are more temperature dependent. Consequently a large-scale reactor's temperature uniformity can be revealed through the growth of AlGaInP layers. Epiwafers produced on a 12 × 4 inch platform show typical photoluminescence (PL) uniformities of less than 0.45 nm (3 mm edge excluded) and a wafer-to-wafer variation below 0.8 nm, indicating excellent growth temperature homogeneity (figure 2).

Aixtron's reactor is also suited to high epi-wafer yields using the 49 × 2 inch configuration. PL on-wafer uniformities of 0.53 nm (3 mm edge excluded) and wafer-to-wafer uniformi-

ties of 0.78 nm were achieved from a full load of wafers containing an AlGaInP multiple quantum well active region emitting at 630 nm.

The growth efficiencies of the metal-organic materials used in LEDs were determined for both 12 × 4 inch and 49 × 2 inch reactor configurations (table 1). These efficiencies, which are delivered without compromising material uniformity, are 20% higher than those achieved with the 8 × 4 inch and 35 × 2 inch standard configuration. This improved performance results from the optimization of the gas inlet and the susceptor geometry.

The CoO of the new reactor will be reduced even more through faster growth rates. Although faster growth rates can deteriorate material quality, the very high precursor efficiency and the minimization of parasitic reactions through optimized design of the reactor chamber and the gas inlet were expected to enable rapid growth of high-quality films.

X-ray diffraction and electrical characterization measurements revealed no loss of film quality, despite an increase in the growth rate of AlGaInP and GaAs from 1.5 μm/h and 2 μm/h to 4.3 μm/h and 16.7 μm/h, respectively. These significant increases indicate the huge potential for additional cuts in growth time that will lead to lower production costs.

These new 12 × 4 inch or 49 × 2 inch planetary reactors, which are suitable for red and yellow LED production, satisfy the requirements for high-quality material and meet well defined CoO targets. This design, which is also suitable for solar cell or laser manufacturing, reflects the growing level of maturity within the III-V industry.

Rainer Beccard is director of marketing for Aixtron's Compound Semiconductor Technologies business unit. E-mail: r.beccard@aixtron.com.

AXT struggles with client trust

AXT has blamed its low revenue for the recent quarter on GaAs substrate customers requiring longer-than-expected qualification periods.

The substrate manufacturer's revenue for the second fiscal quarter was \$6 million, down \$0.6 million sequentially. GaAs substrate sales were 13% lower than the previous quarter, and generated \$4.5 million. Second-quarter gross margin was 2.1%, and the loss for this period was \$3.3 million.

"My main focus is to restore the reputation and credibility of AXT," remarked Phil Yin, AXT's CEO. He says that the quality issue that the company has faced requires "focused

attention" and that, although progress has been made, further work is needed. The company hopes that its new organizational structure will help to restore the company's revenue.

Minsheng Lin has joined AXT as COO, effective from July 11. Lin, a former employee of silicon wafer manufacturer Helitek, will oversee the company's day-to-day operations in Fremont, CA, and Beijing, China.

AXT has also transferred Morris Young from CEO of the company's China operations to CTO, and moved Davis Zhang from the position of president of China operations to president of joint venture operations.

Tegal signs \$22.5 million investment deal

Plasma etch and deposition equipment supplier Tegal says it has agreed new financing worth \$22.5 million. The Petaluma, CA, company has agreed to sell common stock and five-year warrants in two stages to unspecified investors.

The initial step will see \$4.1 million raised,

with the remaining \$18.4 million to follow.

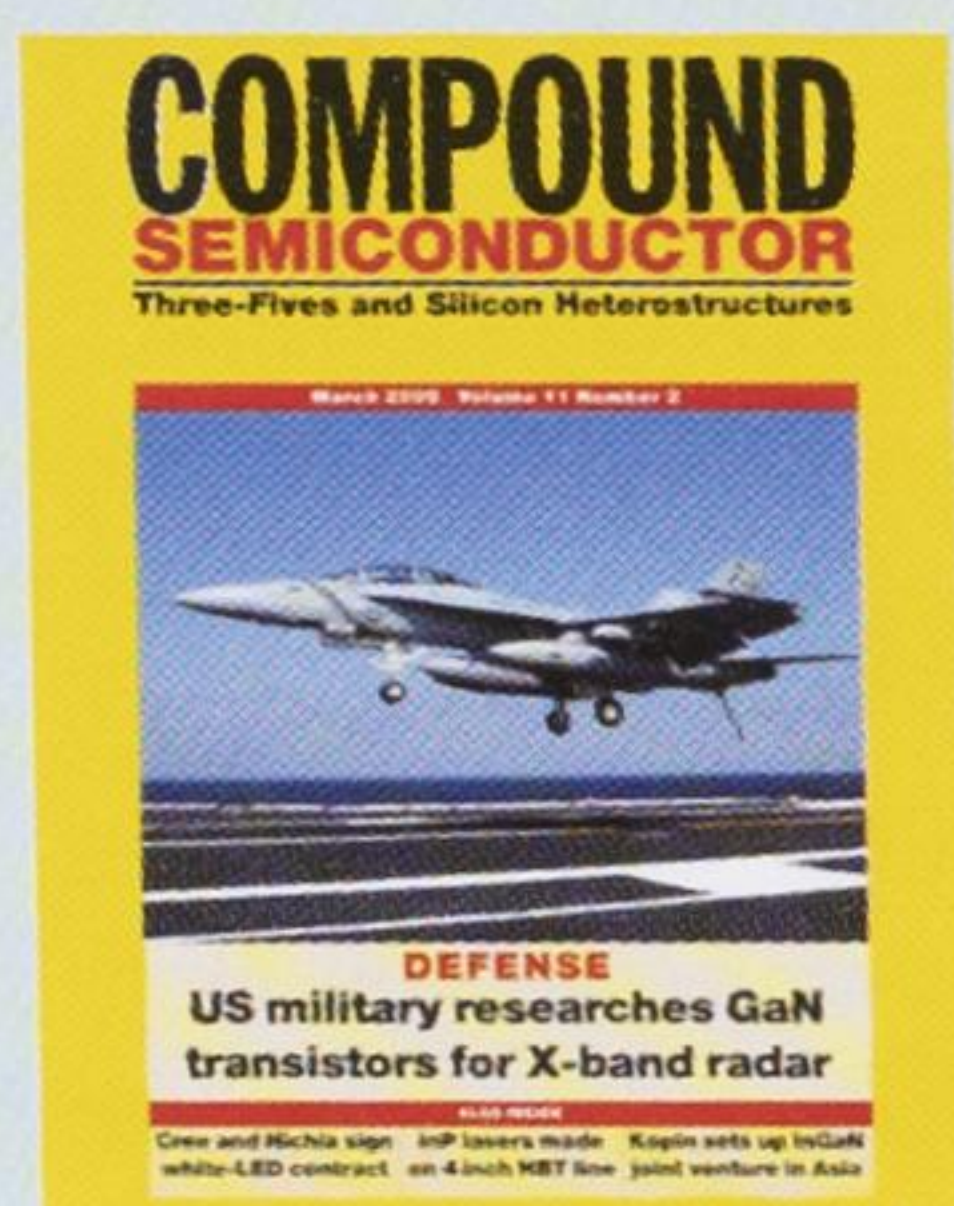
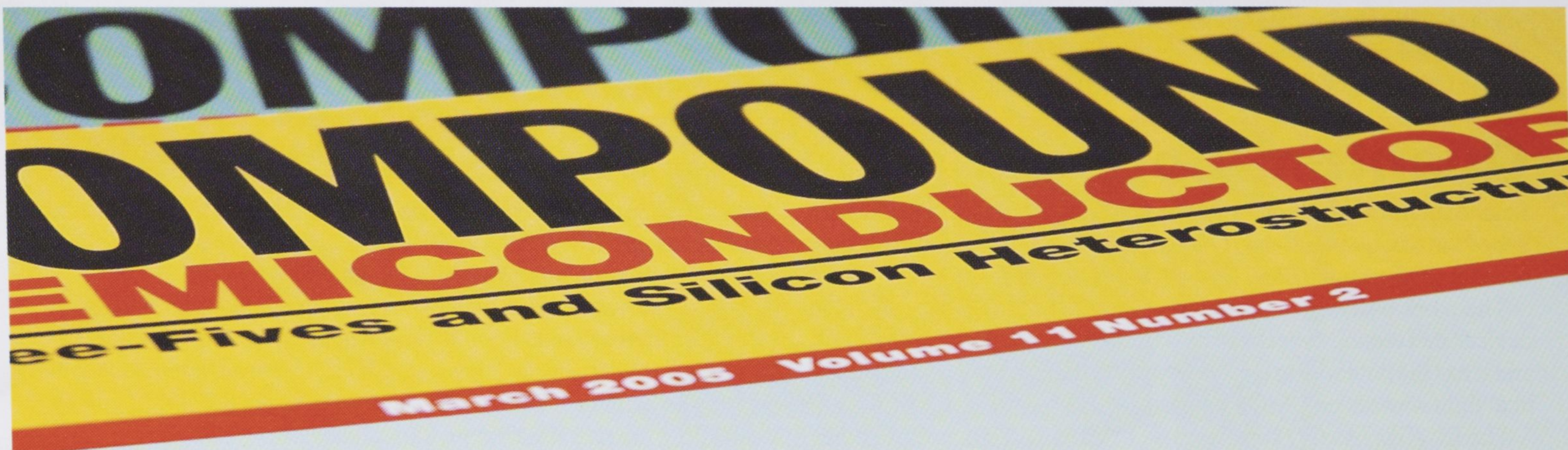
The sale will involve 34.6 million common shares plus 17.35 million warrants to purchase additional common shares for \$1. Tegal currently has a market capitalization of around \$49 million and a share value of just under \$1.

In brief

- Hangzhou Silan Azure, a Chinese start-up company that has plans to mass-produce high-brightness LEDs, has ordered an **Aixtron** AIX 2400G3 HT and a 19 × 2 inch Thomas Swan close-couple showerhead system.

- **Molecular Imprints**, a developer of step-and-flash imprint lithography technology, has sold Imprio 55 systems to Lawrence Berkeley National Laboratory's Molecular Foundry in California, the University of Texas at Austin, and Pennsylvania State Nanofabrication Facility.

- **Oxford Instruments** has received an order for a V90 MBE system from the United States Air Force Research Laboratory. The system will be installed at the Directed Energy Directorate in Albuquerque, NM, and used by Ron Kaspi and his mid-infrared laser group.



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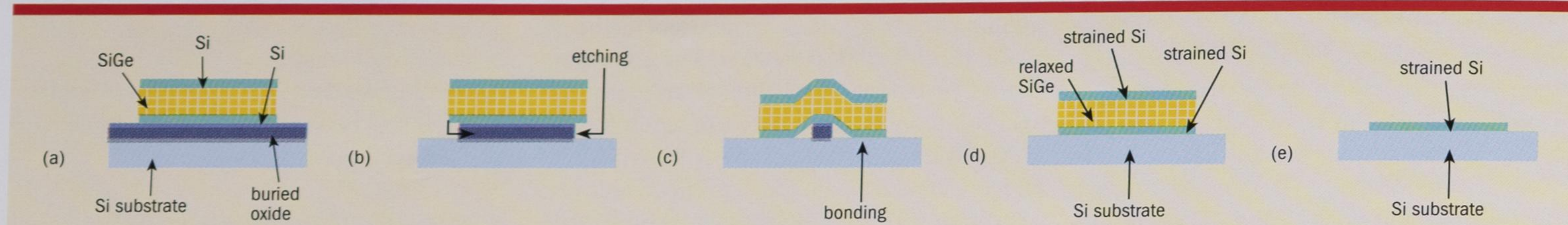
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IBM develops smooth strained silicon



Fabrication of strained silicon-on-silicon structures begins with epitaxial growth of sequential silicon – $\text{Si}_{0.8}\text{Ge}_{0.2}$ – and silicon layers onto silicon-on-insulator substrates incorporating a 145 nm-thick layer of buried oxide. Reactive ion etching and conventional lithography then define isolated slabs in these epiwafers (a). This is followed by removing the buried oxide layer by etching with diluted hydrofluoric acid (b), which allows the SiGe layer to relax elastically and induce tensile strain in the silicon films (c). The free-standing silicon surface is then bonded to the silicon substrate by hydrophobic attraction (d). Adhesion between the two surfaces is strengthened by annealing for 3 h at 800 °C under nitrogen, which causes covalent bonding at the interface. Finally, the top silicon and SiGe layers are removed by chemical etching (e).

IBM researchers have fabricated dislocation-free strained silicon slabs that are bonded directly to silicon wafers (*Appl. Phys. Lett.* **86** 251902). These smooth strained silicon surfaces could improve the performance of MOSFETs.

The team, based at IBM's T J Watson Research Center in New York, said that their material's smooth surface arises from the elastic relaxation of SiGe, which induces the strain in the silicon slabs. This is unlike the plastic relaxation that occurs when thick SiGe layers are used to fabricate strained silicon-on-silicon and strained silicon-on-insulator structures, which causes a cross-hatched rough surface. This complicates device fabrication, while dislocations in the strained silicon layer may degrade yield and reliability.

The team claims that this new fabrication procedure for produc-

ing strained silicon-on-silicon wafers is suitable for high-volume manufacturing because every step is a standard silicon manufacturing process (see figure above).

AFM images of an $8.5 \times 8.5 \mu\text{m}$ strained silicon slab revealed a "flat and smooth" surface with a root-mean-square surface roughness of 0.16 nm. This roughness is almost three times smoother than that of the surrounding silicon substrate, which deteriorates because of the wet chemical processes used to removed silicon and SiGe.

The team has not measured the electron mobility in the slabs. However, researchers Guy Cohen and Patricia Mooney say that they expect the mobility to be the same as that of other forms of biaxially strained silicon bonded by the whole-wafer method, unless scattering centers at the strained silicon-silicon interface degrade mobility.

Quantum-dot laser suggests CMOS compatibility

Scientists from the University of Michigan, MI, claim to have produced the first quantum-dot (QD) lasers on silicon substrates that emit at room temperature (*Elec. Lett.* **41** 742).

The work will help with the development of high-speed silicon devices that combine electronic circuits and optoelectronic functions, and it has the potential to pave the way to QD lasers featuring as practical light sources on CMOS chips.

The $\text{In}_{0.5}\text{Ga}_{0.5}\text{As}$ QD structures were grown on silicon substrates misoriented by 4° towards the [111] direction. A $2 \mu\text{m}$ -thick GaAs buffer was deposited by MOCVD, before MBE growth formed the remainder of the device, including several QD layers.

The structure's quality was confirmed by room-temperature photo-

luminescence measurements on the epiwafers. These showed that the intensities and linewidths from this material were comparable to QD heterostructures grown on GaAs substrates.

Lasers fabricated from the epiwafers produced output powers of over 50 mW at a wavelength of $1 \mu\text{m}$ when driven at room-temperature with a 1% duty cycle. However, according to team member Pallab Bhattacharya, the emission could be tuned between 0.9 and $1.5 \mu\text{m}$ by controlling the size and composition of the dots.

The InGaAs-on-silicon laser's threshold current is typically 1500 A/cm^2 – 15 times higher than that of comparable structures on GaAs substrates. However, Bhattacharya is looking to introduce a SiGe buffer layer into the structure to reduce this threshold current.

Robust GaN pressure gauge suits remote sensing

A collaboration from the University of Florida, Nitronex and US optical component manufacturer Multiplex has made a capacitance pressure sensor featuring a GaN HEMT-on-silicon membrane (*Appl. Phys. Lett.* **86** 253502).

The sensor, which can be used under vacuum and positive pressure conditions, is suitable for harsh and high-temperature environments, says Steve Pearton from the University of Florida. It can also be used for remote sensing by integration with a GaN-based wireless device.

The sensors were made by etching 200–600 μm -diameter circular holes into the substrates of Nitronex's GaN-on-silicon HEMT epiwafers.

Pressure differences across the device can induce a tensile strain in the membrane, leading to a change in the two-dimensional electron gas density at the AlGaIn/GaN interface, which in turn alters the capacitance of the HEMT diaphragm.

Pearton says that the device has a linear response to pressures from –1.5 to 12.3 bar, but this range can be significantly increased by adjusting layer thicknesses and the hole's diameter.

The researchers say their capacitance-based sensors offer an advantage over piezoresistive sensors because the latter are more sensitive to contact resistance, which can be highly temperature-dependent.

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